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NUREG-0712

Safety Evaluation Report
(Geology and Seismology) related to the operation of San Onofre Nuclear Generating Station, Units 2 and 3

Docket Nos. 50-361 and 50-362

Southern California Edison Company, et al.

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

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1.0 Introduction

The U. S. Nuclear Regulatory Commission (NRC) staff has completed its review of the geologic and seismic aspects of the San Onofre Nuclear Generating Station, Units 2 and 3 (San Onofre 2 and 3). The staff's safety evaluation of the San Onofre 2 and 3 geology and seismology are included in this report. Other aspects of the staff safety review are still in progress. When the staff review of the other safety areas is complete, a complete Safety Evaluation Report will be issued, which will incorporate the material included in this report.

2.5 Geology, Seismology, and Geotechnical Engineering

2.5.1 Basic Geologic and Seismic Information

2.5.1.1 Introduction

The geology and seismology of the site was reviewed in detail prior to issuance of construction permits for San Onofre 2 and 3 by the staff of the U.S. Atomic Energy Commission (AEC), the predecessor to the U.S. Nuclear Regulatory Commission (NRC), and its geological advisors, the U.S. Geological Survey (USGS) and its seismological advisors, the National Oceanic and Atmospheric Administration. The findings of that review were published on October 20, 1972 (U.S. Atomic Energy Commission, 1972) as part of the Safety Evaluation Report relating to construction of San Onfore 2 and 3, and are summarized below.

Additional investigations made by the applicants after the issuance of construction permits for San Onofre 2 and 3 were prompted by discoveries of faulting in and around the site area and by the occurrence of new seismic activity in the site vicinity near the Cristianitos fault. The incidence of anomalous geologic features, consisting of linear shear zones, discovered during the excavation for San Onofre 2 and 3 into the San Mateo formation, is reported in "Safety Evaluation of the Geologic Features at the Site of the San Onofre Nuclear Generating Station," issued by the NRC on July 8, 1975 and is also summarized below. Other investigations made by the applicants were reviewed by the NRC staff and the results of our review are discussed in the following sections.

Based on our review of the applicants' submittal of all new information which has become available since the CP review, we find no reason to change the conclusion reached in the Safety Evaluation Report for the Construction Permit approving a Safe Shutdown Earthquake (SSE) of .67g for San Onofre, Units 2 and 3.

2.5.1.2 Conclusions Reached Prior to Constructon Permit Issuance

A comprehensive geologic investigation of the site region performed by the applicants included detailed examinations of excavations along the Cristianitos fault and of the sea cliff exposures, geologic mapping, field examinations, and offshore seismic reflection profiles. The information and the data were presented to the AEC in the San Onofre 2 and 3 Preliminary Safety Analysis Report with amendments, which we and our advisors reviewed.

We interpreted the geologic information and data to indicate the existence of a zone of deformation about five miles offshore from the San Onofre site which extends from the Newport-Inglewood fault zone to the north, to the Rose Canyon fault zone to the south. We concluded in the Safety Evaluation Report:

"The present evidence indicates an extensive, linear zone of deformation, at least 240 kilometers (km) long extending from the Santa Monica Mountains to at least Baja, California. We and our consultants consider this zone of deformation to be potentially active and capable of an earthquake whose magnitude could be commensurate with the length of the zone. Onshore, data does not show evidence that there are any faults immediately underlying the planned reactor facilities.

Although the site is located within 1 mile of the Cristianitos fault zone, exposures of parts of this fault at the coast and at the Plano Trabuco excavations made by the applicant about 16 miles north of the coastal exposure, show that the overlying terrace deposits have not been offset by the fault at these locations. All of the available evidence indicates that the Cristianitos fault is inactive when evaluated using procedures described in the proposed 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," November 25, 1971."

2.5.1.3 Geologic Features Found During Excavation for Plant Foundations

On June 5, 1974, the applicants advised the NRC that anomalous geologic features had been discovered at the site during the excavation for San Onofre 2 and 3. On June 8, 1974, the NRC and the USGS staff examined the features at the site which consisted of a conjugate set of linear shear zones (designated A and B features by the applicants) within the San Mateo formation, which exhibited minor mutual displacements totaling not more than 4 inches at their intersection. In order to assess the possibility of ground rupture under the plant structures, the applicants were requested on June 10, 1974, to perform a detailed study of these shears. On July 12, 1974 the applicants reported their findings and conclusions (Fugro, 1974a).

On September 11, 1974 the applicants informed the NRC of the discovery of two additional geologic features, designated the C and D features, which we examined at the site on October 3, 1974. On November 1, 1974 the applicants submitted their report (Fugro, 1974b) of investigations of these features. A final report of all geologic features observed was submitted (Fugro, 1976). Sufficient information and analyses had been generated by the applicants in the interim reports to permit the NRC and our advisors, the USGS, to complete our evaluations prior to submittal of the final Fugro report.

We and our USGS advisors concurred in the Fugro findings and we concluded in our report (U.S. Nuclear Regulatory Commission, 1975) that all of the geologic features at the site are older than the wave-cut terrace which is estimated to be 70,000 to 130,000 years old. This conclusion is based on the observation that none of them displace the terrace/bedrock contact. Therefore, they are not capable faults as defined in Appendix A to 10 CFR Part 100.

2.5.1.4 Investigation of Trenching Across the Cristianitos Fault

A condition, described in the literature (Fife, 1974) as evidence suggestive of Holocene movement on the Cristianitos fault, was observed (photo 2 of the Fife report) in a trench excavated in colluvium where the main branch of the fault crosses Oso Creek. A single lime-filled fissure was found in the trench wall immediately over the fault contact between the Oso member of the Capistrano formation and the La Vida member of the Puente formation. The report stated that "No conclusive evidence of Holocene displacement was found on the Cristianitos fault in the study area. Undisturbed Holocene or earlier terrace deposits cap fault traces in Aliso Canyon, Plano Trabuco, and on the coast at San Onofre Bluff."

However, the report further states that the lime-filled vertical crack over the fault trace "is believed to have resulted from differential seismic shaking of Oso and La Vida beds on opposite sides of the fault. This may have occurred during any one of the historic earthquakes that were strongly felt locally." This could have indicated capability of the Cristianitos fault.

An apparently similar condition was observed on an April 9, 1975 site visit by the NRC staff in a bulldozer excavation, made to examine the proposed Viejo Substation site, which cut the Cristianitos fault at the north end of Aliso Valley approximately one mile north of the Oso Valley exposure. We observed in the excavation wall, a river terrace deposit with a linear separation or open crack (unfilled), which was located immediately above and along the projection of one of the principal traces of the Cristianitos fault observed in the bedrock.

Morton and others (1974) mention a backhoe trench, placed in 1971 by the California Division of Mines and Geology, which succeeded in exposing the western branch of the Cristianitos fault. He states that this trench showed apparent displacement of a two-foot thick slope-wash cover along two shears a few feet apart. Maximum dislocation of the soil-bedrock interface was approximately two feet. Additional trenching was placed in the same area by the applicants in June, 1974 in order to check this possibility.

Morton concludes:

> "These excavations suggested that the apparent displacement of the soil cover may have been due to a combination of animal borings and differential erosion of the bedrock surface with subsequent soil deposition. However, Holocene movement has not been ruled out. To satisfactorily resolve the problem the authors believe that additional trenches exposing the base of Holocene alluvium are necessary."

In view of the coincidence and similarity of the phenomena observed by D. L. Fife and the NRC staff and the concern raised by P. Morton, we requested that the applicants perform a detailed investigation of the conditions observed and demonstrate with reasonable assurance that the Cristianitos fault does not present a hazard to San Onofre 2 and 3. A log of the original excavation in the D. L. Fife report was obtained and the trench was re-excavated and logged during September, 1975. The findings reported (Southern California Edison Company, 1976, Enclosure 1 of Volume 1) were as follows:

(1) The lime-filled crack does not coincide with the Cristianitos fault, but is located 10 to 12 feet west of the western edge of the fault. The crack is most likely due to consolidation creep or to downslope movements in the underlying debris.

(2) Detailed mapping of the Viejo Substation excavation showed that fault displacement or shearing was not evidenced at the basal contact of the fluvial terrace nor do the overlying terrace deposits show any evidence of shearing.

The staff has reviewed the reports and examined the field evidence. As a result, we concur in the applicant's findings and conclude that the evidence indicates that the Cristianitos fault does not present a hazard to San Onofre 2 and 3.

2.5.1.5 Stratigraphy and Mapping of the Site Area

During the course of our review of the application for operating licenses for San Onofre 2 and 3, we observed that Figure 2.5-9 of the Final Safety Analysis Report (FSAR) shows the San Mateo formation outcropping to the southeast of the Cristianitos fault, which is in contradiction to the geologic structural interpretation at the site. Consequently the applicants were requested to explain more completely the stratigraphic and structural relationship between the San Onofre Breccia, Monterey, Capistrano, and San Mateo formations. Of particular concern was the geometric configuration of these units with regard to the Cristianitos fault and the possibility of other branches of the fault southeast of the mapped location of the fault at the sea cliff. If other unobserved branches of the fault exist, they could exhibit evidence of movement on the fault which is more recent than that exhibited in the mapped fault at the sea cliff. That evidence could have indicated that the Cristianitos fault is capable.

The applicants contracted with Dr. P. F. Ehlig to analyze the stratigraphy and to map the area adjacent to and south of the San Onofre site. He mapped, in detail, a 24 square mile area, extending from San Mateo Canyon on the northwest to Las Pulgas Canyon on the southeast and from the coast to the east side of the San Onofre Mountains. His report (Ehlig, 1977) provides new information on the relationship of the rock units, and geologic structure in the vicinity of the Cristianitos fault. The report concludes:

(1) The coastal area adjacent to the San Onofre site appears to have been tectonically stable since late Pliocene time except for regional uplift.

(2) The Cristianitos fault is the only major fault within the area.

(3) Four minor faults have been mapped on the northwest flank of the San Onofre Mountains to the east of the Cristianitos fault. None of these faults shows evidence of Quaternary displacement.

(4) No other significant faults have been recognized within the area between the coast and the San Onofre Mountains from the Cristianitos fault southeastward to Las Pulgas Canyon. There is continuity in the geologic structure.

The analysis and mapping performed by Dr. Ehlig are, in our opinion, carefully derived and adequately represent those aspects of the geology pertinent to an evaluation of the safety of the site. Figure 2.5-9 of the FSAR is shown to be in error because the San Mateo formation does not exist south of the Cristianitos fault. We concur in the findings and conclusions presented in the report as stated above.

2.5.1.6 Investigation of Offset in the Sea Cliff South of San Onofre 2 and 3

On May 20, 1977 a staff member of the California Energy Commission informed the NRC of an apparent fault in the sea cliff approximately 3 miles south of the San Onofre plant. The apparent fault, located within the margin of a large landslide, displaces the bedrock/marine terrace deposit contact at the top of the San Mateo formation a total of approximately 3 feet with reverse movement.

At our request the applicants performed a detailed geologic investigation, including trenching, to study the apparent fault and to determine its relationship to the landslide. They were asked to determine whether the displacements were tectonically induced or are related to landslides. We requested that the applicants, if feasible, trench along the trend of the apparent fault to where it intersects the failure plane along which the land mass slumped.

The exposures in the two trenches excavated along the principal fracture clearly show in the Fugro supplemental report (Fugro, 1977) the relationship of the fracture and the landslide rupture surface. The report concludes that the apparent fault is caused by failure of the landslide mass and is not related to tectonic stresses. The fracture that displaces the bedrock/marine terrace deposit contact is confined within the southeastern boundary of the landslide and therefore is not significant to the safety of San Onofre 2 and 3.

It is our opinion that the evidence demonstrates that displacement of the bedrock/ marine terrace deposit contact by the fracture terminates at the landslide rupture surface, and that the displacement does not extend beyond the limits of landsliding. Therefore, we conclude that the displacement of the bedrock/marine terrace deposit contact is the result of landsliding and has no significance to the seismic design of the San Onofre plant structures.

2.5.1.7 Orange County Earthquakes of Janury 1975

Two small earthquakes of 3.3 and 3.8 magnitude occurred on January 3, 1975 near San Juan Capistrano, California. The preliminary locations of the events were near the central portion of the Cristianitos fault. These events were of concern to us because if the Cristianitos fault had generated these events, this would constitute evidence that at least a portion of the fault might have moved during historic time and therefore the fault might be considered capable.

A program of investigations was conducted by the applicants (Southern California Edison Company, 1976) to evaluate the relationship of the two seismic events to the tectonics of the area. A number of studies of the area were undertaken, including a geomorphic study, an evaluation of microseismic events, a study of focal mechanisms, the construction of a subsurface contour map with appropriate geologic structure sections, an updating of historic seimicity, and geophysical surveys. The results were integrated to develop the relationship between historic seismicity, including the two recent events, and the regional tectonic structure, in particular the Cristianitos fault.

Biehler (1975) concluded that the two seismic events of January 3, 1975 cannot be located on the Cristianitos fault, using the best seismic model for the crustal structure, but rather appear to be associated with a northeast-trending fault which parallels Trabuco Canyon. This conclusion is supported by the focal mechanism study which indicates that the sense of motion was left-lateral oblique thrust, which is opposite to the historic normal dip-slip motion on the Cristianitos fault. (See Section 2.5.2.2 for further discussion.)

2.5.1.8 Tectonics of Capistrano Embayment

Another report (West, 1975) resulting from the applicants' studies evaluates the geologic structure and tectonics of the Capistrano Embayment. It concludes that no significant movement has occurred along the Cristianitos fault since late Pliocene time. The study indicates that the epicenters of the January 3, 1975 earthquakes did not occur on the Cristianitos fault. In fact, there was not substantial evidence that any structure as interpreted by the study is compatible with the epicenters. The report states that the earthquakes may be the result of differential settling within the embayment.

In the report, geophysical and well log data are analyzed by the author resulting in an interpretation of the age and noncapability of the structures in the Capistrano Embayment. Because of insufficient information supporting the bases for the interpretations of the geologic structure made in the report, additional information was requested. This request resulted in additional studies by West (1979) and Shlemon (January 1978, October 1978) and new seismic reflection profiles described in a Woodward-Clyde Consultants supplementary report. West (1979) concluded that the structural interpretations made in his report suggest that the major tectonic activity within ten miles of San Onofre site took place prior to the termination of the Pliocene epoch, possibly two million years before present. Since that time the area has been tectonically quiet with the exception of the South Coast Offshore fault zone, along which some movement probably occurred in the Late Pliestocene. He further states that the data examined by him revealed no additional faults of this or younger age within five miles of the San Onofre site.

Because of the relative concentration of seismic activity near the Capistrano Embayment and the faulting within the embayment, the applicants were requested to investigate and evaluate any terrace deformation across the embayment. In response, Shlemon (October, 1978) reported the results of a study of the Late Quaternary rates of deformation along the coastal area. Specific objectives of the study were to delineate the continuity and elevation of the 120,000 year old terrace contact, to determine Late Quaternary rates of deformation, and to locate possible Late Quaternary structural displacements between Laguna Beach and San Onofre State Beach, in particular across the Capistrano Embayment.

The report concluded that within the resolution of the survey (1 meter), the 120,000 year old terrace is not displaced between San Onofre 2 and 3 and Dana Point. Regional uplift rates between Target Canyon and Dana Point increase northward from about 6 to 26 cm/1000 years; and indicate longitudinal up-to-the-northwest tilt of the coast across the Capistrano Embayment and toward the San Joaquin Hills. In terms of local late Quaternary uplift, the 9 cm/1000 year rate at San Onofre 2 and 3 compares with approximately 11-16 cm/1000 years for the San Diego area, 40-50 cm/1000 years and conceivably 500-800 cm/1000 years for Rancho La Brea and Baldwin Hills, respectively, and 620 cm/1000 years for the Ventura coast. Therefore, compared with Late Quaternary uplift rates elsewhere in California, the San Onofre region must be viewed as being one of the most tectonically stable coastal areas in Southern California.

2.5.1.9 Slip Rate Versus Magnitude and Its Application to the Offshore Zone of Deformation

For the Construction Permit, a Modified Mercalli intensity value was used to represent the Safe Shutdown Earthquake (SSE)* originating on the Offshore Zone of Deformation (OZD). Because the magnitude is a better measure of the size of an earthquake (see Section 2.5.2.3), we asked that the applicants use magnitude in defining the maximum earthquake potential for the OZD.

The applicants submitted a report (Woodward-Clyde Consultants 1979) which is to be used in partial support for the determination of the maximum earthquake magnitude on the OZD. It described a new method of determining earthquake magnitude by comparing the degree of fault activity on the OZD with that of faults of similar style around the world. According to Slemmons (1977), faults having higher degrees of activity produce larger magnitude earthquakes than faults having lower degrees of activity. The parameter chosen to represent the degree of activity is the fault slip rate. The method was used to estimate the maximum earthquake magnitude associated with the OZD by evaluating fault slip rates and historical seismicity of many faults of similar style around the world. Data was collected and plotted on magnitude versus slip rate (logarithmic) coordinates and a line enveloping the maximum historical earthquake was considered to represent the maximum earthquake associated with each slip rate. This was called the Design Earthquake Limit (DEL).

2.5.1.10 Evaluation of the Slip Rate and Magnitude Data Used in the WCC Report

Figure 7 of the Woodward-Clyde Consultants (WCC) report is a plot of the long-term slip rate measured on a fault versus the maximum historical earthquake magnitude observed on that fault. The slip rates and magnitudes were taken from the literature where there were often several values given for each fault as shown in Table G-1 of Appendix G. The slip rate on the Newport-Inglewood fault zone portion of the OZD, determined from analysis of electric well log data, was calculated to be 0.5 mm/yr. The 0.5 mm/yr was considered to be representative of the slip rate for the OZD which correlated with a maximum magnitude of 6 1/2 from the DEL in Figure 7. Thus, the applicants concluded that the maximum magnitude that can be associated with the OZD is $M_S = 6\ 1/2$.

A study of the data base in Table G-1 for Figure 7 of the WCC report showed that some inconsistencies occur among the various reports on slip rate and magnitude for a given fault. Since numerous publications were reviewed by WCC, a wide variation in the data is bound to exist due to the differences in approach and scope of work of the various investigators. Table G-1 presents the range of data and interpretations, but does not reflect any attempt to appraise the quality or validity of the data. Therefore, it was the opinion of the staff that the data selected for Figure 7 of the June 1979 WCC report were not adequate.

*The SSE is also called the design basis earthquake (DBE).

To compensate for the wide range of data, the applicants were requested (in question number 361.45; both the staff questions and the applicants' answers are given in the "Question and Response" section of the FSAR) to provide a detailed description of the method of selecting or rejecting basic data and to use error bands of variations which encompass all of the values of slip rate and magnitude determinations by the various investigators cited in Table G-1. As a result, the data selection process was described in greater detail and several modifications to the data were made in Amendment 18 to the FSAR. Extraneous or unverifiable data included in the WCC report were eliminated and new data obtained since publications of the WCC report were added. Also, in response to our request, preference was given to the slip rate values based on Quaternary data because they best represent the current tectonic environment and activity of the faults. The line bounding the augmented data set was called the Historic Earthquake Limit (HEL); while the line bounding all of the data established the Maximum Earthquake Limit (MEL) in Figure 361.45-4 in Amendment 18 to the FSAR. The applicants state, "The MEL is interpreted most conservatively by enveloping the lowest slip rate ranges and the maximum magnitude ranges of all the data points. The most conservative use of the line is to estimate a maximum earthquake by reading the MEL value based on the maximum slip rate value provided for each fault."

We concur that the MEL line represents a conservative estimate of the maximum magnitude of future earthquakes on these faults or faults of similar style. The maximum magnitude for the OZD is $M_S = 7.0$ applying the conservative interpretation of the MEL line and assuming the highest slip rate 0.68 mm/yr calculated for the Newport-Inglewood fault zone as part of and representative of the OZD. Although there is a paucity of data below 1.0 mm/yr, which reduces our confidence in the correlation in the range below that value, we agree that $M_S = 7.0$ is a conservative outcome for this method of approach to a determination of the SSE magnitude for the OZD.

Dr. David Slemmons, consulting geologist to the staff, was contracted to review the WCC report and responses to NRC questions which resulted from our initial review of the report. In his report to NRC, which is Appendix E to this report, he comments on the slip rate versus magnitude relationship, the adequacy of the WCC data base used in deriving this relationship, and the maximum earthquake magnitude assigned to the OZD. We concur with his recommendation that the new approach presented by WCC is the firmest, most quantitative approach for the evaluation of the maximum earthquake for SAn Onofre 2 and 3 but it should be one of several approaches in a balanced multi-approach to the determination of the maximum earthquake magnitude. Dr. Slemmons concurred in the applicants fault slip rate for the Newport-Inglewood fault zone at 0.5 mm/yr and with the maximum magnitude of 7 for the OZD.

2.5.1.11 Determination of the OZD Rupture Length

Dr. Slemmons (Appendix E) also provided a discussion of other methods that relate fault parameters to estimating maximum earthquake magnitude on the OZD, with particular attention to those methods relying upon fault length. He provided an extensive discussion of the appropriate fault lengths to be used for the OZD and the tectonic relationship of the OZD to faulting in Baja California.

Physical characteristics of a fault zone have been used in the past to estimate the maximum earthquake potential. Typically a correlation is sought between earthquake magnitude and recorded or estimated rupture length. Generally, these correlations are poor because of the large scatter of data. While some of the scatter is due to the inability to arrive at accurate estimates of rupture and displacement over the whole fault plane, a great deal of uncertainty arises from the very complex nature of tectonic conditions that lead to earthquake occurrence. Variations in important elements such as local and regional stress conditions and specifics of fault geometry undoubtedly preclude good correlations.

The application of the earthquake magnitude versus surface fault rupture length procedure (Slemmons 1977) requires that brittle fracture occur and that total surface rupture length be observable. However, the surficial offshore materials near SAn Onofre 2 and 3 are such that plastic deformation conceals the tectonic effects along the OZD. In addition, water covers the offshore portion of the OZD. However, Dr. Slemmons (Appendix E) used indirect methods to apply this procedure. From the subsurface rupture lengths observed by means of seismic reflection profiles, he was able to use the earthquake magnitude versus surface rupture length method as another approach to determining the maximum magnitude for the OZD.

A most conservative approach used by Dr. Slemmons was to assume that the OZD is segmented and that the segments are indicated by the length of main rupture not at the surface or at shallow horizons, but at Horizon C, which is several thousand feet deep. The trace of the OZD at Horizon C is shown in Figure D-1 of WCC (1979). The segment of the OZD offshore of San Onofre 2 and 3 (the South Coast Offshore Zone of Deformation) has a total length of 62 km and, applying the relationship of strike slip faults of Slemmons (1977), leads to a maximum earthquake magnitude $M_S = 7.1$. Assuming the values for segment length of 36, 27, and 48 kms provided by the applicants in Table 361.66.1of the FSAR, the maximum earthquake magnitudes are $M_S = 6.7$, $M_S = 6.6$, and $M_S = 6.9$, respectively.

Another approach to determining maximum earthquake magnitudes is to assume that a fraction of the total length of a causative fault will rupture. Since the fraction of the fault that is assumed to rupture varies over a wide range, Dr. Slemmons reviewed the world-wide data for strike-slip faults to determine the fraction of total fault length that has accompanied earthquakes of $M_S = 6$ or greater (Appendix E). The mean of the highest percentage for each fault was determined to be 22 percent of the total length of strike-slip faults. He applied this method to the OZD, assuming that the zone extends from the Santa Monica fault to the San Diego Bay area. Based on a total length of 200 km, and assuming the mean fractional rupture length of 22 percent (44 km), a maximum magnitude $M_s = 6.9$ is obtained. Using the fractional rupture length corresponding to the mean plus one signer of 30 percent (60 km), a maximum maggitude of $M_s = 7.1$ results.

We concur with Dr. Slemmons that the north end of the OZD is truncated by the Santa Monica fault, however, the south end is not clearly defined. Here the tectonic style does appear to change from strike slip to normal faulting, which is the basis for Dr. Slemmons southern terminus, giving a total length of 200 km. However, Greene and others (1979) define the OZD as a discrete belt that extends at least 240 km from near the Santa Monica Mountains into Baja California. Legg and Kennedy (1979) state that the OZD "apparently merges with the Vallecitos-San Miguel fault zone, although a connection with the Tres Hermanos or Agua Blanca fault zones is also possible." The U.S. Geological Survey in their 1972 report to the AEC (now the NRC) concluded that the OZD appears to extend southeastward to at least the Mexican border and is at least 240 km in length (see Section 2.5.1.2 of this report).

The applicants (see FSAR response to Question 361.66) have argued that the OZD and the major Vallecitos-San Miguel faults in Baja California should not be associated structurally. In support of their view they point to an absence of faulting and an apparent age difference in faulting between the southern OZD and the northern Vallecitos-San Miguel. Seismicity and fault offsets vary greatly over both fault zones. The most seismically active segments being the northern end of the OZD (Newport-Inglewood fault zone) and southern section of the San Miguel fault.

Gastil (1979) discusses the evidence suggestive of a possible connection in the form of a northwest trending lineament which extends from the southernmost end of the known Rose Canyon segment of the OZD to the northernmost end of the known Calabasas-Vallecitos-San Miguel fault zone. Evidence for the lineament are:

(1) Northwest trending faults in the San Ysidro area at the north end of the lineament.

(2) Alignment of thermal springs.

(3) Alignment of the Tijuana Valley.

(4) Stratigraphic contrasts or facies changes across the lineament.

(5) A set of northeast trending faults appears to be truncated by the lineaments.

(6) Apparent offset (1 km) of the Pacific Boundary faults.

(7) A Richter magnitude 3.5 seismic event toward the south end of the lineament.

(8) Undocumented report of equivocal evidence for faulting in the Canon de la Presa, the epicentral location of the magnitude 3.5 earthquake, by Robert Washburn.

The primary evidence given by Gastil against the lineament being structurally controlled is that there is no photographic evidence of faulting in the bedrock exposures across the lineament. This would suggest that throughgoing faulting has not occurred in the area. The staff is of the opinion that the lineament is not an expression of faulting of the type that would be needed to connect the OZD with the Calabasas-Vallecitos-San Miguel fault zone.

The applicants argue that the evidence is not supportive of a throughgoing fault and that the occurrence of only one small earthquake (the 1978 event) near the proposed connection is evidence of an historically quiet seismic record. While the existence or non existence of this connection cannot be unequivocally demonstrated at this time, nor can the structural tectonic relationship between the southern OZD and Baja California be established, we conclude that, based upon the differences cited above, it is unwarranted to consider the combined OZD-Calabasas-Vallecitos-San Miguel fault zones capable of rupturing along major portions of its total length.

As further evidence of discontinuity, Dr. Slemmons states that the Vallecitos fault lacks geomorphic evidence for activity. Mesozoic dikes appear to be offset by only 100 m or so (Gastil 1979) which would indicate very low slip rate activity. He concludes that, "It is reasonable to interpret this zone in terms of separate, partly en echelon, individual faults with very low slip rates and low activity that may be activated independently, and the length of the zone should not be added to that of the OZD." Based on the available evidence, as discussed above, the staff agrees with Dr. Slemmons' interpretation that the Calabasas-Vallecitos-San Miguel fault zone should not be added to that of the OZD to form a continuous fault zone. It should be assumed that the two fault zones would rupture independently.

In response to question 361.66, the applicants provided a discussion of the comparable activity of the OZD and the Agua Blanca faults. The data are summarized in the FSAR in Table 361.66-1. The characteristics that most prominently distinguish the Agua Blanca fault from the OZD are the slip rate and the geomorphic features. The slip rate on the Agua Blanca is given as 2.7 mm/yr as compared to 0.5 mm/yr on the OZD. The geomorphic features of the Agua Blanca fault are characterized as considerably prominent with a strong linear trace in alluvium, offset streams, shutterridges, and fault sags. These features are not characteristic of the OZD.

In the opinion of the staff, the tectonic activity of the Agua Blanca fault is distributed to the northwest via a connection (Legg and Kennedy, 1979) with the Coronado Banks fault. There probably is lesser distribution to the Maximinos fault, via a splay in the Agua Blanca near Valle Santo Tomas, and the San Clemente fault. Activity may be indirectly distributed to the OZD as a branch or conjugate fault to the Coronado Banks fault. In view of the above, we agree with the applicants that the OZD should not be considered comparable to the Agua Blanca fault, but is of a lower order of tectonic activity.

Dr. Slemmons indicates a possible connection of the OZD with the Coronado Banks fault and ultimately to the Agua Blanca fault. If such a connection exists, the OZD would be 247 km long where it connected with the Coronado Banks fault, and 300 km long where it extended to the Agua Blanca fault. Assuming the mean fractional rupture length (22 percent of the fault length), the respective earthquake magnitudes would be $M_S = 7.0$ and $M_S = 7.1$. The mean plus one sigma fractional rupture length (30 percent of the fault length) results in estimated magnitude of $M_S = 7.2$ and $M_S = 7.3$, respectively.

The OZD changes from a southeasterly to a southwesterly direction and from strike-slip to normal faulting starting at San Diego Bay where it appears to continue offshore. Dr. Slemmons points out that such a change in strike and sense of movement may cause the OZD to break as independent segments to the north and south of San Diego Bay. He further concludes "If the OZD extends to the Agua Blanca fault, the branching relation, the different strike, and the possibly different slip mechanism suggest that it should be considered separately from the Agua Blanca fault; worldwide data on branching faults suggest major rupture on one does not immediately cause major rupture on the other."

The maximum earthquake magnitudes resulting from the various tectonic models characterizing the OZD are discussed in Section 2.5.2.3 of this report.

2.5.1.12 Investigation of Offshore Extension of the Cristianitos Fault

(1) Discussion of H. G. Greene, and others, Paper
In the publication entitled, "Earthquakes and Other Perils San Diego Region" edited by Abbott and Elliott, one of the articles in this reference, "Implication of Fault Patterns of the Inner California Continental Borderland Between San Pedro and San Diego" by Greene and others contains a map (page 22) which indicates a possible connection between the Cristianitos fault and the OZD. Recent movement on the fault is also indicated. A discussion with two of the authors, H. G. Greene and J. I Ziony, confirmed the possibility of this connection. This postulation was based on limited reflection profiling by the USGS.

(2) Early NRC Staff Position
The staff was concerned that if the Cristianitos fault was deemed capable, a large earthquake on it could result in high amplitude ground motion at the site; however, the possibility of ground surface rupture under the San Onofre 2 and 3 plant facilities is negligible. Post Pliocene movements on the Cristianitos fault, if they occurred, are not reflected in the excellent exposure of San Mateo formation between the fault and the site. Except for the minor shears which appeared in the plant excavations, discussed in Section 2.5.1.3, there are no visible faults within one-half mile of the plant site.

(3) USGS Evaluation of Seismic Reflection Profiles
A number of offshore seismic reflection surveys were performed by the applicant and by others in the vicinity of the site over the 10-year period beginning with the development of the safety analysis for the construction permit. The purpose was to investigate the structural features offshore.

On May 8, 1980, we requested that a comprehensive review be made by the USGS of all marine geophysical data relevant to the character and recency of faulting along the offshore extension of the Cristianitos fault in the vicinity of the San Onofre 2 and 3. This request was concerned specifically with a proposed structural relationship between the Cristianitos zone of deformation (CZD) and the OZD. The NRC requested that this review be made jointly by H. G. Greene of the USGS and M. P. Kennedy of the California Division of Mines and Geology, because of the extensive joint research effort then underway by Greene and

Kennedy on aspects of the structural geology of the southern California borderland. Their review and a subsequent report were completed on July 18, 1980. Their report, "Review of Offshore Seismic Reflection Profiles in the Vicinity of the Cristianitos Fault, San Onofre, California" is appended as Appendix F.

Plate 1 (Appendix F) shows the CZD extending offshore of the San Onofre 2 and 3 site and oblique to the OZD and to within less than 1 mile of the OZD. The segment of the CZD shown was made with a high degree of confidence; however, continuation to the OZD and its connection with the onshore Cristianitos segment are obscured due to data voids in these areas. The report concludes that their interpretation of the offshore seismic reflection profiles in the vicinity of San Onofre 2 and 3 indicates that two structural zones of deformation are present in this area. The first and most well defined zone is a segment of the OZD, a recognized Quaternary fault zone. The second, the CZD, is less well defined but nevertheless exhibits characteristics similar to those of the OZD. It consists principally of highly fractured and faulted asymmetrical anticlinal structures.

The CZD and associated folds to the east combine to form a broad structural zone (up to 3 km in width) which projects onshore to the north. The southeast end of the CZD could become incorporated with a major syncline of the OZD; however, the structural relationship of the CZD with the OZD is unconfirmed because of a data void. The authors intepret a data void as an area where data may be available but not able to be interpreted due either to structural complexity or poor reflections.

The age of most recent faulting along the CZD is unknown. All seismic profiles examined show that faults associated with the zone end at or near the surface of an apparent wave-cut platform that is overlain by Pleistocene sediment. Nowhere within the zone is there evidence of seafloor displacement.

The report concluded that a structurally deformed zone consisting of correlatable en echelon faults and folds, many extending into shallow subsurface strata (probably Neogene in age), is present along the expected offshore extension of the zone. The seismic reflection data reviewed show that a fairly continuous fault zone extends south to southeastward offshore from San Onofre 2 and 3 to within 1 km of the OZD, where a projected connection is possible.

(4) <u>May 1980 Seismic Reflection Profiles by Nekton, Inc.</u>
A seismic reflection profile survey was conducted by Nekton, Inc. for the applicant to provide higher resolution in the shallow offshore strata to help determine whether or not the Cristianitos fault projects toward the OZD. The report (Nekton, 1980) concludes:

(a) The Cristianitos fault does not project far enough seaward (i.e., south-southeasterly) to be identified in the survey area. Where the fault may be projected to occur, there is no evidence of its existence. Nekton concluded that along its offshore projection, displacement diminishes and the Cristianitos Fault dies out, possibly in a number of lesser faults and small folds. It does not connect to the OZD.

(b) The OZD was mapped parallel to the coastline for 8.8 kilometers in the central and northern oceanside survey area. In the central part, at least two branches of the fault occur and their width is limited. To the north, it broadens to a zone of deformation up to 0.6 kilometers (0.4 miles) wide. The OZD is not present in the Dana Point survey area.

(c) Other faulting offshore - a number of minor faults are interpreted to be present offshore in the survey area. Minor faults in the area are short in length and occur below a Pleistocene erosion surface in Tertiary age beds.

(d) Fault movement - none of the minor faults shows evidence of movement following the period of erosion which developed the Pleistocene erosion surface. Eighteen kilometers south of San Onofre, the OZD shows evidence for at least two periods of probable movements. Movements during one period have displaced the Pleistocene erosion surface and the movements during the other period appear (locally) to displace terrace deposits of probably Holocene age.

(5) USGS Evaluation of the History and Age of the Cristianitos Fault

On November 26, 1980, our advisors, the U.S. Geological Survey, transmitted to us, in response to our request, their review of the geologic and seismologic data submitted by the applicants in support of their position concerning San Onofre 2 and 3. The review is in the form of a letter report and was prepared by Mr. Robert H. Morris and Mr. James F. Devine, with assistance provided by Dr. H. G. Greene and Dr. Joseph S. Andrews. Attached to the report is an addendum to: "Review of Offshore Seismic Reflection Profiles in the Vicinity of the Cristianitos Fault, San Onofre, California," by H. G. Greene and M. P. Kennedy. This letter report is appended as Appendix G. The following excerpt contains the USGS conclusions regarding the history and age of the Cristianitos fault.

> "In assessing the conclusions drawn by the applicant's consultants in contrast with those by Greene and Kennedy, there emerges a difference in the use of certain named structures. Apparently, the applicant's consultants restrict the use of the term "Cristianitos Zone of Deformation" (CZD), to refer to a zone of short discontinuous faults and folds. The applicant's consultants conclude that the Cristianitos fault dies out to the south whereas Greene and Kennedy project the Cristianitos Zone of Deformation southward to the OZD. SCE recognizes the southward projection by Greene and Kennedy but state in their conclusion that it does not represent an interconnection between the Cristianitos fault and the OZD. Both parties recognize younger undeformed, probably marine terrace, deposits capping the structures near shore. The range in age of these capping deposits is stated by Dr. Shlemon (oral discussion, September 23, 1980, and viewgraph) to be from 80,000 years before present (YBP) to 8,500 YBP. The 8,500 YBP date was obtained by C14 method and the 80,000 YBP was inferred based upon geomorphology and late Pleistocene history. Assuming that the inferred age is a reasonable conclusion, then the applicant's contention that the Cristianitos Fault (restricted use) is not capable is permissive. On land, the Cristianitos Fault is capped by the 125,000 year-old marine terrace, and the above conclusion then is consistent with that evidence.

Applicant's consultant, Dr. Perry Ehlig, discussed the origin of the Cristianitos Fault (restricted use) and concluded that the fault originated from 10 to 4 million years ago during a period of crustal extension and that the present stress regime of generally northeast-southwest compression represents a significant change; therefore, movement on the OZD would not trigger movement on the Cristianitos Fault.

The USGS, in general, concurs with the conclusions stated by the applicant and its consultants regarding the history and age of last movement of the Cristianitos Fault, its relation as one of several faults of the CZD of Greene and Kennedy, and its apparent lack of potential for movement in response to movement on the OZD."

The addendum attached to the above report concludes:

"The CZD merges with or is truncated by the OZD in the area offshore from SONGS (plate 1). Generally faults within the CZD with few exceptions (plate 1) displace shallow stratified sedimentary rock that lies beneath a prominent unconformity and younger poorly stratified sediments. The June 1980 NEKTON data support the conclusions reported previously by Greene and Kennedy (1980)."

(6) Evidence Regarding the Non-Capability of the Cristianitos Fault

(a) Trenching across the Cristianitos fault and Plano Trabuco demonstrated that the segment of the fault observed was capped by non-marine terrace deposits which are older than 33,000 years.

(b) The excellent sea cliff exposure of the fault shows it cutting the San Mateo formation but being truncated by marine and non-marine terrace deposits that are approximately 120,000 years old.

(c) There is no historic seismicity associated with the fault.

(d) Mapping by P. Ehlig and Jack Harris show the fault to be capped by Pleistocene (more than one million years old) or older strata.

(e) Figure 5 of the report by Shlemon discussed in Section 2.5.1.8 of this report shows that the 120,000-year-old terrace is not displaced between Dana Point, north of the site, to Target Canyon south of the site. Furthermore, nowhere in the vicinity of the Cristianitos fault is the bedrock/terrace contact observed to be faulted.

(f) The numerous offshore seismic reflection profiles that cross the fault show that the Pleistocene terrace which is more than 13,000 years old and probably as old as 80,000 years is not offset by the fault.

(g) Comparing the degree of fault activity for the CZD and OZD, we find that the slip rate on the OZD is greater than that on the CZD by a factor of 3. This assumes a vertical displacement of 600 ft since Miocene time (12 million years ago), which calculates to be 0.0015 cm/yr as the slip rate on the CZD. The slip rate on the OZD is that of the Newport-Inglewood fault zone which was given above as 0.5 cm/yr.

The faults are characterized as follows according to Slemmons (1977): The CZD is of low activity, and for the range of 0.001 to 0.01 cm/yr within which it falls, the recurrence interval between magnitude 7 earthquakes or larger is generally measured in many tens of thousands of years to hundreds of thousands of years for recurrence at a given point on the fault.

The OZD is of moderate activity. The slip rate range of 0.01 to 0.1 cm/yr within which the OZD falls has a recurrence interval for generation of magnitude 7 or higher earthquakes generally measured in thousands to few tens of thousands of years for a given point on the fault.

(h) Dr. P. Ehlig's studies of the origin of the Cristianitos fault concluded that the fault originated from 10 to 4 million years ago during a period of crustal extension and that the present stress regime of generally northeast-southwest compression represents a significant change; therefore, movement on the OZD would not trigger movement on the Cristianitos fault.

The above indicates at this time that there is considerable evidence for noncapability of the CZD. Furthermore, it has been amply demonstrated that the CZD fulfills the role of a non-capable fault even assuming a structural relationship between it and the OZD, based on the definitions in Appendix A, 10 CFR Part 100. In the definition of a capable fault, Appendix A states that in the case of a fault having a structural relationship to a known capable fault, the fault is considered capable if movement on the capable fault could be reasonably expected to be accompanied by movement on the fault in question. Movement on the OZD for at least the past 120,000 years has not been accompanied by movement on the CZD.

2.5.2 Seismology

2.5.2.1 Background and Summary

In the seismological review conducted for the Construction Permit (CP) of the San Onofre Units 2 and 3 site, the staff relied primarily upon the evaluation provided by the National Oceanic and Atmospheric Administration (NOAA). They assumed the geological characteristics as defined by the USGS and described above. The "linear zone of deformation.....extending from the Santa Monica Mountains to at least Baja California" passing "within 5 miles of the site" was considered to be of primary importance to the seismic evaluation of the site. NOAA then states that:

"An acceleration of 2/3g, resulting from a strong X intensity (MM) event, (should) be used to represent the ground motion from the maximum earthquake likely to affect this site. However, the accelerogram may contain a few peaks between 2/3 and 3/4g during the 2/3g interval. These accelerations could result from an earthquake occurring within a few miles from the site. Also, it must be assumed that a similar earthquake could occur at any point along this zone of deformation."

The staff agreed with the NOAA evaluation and on this basis approved the earthquake design bases (anchor points) of 0.67g and 0.33g for the Safe Shutdown

Earthquake (SSE) and Operating Basis Earthquake (OBE), as being appropriately conservative. The FSAR refers to the SSE as the Design Basis Earthquake. The response spectra used in conjunction with the above acceleration values were developed from a scaled, smoothed, and modified set of real time histories. The development of these spectra is outlined in Appendix 2.5.B of the FSAR. The staff has reviewed the seismological information presented in the Final Safety Analysis Report (FSAR) and its amendments. Our review of the FSAR has concentrated on the following topics:

(1) Seismicity in the site region since the CP review and additional information on historical earthquakes in southern coastal California and Baja California.

(2) Determination of the maximum earthquake on the Offshore Zone of Deformation (OZD) from historic and instrumented seismicity and fault parameters.

(3) Determination of the vibratory ground motion at the site due to occurrence of the maximum earthquake on the OZD thru the use of empirical methods, theoretical models and an examination of recent recordings of strong ground motion from earthquakes.

(4) A comparision of the ground motion estimated above with the SSE approved for the construction permit.

These topics resulted from a review of the information that has been made available since the CP review, either in the literature or during subsequent analyses of the seismic conditions at the San Onofre site. The new information described in the following sections does not change the conclusions made following the CP review regarding the adequacy of the seismic design basis.

2.5.2.2 Seismicity

The seismic record in the southern California region extends back to the 18th century. Until the early part of this century, reports of earthquakes that were felt were the only records of those events. Few epicenters were reliably determined instrumentally prior to 1932. From 1932 to the present, however, a relatively complete listing of instrumentally determined epicenters is available. In the FSAR the applicants provided a listing of all non-instrumented events that had reported Modified Mercalli Scale Intensities of IV or greater and that could have reasonably occurred within a 320-kilometer (200-mile) radius of the San Onofre site. This list was compiled from a number of earthquake catalogs; the earthquake locations, undoubtedly influenced by population centers, should be considered very approximate. The grid like pattern shown in Figure 2.5-15 of the FSAR reflects locating these earthquakes at the nearest degree or half degree of latitude and longitude. It does not appear useful to attempt to correlate this biased pattern with known faults.

The applicants also provided listings of earthquakes of Richter Magnitude 5 or greater within 320 kilometers (200 miles) of the site and all listed earthquakes within 80 kilometers (50 miles) of the site for which instrumental records are available. The lists were taken from the Historical Earthquake Data File compiled by the National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, National Oceanic and Atmospheric Administration, Boulder, Colorado and contains events through 1975.

Those earthquakes of magnitude 6.0 or larger can be associated with specific faults such as the San Jacinto, San Fernando, White Wolf or Imperial Valley faults. Of particular interest to San Onofre is the 1933 Magnitude 6.3 earthquake on the Newport-Inglewood fault zone approximately 45 km northwest of the site. This fault zone and a proposed southward extension, the Offshore Zone of Deformation, is viewed as the major contributor to seismic hazard at San Onofre. Earthquakes in the range of magnitude 5.0 to 6.0 appear to be associated with what the applicants call major "zones of faulting." Many of these earthquakes are aftershocks of larger events. Earthquakes smaller than magnitude 5.0 do not necessarily correlate well with specific faults or zones of faulting. The density of these events varies with location. The vicinity of the San Onofre site (within approximately 30 km) appears to be one of relatively low seismicity.

In subsequent amendments to the FSAR, and in response to staff question 361.41, the applicants have provided post-1975 (through September 1979) seismicity information for the region within 320 kilometers of the site. Earthquake activity for data sets greater than Local Magnitude (M_L) 3, 4, and 5 were examined. No distinctive new patterns of seismicity different than that evident in the pre-1975 data were observed.

Localized data sets of all magnitudes were also collected and evaluated in several reports submitted to the NRC and the applicants. The occurrence of two small earthquakes (magnitude 3.3 and 3.8) in 1975 several km west of the Cristianitos fault zone, 30 km north of the site, was discussed in a report to the applicant by Biehler (1975). Accurate locations, making use of new velocity data, placed the hypocenters too far west to be on the Cristianitos fault zone. Focal mechanism solutions derived for these events were not consistent with the north trending Cristianitos fault and both historical seismicity and microearthquake surveys conducted in 1975 showed no evidence of the Cristianitos fault being active.

Earthquake activity in the vicinity of the site was also examined in a report to NRC by Whitcomb (1978) and by the applicants in response to Question 361.36. The earthquake closest to the site ($M_L = 2.5$) occurred 14 km to the northwest. This event appears to be part of a broad band of low-level earthquake activity in the Capistrano Embayment. Part of this earthquake activity includes the 1975 events discussed above, and, in addition, a cluster of 5 smaller earthquakes ($1.9 \leq M_L \leq 2.7$) that also occurred within several km of the Cristianitos fault in 1977.

These and the other small earthquakes in the embayment appear to be scattered rather than aligned along faults. These scattered locations and the focal mechanisms discussed above do not indicate any direct relationship between seismicity and observed faulting (including the Cristianitos) within or on the boundaries of the Capistrano Embayment.

2.5.2.3 Magnitude of the Maximum Earthquake on the Offshore Zone of Deformation

In the CP review we and our seismological advisors (NOAA) used a Modified Mercalli Intensity of X to characterize the maximum earthquake that could affect the San Onofre 2 and 3 site. This earthquake was assumed to occur along the Offshore Zone of Deformation five miles from the site. During the OL review the staff concluded that magnitude is a better indicator of earthquake source strength than intensity. Intensity is a measure of observed damage and felt effects. It depends upon the size of the earthquake, its depth, the distance from the earthquake source, the nature of the geologic materials between the source and the point of observation and the geologic conditions at the point of observation itself. Although an attempt is made in the intensity scale to account for differences in structural design, it is only done in a very general way. Particular problems are associated with determination of intensities greater than VIII. Very often these intensities are based upon ground failure (landslides, soil liquefaction, etc.) which are very much dependent upon local conditions rather than ground shaking. Many investigators (for example, Nason, 1978; and Tocher and Hobgood, 1978) have suggested great caution in assigning these high intensities. In addition strong motion data at high intensities is practically nonexistent. Ground motion estimates at these levels are based upon highly non-unique extrapoliations from the more abundant data at lower intensities.

Magnitude is a measure of earthquake source size using instrumental recordings of ground motion at different distances. Different magnitude scales measure different components of motion in different frequency ranges and care must be exercised in choosing the appropriate scale for the intended purpose. Local Magnitude (M_L), the original magnitude scale, was developed from recordings of small earthquakes ($M_L<5.0$) at distances between 20 and 600 km in southern California. It is determined utilizing the largest ground motion recorded on the Wood-Anderson seismograph. As a result, it is particularly sensitive to short period (about 0.8 seconds) horizontal motion. It is not applicable at distances greater than 500 or 600 km and must be used with great care outside of California. Surface wave magnitude (M_S) was developed subsequently to complement M_L for earthquakes of greater size and at different locations. It is determined from longer period (20 second) motion. Richter magnitude (M) as it is commonly, but very often not precisely, used is equal to M_L for magnitudes less than about 6 and M_S for larger earthquakes (Nuttli, 1979). The reason M_L cannot be used for larger earthquakes is the apparent saturation of the scale at around 7 1/4. The great San Francisco earthquake of 1906, for example, had an estimated M_S of 8 1/4 while the M_L is only estimated to have been between 6 3/4 and 7 (Jennings and Kanamori, 1979). M_L saturates because the amplitude of the shorter period waves which determine M_L do not simply increase as the fault length increases. As Kanamori (1978) states, "The amplitude of seismic waves represents the energy released from a volume of crustal rock whose representative dimension is comparable to the wave length." Seismic waves used in the determination of M_L may only reach wave lengths of 6 km. Thus, they cannot be expected to adequately reflect the energy release of earthquakes associated with ruptures tens of kilometers long. Similarly they do not adequately reflect the seismic moment of such earthquakes. Seismic moment, defined as being equivalent to the product of rigidity, fault area, and fault displacement, is the measure most easily related to geologic fault parameters.

In the range of interest for San Onofre (magnitude 6 to 7.5), M_S, determined from waves whose lengths are about 60 Km, is more related to seismic moment than M_L. According to Kanamori (1979), at magnitudes greater than 6, the average M_L begins to deviate and becomes less than the average M_S for the same earthquake until the M_L reaches the previously mentioned saturation point of about 7 1/4.* According to this estimate, an M_S of about 7 would have an average M_L of 6.6 or 6.7. By assuming a simple linear relationship between M_S and M_L, Nuttli (1979 arrives at a similar result.

Thus, in estimating earthquake size from fault studies in southern California, the most directly relateable magnitude scale based upon rupture lengths less than hundreds of kilometers would be M_S. Similarly the saturation of M_L indicates that the amplitude of strong ground motion at periods less than 1 second (periods of interest to nuclear power plants) cannot be assumed to scale simply as M_S or fault size increase. Increases in estimates of maximum earthquake size around or above the saturation level do not necessarily imply increased hazard to nuclear power plants.

We asked the applicants to specify the maximum magnitude of an earthquake on the OZD. In the following subsections, we review several methods of determining the maximum magnitude earthquake on the OZD, including the method used by the applicants. Considerable research effort has been expended in an attempt to define more precisely the maximum size of an earthquake that can be associated with various types of faults and tectonic environments. However, in evaluation of the seismological characteristics of a nuclear plant site, we must use theories and empirical data cautiously until sufficient data have established their validity. Our discussions will note areas of uncertainty and areas where we have used conservatism.

2.5.2.3.1 Maximum Magnitude from Historical Seismicity

A consideration of historical seismicity for the determination of the maximum earthquake on the Offshore Zone of Deformation should include south coastal California and postulated extensions of this zone of deformation into Baja California. In the southern coastal region of California, there have been three earthquakes in historical time which could have had a major impact upon the San Onofre 2 and 3 site. These occurred on November 22, 1800, December 8, 1812, and March 11, 1933. The California Division of Mines and Geology (CDMG) has estimated epicenters and magnitudes for the 1800 and 1812 earthquakes based upon felt reports (Toppozada and others, 1979). The 1800 event was located near San Diego and the 1812 event was located near San Juan Capistrano where the mission was destroyed. Becuse there were few European settlements (mostly missions) in California at this time, locations based upon felt reports should

*M_S also saturates at about 8.3 and does not reflect the energy release in a truly great earthquake where fault rupture reaches hundreds of kilometers. For this purpose, a new magnitude scale M_W was developed (Kanamori, 1978). For example, the great Chilean Earthquake of 1960 had an M_W of 9.5 while its M_S was only 8.3.

be considered as very approximate. Both these earthquakes were estimated to have had magnitudes of 6.5. It is not quite clear whether this is M_S or M_L, but since the calibration function used to determine magnitude (Toppozada, 1975) used mostly M_S for larger events we can assume that M_S is the appropriate measure.

The 1933 earthquake had both an M_S and an M_L of 6.3 and is the largest instrumentally recorded event within the south coastal area of California. Its epicenter was located on the Newport-Inglewood fault zone, the northern seismically active section of the OZD. The rupture length associated with this earthquake (about 30 km) was based upon aftershock data as there was no surface breakage (Woodward-Clyde, 1979).

In Baja California, the largest instrumental earthquake of postulated significance to the San Onofre site is the El Alamo earthquake of February 9, 1956, which is associated with the San Miguel fault. Evidence for and against a connection between the OZD and the San Miguel fault is discussed in Section 2.5.1.8 above. M_S for this earthquake is reported to be 6.8 while M_L is estimated as 6.6 (see FSAR response to Question 361.68). The length of surface rupture for this event was at least 19 km.

On February 24, 1892, a large earthquake occurred which was felt strongly in southern California, southwestern Arizona, and Baja California. Information on this earthquake is limited to felt reports. Based upon felt reports in Los Angeles, Hanks, and others (1975) suggested a seismic moment of 5×10^{27} dyne-cm and assumed a location on the Agua Blanca fault south of the San Miguel fault. Seismic moments of this size are usually associated with earthquakes of surface wave magnitude close to 8. However, recent and more detailed work by Toppozada and others (1979) states that the 1892 event had a magnitude of 6.9 (probably M_S) and was located in the Peninsular Range of northern Baja California near the Sierra Juarez fault system. This fault system is believed to be related to the spreading of the Gulf of California (Gastil and others, 1979) rather than the San Miguel Fault Zone or other postulated extensions of the OZD into Baja California. Thus, the largest historical earthquakes which have an impact upon the assessment of the maximum earthquake on the OZD are M_S = 6.3, 6.5, and 6.5 in southern coastal California and possibly M_S = 6.8 in Baja California.

2.5.2.3.2 Maximum Magnitude from Fault Parameters

Much of the material relating earthquake magnitude to fault parameters has been discussed in the geology section of this Safety Evaluation Report. In the following paragraphs, we will review the maximum magnitude estimates discussed in that section and discuss other estimates of magnitude based on additional fault parameters.

Typically the most utilized method of estimating earthquake potential has been the use of fault rupture length. As our consultant, Dr. Slemmons, has pointed out (Appendix E) direct application of this method "is not possible for the OZD as surface faulting is rare along the zone." Indirect application of fault rupture length earthquake magnitude methodology by our consultant as described in Section 2.5.1.9, must rely upon subsurface estimates of individual rupture lengths or appropriate percentages of estimated total fault length.

Utilizing Slemmons (1977), over 10 different estimates were made (Appendix E) for the maximum magnitude on the OZD. These estimates ranged from $M_S = 6.6$ to 7.3 depending upon the specific approach, level of conservatism and fault length assumed. The lowest estimate was derived using an inferred subsurface rupture length on the segment of the OZD nearest the site while the largest estimate was derived assuming a total fault length of 300 km (from Santa Monica to the Agua Blanca fault in Baja California) and that a fraction of this length would rupture consistent with the mean plus one sigma fraction of observed strike-slip faults. The inability in this case to use this method directly, the uncertainty associated with the assumed fault lengths, and the scatter of resulting estimates preclude placing much weight on the fault length versus magnitude approach.

Slemmons (1977) has also developed correlations between magnitude and fault displacement. It is not possible to apply this method directly to surface displacement on the OZD because of the plastic deformation of tertiary sediments (Appendix E). We also find it inappropriate to take total displacement along the OZD that relates to the past few million years and assume that it or any significant portion of it could occur during one earthquake. However, the applicants have developed a correlation between the average yearly displacement (slip-rate) and maximum magnitude which has been reviewed in Section 2.5.1.8 and will be discussed below.

For the purpose of estimating maximum magnitude, Wyss (1979) advocated the use of source length rather than surface rupture length, also postulated that fault area (source length multiplied by fault width) would provide a more accurate and appropriate estimate than length alone. Bonilla (1980) has pointed out some problems associated with this technique. In order to compare Wyss' proposal with estimates derived using fault length, maximum magnitude for the OZD was computed assuming a conservative fault width (depth) of 15 km and the range of fault lengths proposed by our consultant in Appendix E. A similar range of maximum magnitudes ($6.8 \leq M_S \leq 7.2$) was calculated. Because this method also relies upon indirect estimates of fault or source length and an assumed fault width, little additional consideration should be given to this approach.

The applicants have developed a methodology (Woodward-Clyde, 1979) relating maximum earthquake magnitude to slip rate or degree of fault activity. As previously discussed, it is our consultants' (Appendix E) and the staff's opinion that an appropriate application of this approach results in an estimated maximum magnitude of $M_S = 7.0$ for the OZD. In a test of consistency between slip-rate and fault-length estimates for maximum magnitude, the applicants developed a correlation between slip-rate and fault-length from selected data. Half-lengths were conservatively assumed to be the portion of total fault-length capable of rupturing in one earthquake. This correlation was then used in conjunction with Slemmons (1977) proposed relationship between fault-length and magnitude for strike-slip faults. The resulting plot of magnitude versus slip-rate called the Synthetic Earthquake Limit (SEL) was then compared to the direct slip-rate estimates. This estimate had a somewhat steeper slope than the direct estimate, that is, lower maximum magnitude for high slip-rates and higher maximum magnitude for very low slip-rates. In the range of interest for the OZD (slip-rate of 0.5 mm/year), the SEL was slightly less than the applicants' conservative Maximum Earthquake Limit.

The applicants have presented an additional argument as to the conservatism of the slip-rate estimate. Assuming a constant b value of 0.85 and utilizing Anderson's (1979) method, recurrence curves were computed from slip-rates and fault-lengths assuming different maximum magnitudes (6.0, 6.5, 7.0 and 7.5). It is proposed that the occurrence of the 1933 Long Beach and possibly the 1800 and 1812 earthquakes is consistent with an assumed maximum magnitude of 6.5, while assuming a maximum magnitude of 7.5 results in return periods (270 years for $M_S = 6.0 \pm 0.25$, 720 years for $M_S = 6.5 \pm 0.25$) longer than the historical data would suggest.

Our consultant, Dr. Slemmons, has stated that the "fault-slip rate method is the firmest, most quantitative approach for state-of-the-art assessment of the maximum earthquake on the OZD." In a limited review of the applicants' slip-rate method, the USGS (Appendix G) states that because of the limited data base at low geologic slip-rates this technique "cannot be considered definitive in assessing maximum magnitude." However, it "is helpful, when considered along with other procedures for estimating earthquake size to assess the potential impact of earthquakes on the SONGS site." Our evaluation of the applicants' slip-rate methodology can be stated as follows:

(1) Correlation of maximum earthquake potential and degree of fault activity is in itself a geological reasonable and intuitively sound idea.

(2) Use of present estimates of slip-rate to establish maximum earthquake magnitude based upon the limited geological and seismological data requires both caution and conservatism. This limited data set and limited understanding of the physical basis between maximum magnitude and slip-rate preclude the exclusive use of this technique in establishing maximum magnitude.

(3) The most appropriate slip-rate estimate used by the applicants is the Maximum Earthquake Limit. This estimate ($M_S = 7.0$ for the OZD) makes a specific attempt to account for uncertainties.

As with many geologic and seismological assessments, estimation of maximum magnitude for the OZD from fault parameters is not an unequivocal procedure. No single technique, be it fault-length, fault-displacement, fault-area or slip-rate should be considered as adequate in itself. Based upon the above discussions, it is our position that $M_S = 7.0$ is a reasonable, yet conservative, estimate of maximum earthquake potential based upon fault parameter evaluation.

2.5.2.3.3 Maximum Magnitude from Intensity

In the CP review, the staff adopted the position of its seismological consultant (NOAA) that "an acceleration... for a strong MM intensity X be used to represent ground motion from the maximum earthquake likely to affect the site." Various correlations relating magnitude to intensity have been proposed. Assuming an intensity X would yield, for example, magnitude 7.7 from Gutenberg and Richter (1942), 7 from Richter (1958), 7.1 from Krinitzky and Chang (1975) and 6.75 from Toppozada (1975). It is not always clear which magnitude scale is being referred to but, since the data sets rely upon surface wave magnitudes for the larger events, we assume that M_S is the appropriate measure. However, we do not believe it is appropriate to relate epicentral or maximum intensity to magnitude at high intensities because of the paucity of data at these intensities and the presence of other factors such as site conditions which have a strong effect upon all intensity estimates. In addition, most estimates are based upon linear fits to scattered data at lower intensities extrapolated to few, if any, points at higher intensities.

2.5.2.3.4 Conclusions

Based upon our evaluation of the various approaches outlined above, we conclude that an appropriate representation of the maximum earthquake on the OZD to be used in determining the SSE at San Onofre is $M_S = 7.0$. This conclusion rests upon the combined results from the following approaches:

(1) Evaluation of Historical Seismicity -

  (a) largest earthquake in southern coastal California: $M_S = 6.3$ (1933); possible $M_S = 6.5$ (1800, 1812)

  (b) largest earthquake on postulated extensions of the OZD into Baja California: $M_S = 6.8$ (1956).

(2) Evaluation of Fault Parameters (in order of relative importance)-

  (a) Slip-rate: utilizing the estimator called Maximum Earthquake Limit which incorporates uncertainty in both magnitude and slip-rate results in $M_S = 7.0$.

  (b) Fault-length: utilizing the range of inferred fault lengths results in estimates ranging from $6.6 \leq M_S \leq 7.3$.

  (c) Fault-area: utilizing the range of inferred fault lengths with an estimated fault width of 15 km results in magnitudes of $6.8 \leq M_S \leq 7.2$.

While it is impossible to absolutely rule out the occurrence of an earthquake larger than $M_S = 7.0$ on the OZD, it is the staff's position that a maximum magnitude of $M_S = 7.0$ is based upon a reasonable and conservative interpretation of all available geological and seismological information.

2.5.2.4 Vibratory Ground Motion

The SER for the San Onofre 2 and 3 CP approved an SSE (then designated the DBE) defined by a response spectrum shape derived from a scaled and modified study of real earthquakes anchored at 0.67g. It was also required that consideration be given to peaks of ground motion between 0.67 and 0.75g. In this section we will evaluate that spectrum with respect to ground motion from the controlling event defined as an earthquake of $M_S = 7.0$ occuring on the OZD at its closest location to the site (8 km).

Determination of ground motion in the near field of large earthquakes is a difficult and problematic task. Although "near field" has several definitions it is being used here in the context of the "geometrical near field"; that is, at distances less than the dimensions of the earthquake source. Since the earthquake assumed to occur on the OZD is also assumed to result from a rupture tens of kilometers long and at least 10 km wide (deep), estimation of ground motion at a distance of 8 km from the fault can be clearly considered a "near field" problem.

The sources of uncertainty in near-field ground motion estimation are several. First of all, there has been a relative lack of data recorded close in (less than 10 km) from earthquakes, particularly those larger than $M_S = 6.0$. The vast majority of data was recorded at distances greater than 20 km. Simple extrapolation of the data to close-in distances is not easily accomplished since ground motion at these distances is less sensitive to factors such as gross source strength, geometric spreading, and seismic wave attenuation which affect far field motion and is more sensitive to source geometry and details such as localized stress conditions and direction of faulting. The interpretation of these near-field effects and the type of "best fit" curve one uses can lead to large differences in the near field. Those seismologists who may agree with each other within a factor of two in predicting ground motion from a magnitude 7 earthquake at 30 km, also find more than an order of magnitude differences in their predictions for the same earthquake at a distance of 5 km (Swanger and others, 1980).

Recently, a great deal of effort has been placed on theoretical models of earthquake sources and attempts have been made to theoretically predict ground motion at various distances. While these efforts are certainly encouraging they are controlled by assumptions about the physical nature of the earthquake source. Different assumptions such as the size of the stress drop and the effect of local inhomogeneities have a major impact upon ground motion particularly at those frequencies (greater than 2 Hz) of concern to nuclear power plants. As of this time, no consensus with sufficient detail exists within the seismological community that would allow the exclusive use of theoretical models in order to estimate ground motion in the near field. In face of the problems (not necessarily the same) associated with either the empirical or theoretical approaches in estimating near field ground motion, it is our position that the most appropriate way to arrive at an estimate involves the pursuit of both approaches and a conservative comparison. As there are characteristics of ground motion not directly related to nuclear power plant safety (for example, low frequency motion and isolated high frequency peaks) it is important to take into account engineering considerations so as to concentrate the analysis on those elements which have a direct bearing upon safety.

A final confirmatory element can also be used to evaluate the adequacy of the ground motion estimate. The October 1979 Imperial Valley earthquake ($M_S = 6.9$, $M_L = 6.6$) has provided an unprecedented set of data from an earthquake of the appropriate size at distances as close as 1 km from the fault rupture. In the sections below we discuss the applicants effort at predicting ground motion from the controlling earthquake using both empirical and theoretical approaches and a comparison of their results with data from the October 1979 Imperial Valley earthquake. We find that the ground motion specified in the SER for the San Onofre 2 and 3 CP exceeds a conservative representation of ground motion expected at the site from an occurrence of the controlling earthquake; that is an $M_S = 7.0$ on the OZD at a distance of 8 km.

2.5.2.4.1 <u>Empirical Approach</u>

In order to estimate the ground motion at the site, the applicants (Woodward-Clyde, 1979) collected all available high quality digitized and processed horizontal strong motion recordings from the western United States recorded at site conditions similar to San Onofre (deep, stiff soil) from earthquakes of magnitude approximately equal to 6.5. This collection, which was assembled prior to the 1979 Imperial Valley event, yielded 56 recordings from 7 earthquakes. The M_L of the earthquakes ranged from 6.3 to 6.5 with 48 of the records coming from earthquakes of $M_L = 6.4$. The M_S of the earthquakes ranged from 6.3 to 6.7 with 46 of the records coming from earthquakes of $M_S = 6.6$. In order to reduce the bias from the heavily represented San Fernando earthquake of 1971, a weighing procedure was applied so that each earthquake had equal influence in any given distance interval where recordings were available. The data (peak accelerations and response spectrum values at periods of 0.04 to 2.0 seconds at 2 percent damping) were then fit to a regression curve of a widely used form first proposed by Esteva (1970).

Curves were computed for the mean and 84th percentile (mean plus one sigma) of each period, and extrapolated to 10 km. This distance was used assuming the center of energy release occurred on a vertical fault 8 km away at depth of 6 km. A 2 percent damped response spectrum of horizontal ground motion for an $M_S = 6.5$ earthquake was then constructed from these extrapolated values. A response spectrum for $M_S = 7.0$ was estimated (see FSAR response to Question 361.54) by multiplying the peak acceleration and spectra by scaling factors. These factors were determined from several published ratios of peak accelerations at 10 km for $M_S = 6.5$ to $M_S = 7.0$ events and an empirical study of the effects of magnitude on spectral shape. The peak accelerations associated with the mean and 84th percentile of $M_S = 6.5$ are 0.42g and 0.57g while those associated with $M_S = 7.0$ are 0.47g and 0.63g. As expected, larger differences exist in the response spectra at long periods. The SSE spectrum approved in the CP SER exceeds the 84th percentile $M_S = 7.0$ spectrum at all frequencies.

During the review of the applicants methodology, several issues were raised. The most important of these were:

(1) The adequacy of the assumed attenuation relationship, that is, that acceleration is proportional to $(R+C)^B$ where R is distance, B determines attenuation in the far field, and C determines the flattening of the regression line in the near field. Based upon examination of the data, C = 20 was judged to be appropriate. A smaller value of C would tend to increase near field values. C = 0, for example, implies infinite acceleration at the fault.

(2) The effect of focusing upon the assumed results. Focusing is the effect caused by a propagating rupture which results in increased seismic amplitudes in the direction of propagation and lower amplitudes in the opposite direction.

(3) Use of distance to the center of energy release rather than distance to the fault.

(4) Inclusion of data within the analysis which may have been recorded on buildings with large foundations and may, as a result, have lower peak accelerations than the free field.

(5) The impact of including data from northwest California earthquakes whose locations are subject to large uncertainties.

The applicants' response to these issues follows:

(1) The appropriateness and degree of conversatism for the choice of C = 20 was evaluated using a theoretical model of Hadley and Helmberger (1980) which simulates the effects of large earthquakes through the mathematical superposition of small, well-recorded earthquakes. These studies show that for a magnitude 6.5 earthquake, the best choice of C is 22 while for a magnitude 7.0, the best choice would be 30. The use of the smaller C = 20 would, according to these studies, be conservative see FSAR (response to Question 361.53). In addition a recent study by TERA Corporation (TERA, 1980), was submitted by the applicants. This study gathered all recent earthquake data between magnitudes 4 and 8 at distances less than 50 km. One hundred and ninety-two peak accelerations from 22 earthquakes were used. Of these, 31 were from M_S = 6.5 or greater events recorded at distances less than 10 km. Regressions on this data set using different assumptions as to the choice of B and C indicated little variation in predictions for M_S = 7.0 at 8 km. Predicted peak accelerations ranged from 0.50g to 0.55g for the mean plus one standard deviation.

(2) The data set used includes in it much data recorded under conditions of above average focusing (see FSAR response to Question 361.56). In addition, it was argued from a theoretical point of view that at a distance of 8 km the effect of changing radiation pattern as seen by the station would rapidly diminish the effect of focusing (see FSAR response to Question 361.53).

(3) The applicants believe that the closest distance to the center of energy release is more appropriate. However, the data was also plotted assuming closest distance to the fault. The original curves assuming closest distance to center of energy release were shown to be more conservative at moderate and close distances (see FSAR response to Question 361.62).

(4) The applicants concur with proponents of differences between small and large structures (Boore and others, 1978) who state that "the differences between the data from the large structures and the small structures are relatively small compared with the range of either data set, and we do

not believe that firm conclusions are warranted solely on the basis of formal statistical tests. The differences may be due to soil-structure interaction, but more study would be required to demonstrate this" (see FSAR response to Question 361.55).

(5) Removal of data from northwest California earthquakes would result in lower peak accelerations at 10 km than those originally proposed.

We find their answers to the questions raised and the proposed spectra reasonable as long as the general limitations inherent in empirical extrapolation into the near field as outlined above are taken into account. The conservatism of the estimated ground motion can also be judged when compared to the theoretical estimates and recent earthquake data as discussed below.

2.5.2.4.2 Theoretical Estimates of Ground Motion

As part of the Systematic Evaluation Program of older operating plants, the staff is reviewing the design of the San Onofre Nuclear Generating Station, Unit 1 (San Onofre 1). This review is still underway and a final evaluation will be published in the future. However, in support of the seismic reevaluation of San Onofre 1, the licensee has submitted a series of theoretical studies whose purpose is the prediction of ground motion at the site from an earthquake caused by a rupture along the Offshore Zone of Deformation.

These studies (Del Mar Technical Associates, 1978, 1979a, 1979b, 1980a, and 1980b) are described below and in Section 2.5.2.4.5 and discussed with reference to the conservatism of the SSE adopted for San Onofre 2 and 3.

For the San Onofre 1 studies, a kinematic source model was assumed. The procedure for modeling ground motion was accomplished in three steps:

(1) Fault-slip is characterized in terms of fault type, rupture velocity, dynamic stress drop (slip velocity at the onset of rupture at each point on the fault) static stress drop (fault offset), and duration of slip at each point. Random processes are included to approximate irregularities in actual earthquake rupture.

(2) Propagation characteristics (Green's functions) are calculated for the particular earth structure, that is, surface motions are computed for several hundred point sources along the fault plane. These earth response calculations include all wave types up to frequencies of 20 Hz.

(3) Ground motion is calculated by convolving in time and space the fault-slip characterization from Step 1 with the earth response functions from Step 2. By specifying hypocentral location, rupture extent and site location, the different source site configurations can be examined.

For the initial study (Del Mar Technical Associates, 1978) the model (particularly the slip-function) was calibrated using the 1966 Parkfield Earthquake ($M_S = 6.0$, $M_L = 5.8$). Prior to 1979 this was the best recorded earthquake in the near field. In addition, the recordings from the 1940 Imperial Valley Earthquake (M_L = 6.5, M_S = 7.1) and the 1976 Brawley earthquake (M_S = 4.9) were modeled. Utilizing subsurface knowledge of the San Onofre site, P and S wave velocity, density, attentuation, and layer thickness were computed. Green's functions were calculated to predict propagation characteristics from source depths extending to 15 km, out to epicentral distances of 60 km. The ground motion modeling centered about the effects of a 40 km long rupture at a distance of 8 km from the site. This is an approximate representation of an M_S = 7.0 earthquake on the OZD. Sensitivity tests were conducted to test the effect of variations in site distance, fault length, and fault location along the OZD (focusing), fault depth, hypocentral depth, changes in dynamic and static stress drop, duration of slip, and changes in earth structure, upon estimated ground motion.

In response to the staff's and its consultants' (Dr. Keiiti Aki, M.I.T.; Don L. Bernreuter, Lawrence Livermore Labs; Dr. Robert Herrmann, St. Louis University; and Dr. J. Enrique Luco, University of California-San Diego) review, a revised model and additional studies were submitted (Del Mar Technical Associates 1979a). The revisions in the model included:

(1) Utilization of additional randomness.

(2) Revision of the three parameter slip-function.

Additional studies were conducted with respect to:

(1) The effect of grid spacing used in the numerical modeling procedure upon results.

(2) The assumption of a two parameter slip-function.

(3) Sensitivity of the results to changes in earth structure and fault parameters.

In response to other concerns, the licensee submitted (Del Mar Technical Associates, 1979b) calculations and discussions relating to magnitude and moment estimates of the proposed numerical estimates of ground motion and estimated ground motion at distances greater than 20 km. Utilizing a relationship between seismic moment and surface-wave magnitude, the M_S of the hypothesized offshore earthquake was calculated to be 6.94. An M_L of about 6 was calculated using the technique developed by Kanamori and Jennings (1978) to estimate M_L from strong motion records.

In addition to the above mentioned consultants, the staff initiated a separate study carried out on the Illiac Computer by Systems, Science, and Software (Day, 1979) to investigate slip-functions. Making use of the unique capabilities of the Illiac, numerical dynamic studies were carried out to test the sensitivity of earthquake slip functions to fault geometry, functional strength, and prestress configuration. Ground motion at different distances from the fault was not examined.

The revised model (Del Mar Technical Associates, 1979a) used by the licensee in generating the proposed response spectra at the San Onofre 1 site assumes a 40 km rupture maximally focused at the site with a fault offset of 130 cm and a rupture velocity nine-tenths the shear wave velocity. Mean and 84th percentile spectra have peak accelerations of 0.31 and 0.37g respectively. These spectra fall below the empirically-derived spectra for $M_S = 7.0$ and well below the SSE. The staff's consultants reviewed the revised model and assumptions. Generally it was concluded that there was an improvement but questions still remained regarding various aspects, in particular, the slip function. All felt that the proposed spectra were good representations of ground motion from rupture on the OZD. There was some question whether this motion was appropriate for an $M_L = 6.0$ or for a larger earthquake. In general, the consultants suggested multiplication of the spectra by a factor of about 2 to account for uncertainties in the modeling process or an increase in magnitude. Doubling the mean theoretical spectra would place it below the SSE at approximately the 84th percentile level of the $M_S = 7.0$ empirical estimate discussed previously.

It is the staff's position that the modeling procedure utilized demonstrate the conservatism of the empirically derived spectra and particularly the SSE.

2.5.2.4.3 Comparison of Estimated Ground Motion with Recent Earthquake Data - The 1979 Imperial Valley Earthquake

The occurrence of an earthquake in the Imperial Valley in October 1979 provided an excellent opportunity to judge the adequacy and conservatism of the previous ground motion estimates and the SSE approved for the San Onofre 2 and 3 CP. This earthquake of $M_S = 6.9$ and $M_L = 6.6$ occuring on the same fault (Imperial) that produced the 1940 $M_S = 7.1$, $M_L = 6.5$ earthquake resulted in approximately 31 km of surface rupture. Rupture at depth was undoubtedly larger. It was a predominantly strike-slip earthquake with some vertical movement at the northern end of the fault and possibly some simultaneous movement on the adjacent Brawley Fault. The fault and vicinity were heavily instrumented and provided the most extensive set of near-field ground motion recordings available at distances as close as one kilometer. Aside from a difference in site conditions (the Imperial Valley is a deep, alluvial valley) this event is similar to the proposed M_S = 7.0 maximum earthquake on the OZD.

2.5.2.4.4 Comparison with the Empirical Approach

A comparison (see FSAR response to Question 361.55) of the mean and 84th percentile empirical attenuation curves with the horizontal peak accelerations recorded during this event indicate the general conservatism of the empirical approach. While the mean and 84th percentile peak accelerations of the new data at 8 km from the fault are 0.32 and 0.44g, the mean and 84th percentile estimated for a magnitude 6.5 at the SONGS site are 0.42g and 0.57g. Only 4 horizontal peak accelerations at any distance exceed 0.57g. These were from the two components at Bonds Corners (0.81g and 0.66g) at three km from the fault, 0.72g from one record at Station #6 one kilometer from the fault, and 0.61g from one record at Station #4 seven km from the fault.

A compilation of horizontal response spectra from the October 15 earthquake (see FSAR response to Question 361.55) shows that the mean and 84th percentile of 14 response spectra recorded at distances between 6 and 13 km fall well below the predicted mean and 84th percentile spectra for a magnitude 6.5 earthquake at almost all frequencies. Between 5 and 10 Hz, the Imperial Valley spectra approach the level of the predicted spectra.

2.5.2.4.5 Comparison with Theoretical Models

The theoretical model used to estimate ground motion for San Onofre 1 is currently being evaluated with respect to its ability to predict observed ground motion from the 1979 Imperial Valley earthquake (Del Mar Technical Associates, 1980b).

In order to better fit the observed data further refinements, mostly additional randomness, were introduced into the earthquake model. As a result of these refinements, better fits are obtained to the data particularly with respect to high frequency vertical and close-in horizontal ground motion. Sensitivity tests were carried out with respect to changes in the character of slip, inclusion of rupture along the Brawley Fault, and proximity of the rupture to the surface.

Although this refined model produced better results for this earthquake than the previous model, no comparison was made with respect to the original predictions for the 1940 Imperial Valley earthquake, the 1966 Parkfield earthquake, and the 1976 Brawley earthquake (Del Mar Technical Associates, 1979a); additional events shown in Supplement II (Del Mar Technical Associates, 1980a). Supplement II showed estimates of ground motion for the 1933 Long Beach earthquake and 1971 San Fernando earthquake based upon the original (revised) model and some, but not all, of the refinements introduced above. It is difficult to judge as to the relative validity of the original and refined models without a comparison of at least several different earthquakes. However, computation of ground motion at San Onofre using the refined model provided an assessment as to the significance of these differences with respect to estimation of ground motion from the occurrence of an earthquake on the OZD. These comparisons show rough equivalence of horizontal ground motion from both models. At different frequency bands a different model may be more conservative. With respect to vertical motion higher ground motion is predicted at high frequencies utilizing the refined model. This is to be expected since the model was calibrated with the Imperial Valley earthquake in which several stations produced anomalously high vertical accelerations. These accelerations are discussed below in Section 2.4.2.4.6.

As with the response spectra estimated at San Onofre from the original (revised) model response spectra estimated using the refined model fall below the applicants empirically derived spectra for an M_S=7.0 earthquake occurring on the OZD. Thus, while our review of the modeling study has not been completed and there may be uncertainty as to the appropriateness of the different theoretical models proposed, those examined do indicate conservatism in the empirical approach.

2.4.2.4.6 Comparison with the SSE

A direct comparison of ground motion recorded from the 1979 Imperial Valley event with the SSE has been made by the applicants (see FSAR responses to Questions 361.57 and 361.64). The major difference between the M_S = 6.9 October 1979 event and the controlling M_S = 7.0 assumed to occur at the OZD is the difference in site conditions. As indicated above, the Imperial Valley is a deep-alluvial (soft soil) valley, while San Onofre is a stiff soil site that is more rock-like in character. Boore and others (1978) compared ground motion from the San Fernando earthquake at rock and soil sites. They found that while there was no significant difference in peak accelerations, soil sites systematically recorded higher peak velocities and peak displacements. This observation relates to response spectra in that peak accelerations can be correlated with high frequency motion and peak velocities and displacements can be correlated with motion at intermediate and low frequencies. In other words, the major difference we would expect between similar size earthquakes occurring in the Imperial Valley and near San Onofre would be a higher level of ground motion recorded at frequencies of 1 Hz and less in the Imperial Valley.

A comparison of the recorded horizontal motions with the horizontal SSE (anchored at 0.67g) indicates the following:

(1) The mean plus one standard deviation level of ground motion at distances between 6 and 13 km is well below the SSE.

(2) The envelope of all response spectra in this distance range is below the SSE except for some small exceedances. This exceedance is broadest at Bonds Corner some 2 to 3 km from the fault.

A comparison of recorded vertical motion with the vertical SSE (anchored at 0.44g) indicates the following:

(1) The mean spectral level at distances between 6 and 13 km falls below the SSE.

(2) The mean plus one standard deviation of response spectra in this distance range exceeds the SSE by small amounts at frequencies greater than 2 Hz.

(3) There is some significant exceedence of the SSE by vertical response spectra at stations at distances less than 6 km. Most notable is that of Station #6, one km from the fault. The uncorrected peak vertical acceleration recorded at this site was 1.74g the highest acceleration recorded anywhere from any earthquake.

The applicants indicate that these exceedances are not significant and points out the following:

(1) Within a distance of 10 km the fault maximum vertical peak acceleration is substantially higher than other peaks of vertical ground motion in recordings with very high peak accelerations.

(2) Within 15 km of the fault maximum vertical motion occurs early in the recorded motion approximately 2 to 4 seconds before the corresponding horizontal peaks.

(3) Algebraic and vectorial combination of ground motion records from all three components of motion show that vertical and horizontal motions dominate at different times during the ground motion (vertical $\leq$ 5 seconds, horizontal $\geq$ 5 seconds).

With respect to the above, the applicants also indicate that in the design of San Onofre 2 and 3 the significant ground motion from all components was assumed to occur at the same time and the assumed duration of this motion including repetition of high peaks of acceleration was much longer (80 seconds versus 15 seconds or less) than that recorded at Imperial Valley. We agree with the applicants' assessment of the significance of the high vertical motions particularly in light of the following additional information which indicates that these motions are most likely related to the particular site conditions in the Imperial Valley and not directly applicable to San Onofre:

(1) Station #6 (which recorded high peak accelerations) has systematically recorded high peak accelerations from other earthquakes at other locations (Boore and Fletcher, 1980).

(2) Those high vertical accelerations occurring at certain stations within 10 km of the fault did not occur at all stations near the fault and are believed to be related to the interaction of the propagating rupture with the thick sedimentary cover (Archuleta, 1980).

(3) Those strong motion records from other earthquakes in the past which have shown relatively high vertical peak accelerations appear also to be related to site and fault conditions not present at San Onofre. For example, the 1976 Gazli earthquake caused strong vertical motion because the fault beneath the site ruptured vertically up towards the site (Hartzell, 1980), and the 1979 Coyote Lake earthquake resulted in high vertical acceleration at one station because of S to P wave conversion at the interface between the soft alluvium and firm bedrock at depth (Angstman and others, 1979).

In conclusion, it is our position that the analysis of records from the extremely well-recorded October 1979 event indicates that the SSE is a conservative representation of ground motion to be expected at the San Onofre site from occurrence of a similar size earthquake on the OZD at a distance of 8 km.

2.5.2.5 Summary

Our position with regard to the SSE approved for the CP can be summarized as follows:

(1) Specification of the controling earthquake for determining the SSE at San Onofre as an $M_S = 7.0$ on the OZD is conservative.

(2) The applicants' estimate of horizontal ground motion from this earthquake utilizing an empirical methodology is reasonable and conservative and results in an estimated response spectra less than the SSE, for which the facility was designed, at all frequencies.

(3) The conservatism associated with this estimate is supported by a comparison with those estimates computed from San Onofre 1 using theoretical models and with the extensive near-field data set recently recorded from a M_S = 6.9 earthquake in the Imperial Valley.

(4) The SSE for vertical motion is considered to be appropriately conservative. Exceedence of the vertical SSE at some stations in the Imperial Valley earthquake is not considered to be significant due to the short duration of the high acceleration and the lack of correlation between horizontal and vertical peaks of motion. In addition these conditions which are believed to have caused the anomalous high vertical ground motion in the Imperial Valley are not present at San Onofre.

Therefore, based upon our review of the applicants' submittal of new information which has become available since the San Onofre 2 and 3 CP review, we reaffirm our conclusion reached at that time that the San Onofre 2 and 3 SSE high-frequency acceleration anchor point (0.67g) and design spectrum are acceptable.

2.5.2.6 Operating Basis Earthquake (OBE)

The OBE for San Onofre 2 and 3 is 1/2 the SSE. This is conservative with respect to the stipulation in Appendix A that the OBE be that earthquake which could reasonably be expected to affect the plant site during the operating life of the plant. The OBE for San Onofre 2 and 3 also meets the other criteria in Appendix A, which states that it should be at least 1/2 the SSE. We see no reason for changing the conclusion reached in the SER for the CP approving the OBE for San Onofre 2 and 3.

APPENDIX A

Reserved for chronology of radiological review

APPENDIX B-BIBLIOGRAPHY

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*Available for inspection and copying for a fee at Public Document Room, 1717 H St., Washington, D.C. 20555

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APPENDIX C

Reserved for ACRS Generic Concerns

APPENDIX D

Reserved for Evaluation of Onshore Atmospheric
Dispersion at the San Onofre Nuclear Generating Station

APPENDIX E

Letter from David B. Slemmons, Consultant, to Robert E. Jackson, NRC, Dated November 5, 1980 and Errata, dated December 4, 1980.

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November 5, 1980

Dr. Robert E. Jackson, Chief
Geoscience Branch
Division Site Safety and Environmental Analysis
Washington, D.C. 20555

Dear Dr. Jackson:

During the period, May 1979 to present, I have been reviewing reports, maps, responses to questions, and other data that relate to seismic design parameters for the San Onofre Nuclear Generator Units 2 & 3 (SONGS). The main purpose of my review is to evaluate evidence on the seismotectonic setting and methods for estimating the maximum earthquake on the Offshore Zone of Deformation (OZD). My evaluation includes:

(1) Review of the numerous reports, publications, maps, and Landsat imagery of the southern California-Baja California region for information on the seismotectonic setting of the site and the OZD.

(2) Study and appraise the methods used for determining the maximum earthquake to be expected for the OZD, including a careful rechecking of the source data utilized and rationale that forms the basis of the new fault-slip-rate method proposed for the first time in Woodward-Clyde Consultants (1979).

(3) Examine seismologic and geologic evidence that defines the basic fault parameters of the OZD and in turn, affects the maximum earthquake magnitude for this fault zone.

I am impressed with the quantity and quality of the studies and data base that have been assembled for the evaluation of the OZD and its seismic potential. The types of study are appropriate and represent state-of-the-art methods. The seismic reflection profiles and the subsurface electric logging data confirm the OZD to be an active or capable fault zone. The geophysical interpretations of the offshore reflection profiles and the subsurface analysis of the Newport-Inglewood Zone of Deformation (NIZD) provide a basis for analysis of the OZD and its seismic potential. The Woodward-Clyde Consultants (WCC) study of the worldwide strike-slip fault data, and the methods by which this data can be applied to the OZD is carefully and thoroughly prepared in the WCC (1979) report and in the Responses to the NRC Questions (361.38, 44, 45, 46, 47, 48, 50, and 51) submitted by Southern California Edison Company (SCEC) and San Diego Gas and Electric Company (SDG & EC). The main body of data is summarized in the following reports:

Woodward-Clyde Consultants, June 1979, Report of the evaluation of maximum earthquake and site ground motion parameters associated with the Offshore Zone of Deformation, San Onofre Nuclear Generating Station: Woodward-Clyde Consultants, 30 p. with tables, and Appendices A to J.

Southern California Edison Company, and San Diego Gas & Electric Company, 1980, San Onofre Nuclear Generation Station Units 2 & 3, Responses to NRC Questions 361.37 through 361.62.

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In addition to the study of these documents and their supplemental sources of data, I have examined more than 150 papers that discuss regional tectonics, geology, seismicity, and worldwide data on fault characteristics, parameters, and associated earthquake magnitudes. The new methods proposed in the WCC and the SCEC - SDG & EC analyses were rechecked by evaluating the accuracy and scope of the data base, studying critical papers in the general literature, and using my personal familiarity with much of the source data, including visits to many similar faults that are pertinent to this review (southern California, Alaska, Japan, New Zealand, and South America).

My analysis is primarily based on the earthquake magnitude in relation to fault rupture length, maximum displacement, earthquake recurrence, slip rate, and seismotectonic setting. In addition, I have reviewed the subsurface data for the Newport-Inglewood Zone of Deformation (NIZD), the geophysical studies of the South Coast Offshore Zone of Deformation (SCOZD) and the Rose Canyon Fault Zone (RCFZ). Although I am familiar with the types of analysis included for these studies, I do not claim a primary expertise in these methods of analysis; accordingly, in the report that follows, my comments on these analyses are few, and are based on comparison of the basic data, interpretations presented, and the published record.

I concur with the broad-based, multi-method approach presented in the WCC report of June 1979 and in the Responses to Questions. The applicants documentation is a thorough and generally accurate appraisal of the field and geophysical data for the Offshore Zone of Deformation (OZD), a broad zone of faulting and secondary folding between the Santa Monica fault and San Diego Bay. My initial questions about the applicability of the new slip-rate method, including some of the field data and interpretation, have been resolved in responses to subsequent questions. Although the geologic setting is very complex and the question of total fault length is not completely resolved, I believe that the present information provides an adequate base for making decisions on the maximum earthquake parameters for the OZD and their effect on the SONGS site.

My initial opinion of the new fault slip rate method was of skepticism because of some omissions and errors in the original data base, as well as concern with the exclusion of normal-slip and reverse-slip fault data. The responses to questions which are based on additional data, have corrected errors in the original data and justified the omission of normal-slip and reverse-slip data, as well as the omission of inconsistent data from Japan.

I now believe that fault-slip-rate method is the firmest, most quantitative approach for state-of-the-art assessment of the maximum earthquake for the OZD.

My review considers the following topics in order of decreasing importance, weight, and reliability in establishing the maximum earthquake magnitude:

(1) Fault Capability
(2) Fault Slip Rate
(3) Fault Rupture Length
(4) Total Fault Displacement
(5) Degree of Deformation
(6) Maximum Historic Earthquake
(7) Maximum Surface Displacement

FAULT CAPABILITY

The capability of the OZD according to the definition of U.S. CFR Part 100 (1975) is indicated for the NIZD by Pleistocene offsets of alluvial materials (Barrows, 1974), stream channels (Castle and Yerkes, 1976), and shallow faulting noted in oil fields along the fault zone (WCC, 1979, Appendix A, p. A-5 and A-9). The right-slip style of faulting on the NIZD appears to be related to wrench faulting with a north-south compression axis and uniform rate of deformation for at least the last 8 my (WCC, 1979, figs. 4 and 5; Harding, 1973; Yeats, 1973). The capability is shown for NIZD by the 30 km long segment that ruptured in the basement rocks (WCC, 1979, figs. E-7 and E-8) with a shallow focus (10 km), and a right-slip mechanism (WCC, 1979, figs. E-5 and E-10) during the Long Beach earthquake of 1933 (M=6.3).

Capability of the SCOZD is indicated by: (1) ponding of low velocity Quaternary sediments on the landward side of faults and folds of the OZD, (2) projection of faults to the sea floor shown by many seismic reflection profiles (SCE, 361.63), and (3) general continuity, parallelism, and similarity of fault and fold pattern to the NIZD.

Capability of the RCDZ is suggested by several late Quaternary to possible Holocene right-slip faults (Kennedy and others, 1975, with a dated offset of 100,000 yrs; Kern, 1977, with a date of 80,000 to 100,000 yrs; and Liem, 1977, with a dated offset of 28,700 yrs). These dates are summarized in Table C-1 of WCC (1979).

The northern terminus of the OZD is at the intersection with the capable Santa Monica fault zone. Possible connections to the south include the Calabasas fault (Gastil and others, 1975, 1979; fig. 361.66-1, No. 6) which appears to be capable, the San Miguel fault zone (Shor and Roberts, 1958; Gastil and others, 1979), with historic surface rupturing or by offshore connections with the Agua Blanca fault zone (Legg and Kennedy, 1979) which has late Quaternary offsets (Allen and others, 1960; Gastil and others, 1975).

FAULT SLIP RATE

The geologic slip rate method is the primary basis used in the WCC (1979) report and the response to questions 361.38 and 361.45 to determine the maximum earthquake value for the OZD (fig. 7 of WCC, 1979; and questions 361.45-1, 361.38-4). The initial data base, the first compilation of its kind, is in Figure 7 of WCC, 1979, and with extensive revisions, is described in response to questions 361.44, 45, 46, 47, 48, 50, and 51, and shown in Figure 361.45-2 (with error boxes) and Figurés 361.45-2 and 361.38-4 (with proposed limiting lines).

The analysis includes up-to-date published data and, although future earthquakes or new investigations may add new data points or modify old data, the new analysis is accurate, thorough, and state-of-the-art. My review of the data, including Appendix B of WCC (1979), and about 20 percent of the electric log correlations, supports the fault slip rate for the NIZD at 0.5 mm/yr, with a low likelihood that the new data will change this value by greater than 15 percent. The analysis of the worldwide slip rate data, including geologic offsets as a function of time, is accurate and thorough. These data control the line, bounding extremes of bracketed ranges of data (MEL of figure 361.38-4). This boundary is very conservatively determined by using the extreme corners of the error boxes of the existing data, and suggests a maximum magnitude of about 6.85. The probable limiting boundary for a slip rate of 0.5 mm/yr is 6.3, as defined by the line bounding maximum observed historical earthquakes (MEL). The data base for these figures is based on a very short historic record of earthquake activity; future earthquakes and new data are likely to extend the limits to some indeterminate higher value.

Accordingly, I believe that to assure conservatism in analysis, the limiting line for maximum magnitude should be shifted to the right to indicate a maximum earthquake for the NIZD, with 0.5 mm/yr slip rate, to about 7 magnitude. This is an upward shift of about 0.7 magnitude from the probable maximum magnitude of 6.3

and about 0.15 from the extreme corner of the bracketed range at 6.85 magnitude. This assignment of 7 magnitude provides an additional degree of conservatism to allow for:

(1) The possible short-term perturbations from an overall 0.5 mm/yr slip rate of the NIZD, which is assumed to also apply to the Southern California Offshore Zone of Deformation (SCOZD) and the Rose Canyon Fault Zone (RCFZ),

(2) the inaccurate nature of some of the published data points, and

(3) the deficiency in available data for faults with low slip rates (e.g., less than 1.0 mm/yr).

FAULT RUPTURE LENGTH

General Comments

Earthquake magnitude versus surface fault rupture length relationships are summarized by Tocher (1958), Iida (1959 and 1965), Bonilla (1967 and 1970), Bonilla and Buchanan (1970), Mark (1977), Mark and Bonilla (1977), and Slemmons (1977). The theoretical basis for the correlation between size of earthquake and fault rupture length is based on Tsuboi (1956), who related seismic energy release to an earthquake volume (length, width, and thickness of the elastically strained material) to both fault rupture length and amount of fault displacement. The use of empirical correlations of earthquake magnitude versus surface rupture lengths, measurements of geodetic deformation or surface displacement is possible where brittle failure or surface deformation from shallow focus earthquakes occurs in surficial materials.

Direct application of the fault rupture length to magnitude of shallow focus earthquakes requires that the total surface rupture length can be observed. The method is difficult to apply where plastic deformation and/or drag conceals the primary tectonic effects, where bodies of water or other surficial materials conceal the fault surface rupture, or where the fracture patterns form complex distributed systems (Slemmons, 1977; Bonilla, 1979). For such cases, additional subsurface geologic data, geodetic deformation data, aftershock distribution maps, or other geophysical or seismological analyses may be required.

Indirect methods can be applied by using subsurface information or by using fractional fault rupture length data as suggested by Albee and Smith (1966) and Wentworth, Bonilla and Buchanan (1969). This method is in wide use, although it is not always possible to accurately delineate the total length of a fault (Slemmons, 1977; Bonilla, 1979).

Direct Method

The use of the direct method of application of the fault rupture length versus magnitude, or the maximum surface displacement versus magnitude is not possible for the OZD, as surface faulting is rare along the zone. Displacements are normally in the form of plastic deformation of shallow, late Tertiary surficial sediments.

Indirect Method by Fault Segment Lengths

The surface rupture length versus earthquake magnitude relationship can be applied to the OZD by assuming that the zone is segmented, and that the segments are indicated by the length of the main ruptures of the deeper sediments as indicated by displacements on the reflector zones, B and C (figs. D-1 and D-2 of WCC, 1979). This method assumes that the continuity of the fault at depths is defined by lengths of ruptures that cut either the B or C zone. The B and C zones are, respectively, correlated with a post-Miocene unit (about 5 my BP) and the lower to middle San Onofre Breccia units (about 8 my BP). The application also assumes that the subsurface maps of faults cutting reflectors B and C are accurate and that the gaps between fault segments are well-defined. My suggested analysis will require modification if newer maps differ from the reflector profile maps of WCC (1979).

A discontinuity between segments is defined by Horizon B at the break shown in Figure D-2 of WCC (1979), about 35 km NNW of San Onofre near a change in the en echelon and branching patterns (shown in fig. D-1 of WCC, 1979). The fault segment extends south from this area with the southern end at the branching pattern about 10 km WSW of San Onofre. The total length of this segment is 40 km. Another segment extends for 37 km length northward from the on-shore segment of RCFZ. These fault segments provide the following estimated magnitudes for a full rupture length of the segment using the relationship for strike-slip faults of Slemmons (1977) of $M_S = 0.597 + 1.351 \log_{10} L$(in m):

ASSUMED RUPTURE LENGTH	M_S
OZD (40 km length)	6.8
RCFZ (37 km length)	6.8-

A more conservative approach defines the fault segment lengths on the basis of Horizon C. An assumed length is defined on the south and by an inflection point at a break in continuity as shown in Figure D-1 of WCC (1979), the point of marked change in fault strike about 27 km SSE of SONGS, and to the north at the change in rupture pattern and junction with transverse faults about 35 km NNW of SONGS. The total length of this fault segment is 62 km. The relationship for strike-slip faults of Slemmons (1977) indicates the following earthquake magnitude:

ASSUMED RUPTURE LENGTH	M_S
SCODZ (62 km length)	7.1-

A third estimate of earthquake magnitude is derived using the values listed in the response to Question 361.66 (Table 361.66-1) with lengths of 36 km for the NIZD, 27 km for the SCOZD, and 48 km for the RCFZ; the criteria for assigning these lengths is not described. Using the strike-slip fault relations of Slemmons (1977), the following magnitudes are estimated:

ASSUMED RUPTURE LENGTH		M_S
NIZD	(36 km)	6.7+
SCOZD	(27 km)	6.6-
RCFZ	(48 km)	6.9

The above calculations suggest a maximum earthquake for the OZD of 6.5 to 7.0- and, in my opinion, are "soft" values, subject to debate. Accordingly, although these values are considered in this overall analysis, a low weighting is placed on their reliability.

Indirect Method by Fractional Fault Length

The use of an assumed fractional fault rupture length, based on the total fault length is proposed for southern California by Wentworth and others (1969), with a statement that for all slip-type faults in North America, the historic earthquakes have broken lengths of from 2 percent to more than 75 percent of the total fault length. Since 1969, this method has become widely used for evaluation of active strike-slip faults with known lengths, and the assumed rupture length is generally taken at one-half, one-third, or one-fourth of the total fault length to provide a maximum probable earthquake. The length that is determined from the fractional length is then assumed to be the surface rupture length and the M_S magnitude is determined by use of the appropriate rupture length versus magnitude regression equation, or by interpolation from the corresponding graph of Slemmons (1977) or Mark and Bonilla (1977).

In order to apply this method to the OZD, the worldwide data base for strike-slip faults should be reviewed to determine which fraction or percentage of the total fault length should be used. My review of the data uses the following rationale for the basic percentages to be used.

Rationale For Estimation of Total Fault Length

1. Length may be defined by reviews, monographic studies (e.g., U.S. Geological Survey), special papers or discussions, etc., of specific faults.
2. Faults are generally terminated by cross-cutting faults, a branching relationship from a fault with a higher slip or strain rate, or by relation to plate tectonic boundaries. For example, the Hayward fault branches from the Calaveras fault, which branches from the San Andreas fault zone, which connects to the Gulf of California spreading center to the Mendocino fault.
3. Faults of similar style or rate of deformation are assumed to be connected if they are on strike and are separated by short data gaps, are covered, or appear to have an en echelon relationship.
4. Faults with high slip rates and amounts of displacement cannot die out abruptly without terminating against a bounding structure, or connecting with a major causative plate tectonic feature.
5. Faults may gradually die out away from the causative tectonic structure by decreased slip rate, decreased displacement, or change in style of deformation.

The mean percentage of rupture length versus total fault length or fault zone length for available worldwide data is 24 with a standard deviation of 7. This suggests that the typical strike-slip rupture during larger earthquakes is about one-quarter of the total fault length or fault zone length.

Observed Fault Rupture Lengths for Strike-slip Faults

Historic surface rupturing on major strike-slip faults have the following observed, or inferred fault rupture lengths during earthquakes exceeding M_S=6 (see table that follows).

Application to the OZD

1. OZD with a Length from Santa Monica Fault to San Diego Bay:

The field data supports a total fault zone length measured from the northern, truncating Santa Monica fault to the San Diego Bay area for a length of 200 km, or a 22 percent length of 44 km. The northern limit is a truncating capable or active fault. The southern limit corresponds to a point of changed tectonic style to prominent normal faulting. Evidence for continuity between the OZD and faults to the south is inconclusive. Using the 22 percent length value derived above, this corresponds with a surface rupture length of 44 km, and an earthquake of M_S=6.9 or using one standard deviation (30 percent) for a length of 60 km, M_S=7.1-.

The zone offshore from San Diego Bay has a different strike than the OZD and may, if connected, break as an independent segment similar to the discontinuities discussed by Segall and Pollard (1980) for strike-slip faults, or Bakun (1980) for the Calaveras fault during the 1978 to 1979 series of earthquakes which supports the use of the 200 km total length value.

2. Connections to the Coronado Banks and/or the Agua Blanca Fault Zone

Possible continuity with the Agua Blanca has been suggested by an en echelon system connecting to the Coronado Banks and ultimately to the Agua Blanca fault zone. Evidence for this connection is poor and lacks documentation but is suggested in the map of Legg and Kennedy (1979) and Figure 361.40-1. Such a connection would require a change in strike at San Diego Bay with a possible change from purely strike-slip faulting on the OZD to prominent normal faulting components at San Diego Bay and perhaps to Coronado Banks. If such a connection exists, the total length between the Santa Monica fault and the Coronado Banks fault is 247 km. Further extension to the Agua Blanca fault is approximately 300 km. For a 22 percent rupture length of 247 km (54 km), this would indicate an earthquake of M_S=7.0 and for 22 percent of a 300 km length (66 km) to the Agua Blanca for a calculated magnitude of 7.1. Addition of one standard deviation (a total of 30 percent fault length) would yield 74 km length for the

OZD including the segment to the Coronado Banks fault, for a calculated magnitude of 7.2-. For inclusion of the Agua Blanca fault a 30 percent length (90 km) yields a magnitude of 7.3

If the OZD extends to the Agua Blanca fault, the branching relation, the different strike, and the possibly different slip mechanism suggest that it should be considered separately from the Agua Blanca fault; worldwide data on branching faults suggests major rupture on one does not immediately cause major rupture on the other. Accordingly, the 247 km length appears to be an extreme length assumption.

3. Connection to the Calabasas, Vallecitos and the San Miguel Faults

The southeastward connection to the San Miguel fault zone does not appear to be likely, due to: (1) lack of both photogeological evidence and field evidence for continuity (Gastil, Kies and Melius, 1979), (2) some major faults (Vallecitos), of this zone lack geomorphic evidence for activity, (3) geologic units do not appear to have substantial strike-slip offsets, and (4) apparent decrease in activity across the zone east of the San Miguel fault. Additional evidence against this proposed connection is summarized in the NRC answers to the interrogatories by Friends of the Earth (October 17, 1980). This suggests that the San Miguel zone does not connect directly to the OZD, or if deep continuity exists, it is reasonable to interpret this zone in terms of separate, partly en echelon, individual faults with very low slip rates and low activity that may be activated independently, and the length of the zone should not be added to that of the OZD.

Table of major strike-slip faults, with estimated total length, and percent of fault ruptured during earthquakes of about $M_S = 6$ or greater.

FAULT, DATE	M_S	TOTAL LENGTH (KM)	RUPTURE LENGTH (KM)	PERCENT OF LENGTH
San Andreas		1380		
1857	8.25		370-400+	29.0
1906	8.25		435	31.5
North Anatolian				
1939	7.9		350	26.9
1942	7.3		50	3.8
1943	7.6		265	19.9
1944	7.4		190	14.3
1957	7.1		40	3.0
1967	7.1		54	4.1
Fairweather-Queen Charlotte		1150		
1899	8.5?			
1949	8.1		380	33.0
1958	7.9		350	32.6
1972	7.1		170	15.8
Montagua		1100+		
1976	7.5		230-270	21.4
Awatere-Wellington		547		
1948	7.1		100?	18.3?
Clarence-West Wairarapa		600		
1855	7.5		160	26.7
Hope-East Wairarapa		410		
1888	6.7		55	13.4
San Jacinto-Cerro Prieto (incl. Coyote, Superstition Mtns., Superstition Hills and Imperial faults		290		
1934	7.1		?	
1940	6.7		64	22.1
1968	6.4		33	11.4
1979				
Calaveras-Green Valley		272		
1861	6		29	10.7
1979	5.9		16	8.4
Hayward-Rodgers Creek-Healdsburg-Maacama	6.7	285	48	16.8
1868				

The mean for highest percentage on each fault (underlined) = 22.1

Standard deviation = 7.45

TOTAL FAULT DISPLACEMENT

This method is used by WCC (1979) to assist in the qualitative comparison of features as noted in the initial paragraph of the response to question 361.38, and is presumably based primarily on the data of Table G-1, and Table 361.45-2.

For greatest offset during late Tertiary, the following values are tabulated:

		Age (my)	Displ. (km)	Max. M_S
1	San Andreas (northern section)	1-5	30	8.3
2	San Andreas (central section)	ca. 5	80	8.25
3	San Andreas (southern section	10	215	6.5
4	San Jacinto	0.73-	5.7-8.6	7.1
5	Elsinore	2?	5	5.5-6
6	Whittier	2?	2.5	4.2
7	NIZD	3	5?	6.3
8	Calaveras-southern	3.5	11-27	6.6
9	Calaveras-Sunol	5?	4.8	5.3
15	Bocono	5	50	8
16	Hope	5+?	20	6.7
19	N. Anatolian	15	85-95	7.9

The above data only provide a qualitative measure for a maximum earthquake that is suggestive, but is not definitive of, a magnitude. Slip rate provides a similar measure and simultaneously considers displacement and changes in rate of displacement with geologic time.

DEGREE OF DEFORMATION

The degree of deformation is difficult to evaluate in southern California because major surface scarps are poorly developed in the OZD zone of plastic deformation. Although geomorphic expression of the NIZD is inconspicuous or local, the associated wrench fault style of folding is well developed. These features are difficult to directly correlate with other faults where brittle failure occurs at the surface and scarps and associated landforms are conspicuous. I conclude that the degree of deformation of deposits and development of landforms is difficult to assess for the OZD because of the partial water, or ductile sediments cover portion of the zone, and the dissimilar nature of rupture in comparison with many other southern California active faults.

MAXIMUM HISTORIC EARTHQUAKE

The maximum historic earthquake is 6.3 along the NIZD section of the fault zone. If it is assumed that the fault zone extends to the San Miguel fault in Baja California, the maximum earthquake would be the 1956 earthquake of magnitude 6.8, but this assumption is problematic due to uncertainty of a connection and uncertainty of similar mechanisms. I conclude that although the maximum historic earthquake for the zone is 6.3, it is likely the maximum possible earthquake is greater for longer periods of observation. This line of evidence cannot be used to indicate maximum possible or maximum probable earthquakes because of the short historic record.

MAXIMUM SURFACE DISPLACEMENT

There is no stratigraphic or geomorphic evidence to indicate the maximum surface displacements along this zone and hence, the related maximum magnitude. The lack of conspicuous scarps in the NIZD sector may infer small displacements during the late Quaternary. The plastic deformation of the Tertiary sediments, with a wrench fault style of deformation, precludes using this method for the OZD. I conclude that this method cannot be applied to the OZD with current data.

CONCLUSIONS

1. The studies for the SONGS site are accurate, represent state-of-the-art methods and form an adequate basis for evaluating the seismic potential of the OZD.

2. The use of the fractional fault length method suggests a maximum magnitude of about M_S=7.

3. The most quantitative method for estimating the earthquake magnitude is the fault-slip-rate method proposed in the WCC report as modified in subsequent responses to questions. The method is new and untested by use and review by the geologic and seismologic community. I recommend that the maximum earthquake be increased from the 6.3 to 6.5- range as shown in Figure 361.38-4 to about magnitude 7 for earthquakes generated along strike-slip faults with a slip rate of 0.5 mm/yr.

4. The best method of estimating the maximum earthquake magnitude for the OZD is a general, balanced, multi-approach, as used in the WCC report and as modified in the subsequent responses to questions by the applicant.

5. Using a general, balanced, multi-approach, and my study of the OZD in relation to the worldwide fault data for historic surface rupture on active faults, their geomorphic expression, and their general character, the available evidence indicates that the maximum earthquake to be expected for the OZD is approximately M_S=7.

6. My evaluation of the various methods of estimating the maximum magnitude earthquake for the OZD has included an additional degree of conservatism to that of the WCC (1979) report and the responses to questions 361.37 to 361.68.

The above review provides my professional judgement of the seismic potential for the OZD. If you require further details, or wish a response to other related issues, please contact me.

Sincerely,

David B. Slemmons

David B. Slemmons
Consulting Geologist

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December 4, 1980

Dr. Robert E. Jackson, Chief
Geosciences Branch
Division Site Safety and Environmental Analysis
U. S. Nuclear Regulatory Commission
7920 Norfolk Ave.,
Bethesda, MD 20555

In reviewing my draft letter of November 5, 1980, I have noted several omissions or errors. I request that these be corrected on my original report. They are as follows:

U. S. Nuclear Regulatory Commission should be inserted before the streeet address.

p. 13, line 5: Change 200 to 190- and 44 to 42.

p. 13, line 12: Change 60 to 57 and 7.1- to 7.0

p. 13, line 32: Change 247 to 250 and 54 to 55

p. 13, line 34: Change 300 to 275 and 66 to 61.

p. 13, line 35: Change 7.1 to 7.1-

p. 13, line 36: Change 74 to 75

p. 14, line 3: Change 90 to 83 and 7.3 to 7.2

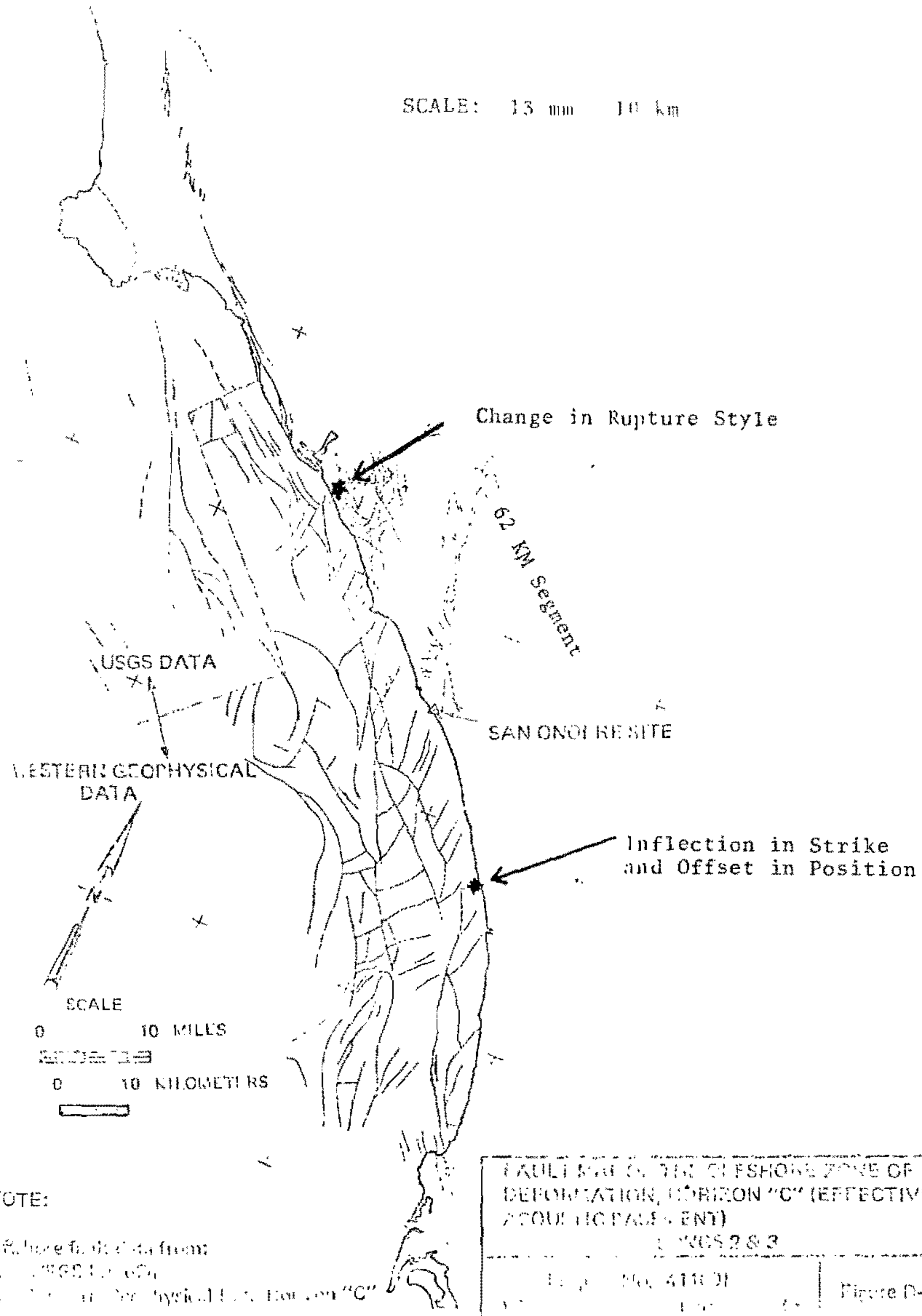
p. 14, line 9: Change 247 to 250

The enclosed pages 9A, 9B, and 13A include maps that indicate the location of points that I have used in my analysis. Inclusion of these figures will indicate more exactly the location of points that I have used in my analysis.

I submitted my original typed copy to you, so the above changes and insertions can readily be made by your secretarial staff. I request that you send me a copy of the revised copy.

Sincerely yours,

David B. Slemmons

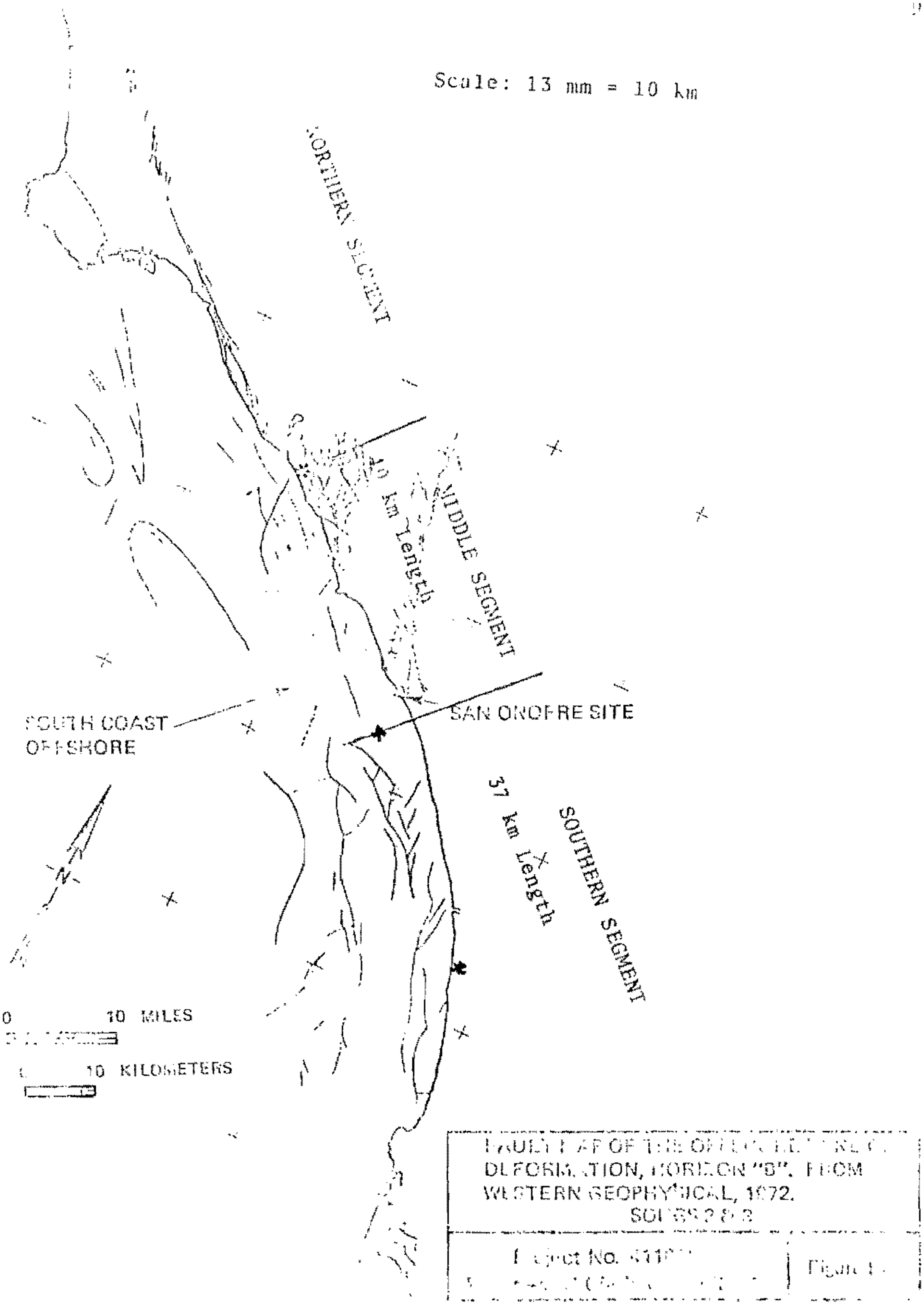


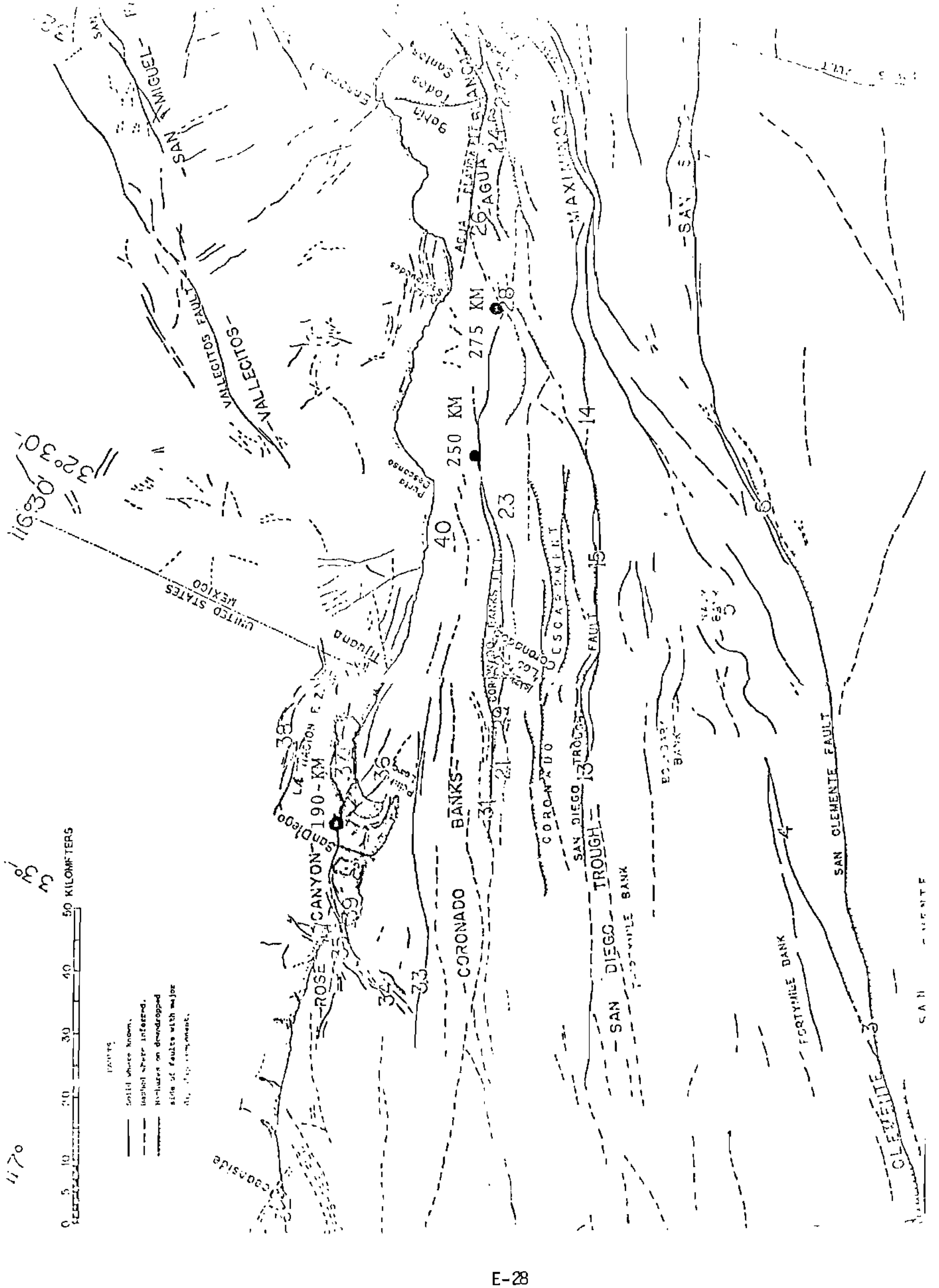
NOTE:

Offshore fault data from:
1. USGS [illegible]
2. [illegible] Geophysical [illegible] Horizon "C"

FAULT MAP OF THE OFFSHORE ZONE OF DEFORMATION, HORIZON "C" (EFFECTIVE ACOUSTIC BASEMENT)
[illegible] NGS 2 & 3

[illegible] No. 411 [illegible] | Figure D-1


Scale: 13 mm = 10 km
NORTHERN SEGMENT
MIDDLE SEGMENT
10 km Length
SAN ONOFRE SITE
SOUTH COAST
OFFSHORE
37 km Length
SOUTHERN SEGMENT
N
0 10 MILES
10 KILOMETERS
DEFORMATION, HORIZON "B", FROM
WESTERN GEOPHYSICAL, 1972.



50 KILOMETERS
0
5
10
20
30
40
50
117°
33°
116°30'
32°30'
UNITED STATES
MEXICO
Tijuana
San Diego
Oceanside
Punta Descanso
Bahia Todos Santos
ROSE CANYON
LA NACION F. Z.
190 KM
250 KM
275 KM
CORONADO BANKS
CORONADO ESCARPMENT
SAN DIEGO TROUGH
SAN DIEGO TROUGH FAULT
FORTYMILE BANK
SAN CLEMENTE FAULT
VALLECITOS FAULT
VALLECITOS
SAN MIGUEL
AGUA BLANCA
MAXIMINOS

APPENDIX F

Letter from Robert H. Morris, USGS, to

Robert Jackson, NRC, dated August 13, 1980

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

Mail Stop 908
August 13, 1980

Mr. Robert Jackson
Geosciences Branch
Division of Site Safety & Environmental
Analysis
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Bob:

In response to your request of July 2, 1980, we are transmitting to you under separate cover the Administrative Report entitled "Review of Offshore Seismic Reflection Profiles in the Vicinity of the Cristianitos Fault, San Onofre, California". The review is a joint collaboration by H. Gary Greene of the USGS and Michael P. Kennedy of the California Division of Mines and Geology and provides data pertinent to the San Onofre Nuclear Generating Station.

Sincerely,

Robert H. Morris
Deputy Chief for Reactor Programs
Office of Environmental Geology

One Hundred Years of Earth Science in the Public Service

REVIEW OF OFFSHORE SEISMIC REFLECTION PROFILES IN THE VICINITY OF THE CRISTIANITOS FAULT, SAN ONOFRE, CALIFORNIA

by

H. Gary Greene[1] and Michael P. Kennedy[2]

INTRODUCTION

The purpose of this investigation is to review offshore seismic-reflection profile data that have been acquired by Southern California Edison (SCE) industry, and government during the past 10 years in the vicinity of the San Onofre Nuclear Generating Station (SONGS). These data were examined and interpreted by us to determine the seaward extension and structural relationship (if any) of the Cristianitos fault and the "Offshore Zone of Deformation" "(OZD)" of Woodward-Clyde (1979). Although many studies have been undertaken and numerous reports have been written regarding the offshore geological structure of this area (Woodward-Clyde, 1979; Ehlig, 1979; Greene and others, 1979, and many others), new data used in conjunction with a recently developed regional tectonic model of the Gulf of Santa Catalina have led to the re-evaluation of the character of faulting in this area (Greene and others, 1979). The present report gives the results of this re-evaluation. We have described the method of the analysis, the interpretation of the data, and have discussed regional tectonics in conclusions.

The report includes new data, items 1 through 4 (table 1) which were supplied by SCE and the remainder were obtained from our files. Interpretive line drawings were made for most Woodward-Clyde, Marine Advisors, Western Geophysical, and USGS 1978-1979 SEA SOUNDER profiles, however, few were made of the others.

---

1. U.S. Geological Survey, Menlo Park, Calif.

2. California Division of Mines and Geology, La Jolla, Calif.

Analysis of the data was accomplished in three steps: (1) all of the seismic profile data were examined to determine the location of major geological structures; (2) line drawings were then constructed showing those features of which we were confident and geological structure was plotted on a 1:24,000 scale planimetric map; (3) the data set was evaluated for its quality and weakly defined or questionable parts were removed from the map. Plate 1 presents only those geologic features that are well defined. Correlation of geological structure on the final map was made with a high degree of confidence.

INTERPRETATION OF DATA

Standard interpretive methods were used in the analysis of the seismic reflection data. For a description of basic seismic reflection techniques and inherent problems in studying reflectors see Moore (1969), Tucker and Yorston (1973), Greene and others (1974), and Payton (1977). Criteria for the interpretation of faults from acoustic profiles are as follows:

Well-defined faults: (1) distinct displacement of prominent reflectors, (2) abrupt discontinuity of prominent reflectors, (3) juxtaposition of an interval of prominent reflectors with an interval having different acoustic characteristics, or (4) abrupt changes in the dips of prominent reflectors along distinct boundaries.

Poorly defined faults: (1) inferred displacement of prominent reflectors, in which the upper or shallow reflectors may be bent rather than broken, (2) discontinuity of prominent reflectors combined with a change in acoustic character, or (3) apparent changes in dip.

Questionable faults: (1) non-instrumental phase shift of reflectors, (2) bent or broken reflectors that can be correlated with known faults on other profiles, (3) discontinuity of poorly defined reflectors, or (4) any other zone of acoustic contrast, especially where the zone appears similar to and aligns with a fault identified on an adjacent profile.

The orientation of faults was determined by the correlation of faults having similar characteristics from one seismic profile to another. Geologic structures have been projected between adjacent profiles on the basis of their overall spatial relationships to one another. Faults that could not be correlated between two or more adjacent profiles are not shown on the map.

Where fault planes dip more than $\sim 35^{\circ}$, vertical exaggeration precludes the determination of the dip of that fault. Such faults are shown to be vertical on the line drawings. Ordinarily, only an apparent vertical component (vertical separation) of slip can be determined on seismic reflection profiles, whereas the apparent horizontal component (strike separation) is generally impossible to determine. The sense of displacement has not been shown on faults mapped in this review because no stratigraphic control was available or observable.

Data Voids

Areas in which good quality data are lacking or the density of seismic profiles are insufficient to map and correlate structures at a scale of 1:24,000 are designated as "Data Voids" (Plate 1). It must be emphasized that the notation "data void" does not mean that no data are available, only that we felt the data are insufficient for correlation with confidence between lines. The data in some areas are of sufficient quality to permit the extension of geologic structures by inference across expanses mapped as data voids; in such cases, these structures are mapped as inferred or questionably inferred.

DISCUSSION

The interpretive geological structure map shows two zones of deformation (Plate 1). The most prominent and well-defined zones lies along the western edge of the map and is a segment of the "OZD." The other zone is less well-defined but is nevertheless distinctive in its character and extends southward offshore from a position a short distance south of SONGS. Between these zones, the stratigraphic succession is only moderately deformed and consists of very gently folded or homoclinal beds.

"Offshore Zone of Deformation"

The "OZD" of Woodward-Clyde (1979) has been referred to in earlier literature as: (1) the South Coast Zone of Deformation, (2) "Newport-Inglewood offshore zone of deformation," and (3) the Newport-Inglewood-Rose Canyon fault zone. This fault zone is generally continuous and well-defined in the seismic profiles examined for this study (Figs. 1, 2, 3, 5, 7, 8, and 9). It is located on the distal part of the nearshore shelf approximately 7 km from SONGS at its closest point. The OZD trends northwest through the area studied; it is narrow (less than 1 km wide) in the northwest part of the area and broadens to over 2 km wide in the southeast where it is less clearly defined (Plate 1).

The OZD is typically characterized in the seismic reflection profiles by abrupt truncation of well-defined reflectors (Figs. 1 and 2). Between the truncated reflectors are tightly folded, incoherent and locally displaced reflectors. A well-developed syncline lies sub-parallel to the "OZD" along its length in the area studied (Figs. 1, 2, 3, 5, and 7; Plate 1). Many of the faults that bound the "OZD" extend upward to the sea floor where they questionably offset Holocene sediment.

"Cristianitos Zone of Deformation"

The "Cristianitos Zone of Deformation" "CZD", trends north in this area, and lies oblique to the "OZD." This zone is less well-defined and more complex in pattern than the "OZD" (Figs. 2, 5, 6, 8, and 10). The "CZD" consists of en echelon faults and folds that extend offshore from SONGS and the zone appears to connect with the "OZD" 16 km southeast of the site, although the area of probable intersection is not well surveyed ("Data Void," Plate 1). The "CZD" appears to be a relatively narrow zone, averaging approximately 0.5 km in width. It narrows to less than 0.5 km about 10 km southeast of SONGS.

The "CZD" is an extensively faulted structure that is grossly manifested as a complex asymmetrical anticline (Figs. 2, 3, and 6). The nearshore end of the "CZD" is dominated by a well-defined fault that cuts near-surface sedimentary rocks and is continuous for nearly 3 km (Plate 1).

Structure landward (east) of the "CZD" is a little more complex than that seaward (west) of the zone (Plate 1). The structure consists primarily of short en echelon folds that are oriented north-south and intersect both the "CZD" and a poorly defined fault zone (A on Plate 1) to the east at an angle of $\sim 30^{\circ}$. The western boundary of this structural zone is composed of en echelon, short, deep-seated faults trending parallel to the "CZD" in the nearshore area (Figs. 2, 4, 6, and 7; Plate 1).

CONCLUSIONS

Interpretation of marine continuous seismic-reflection profiles in the vicinity of SONGS and concentrated along the projected, offshore trace of the Cristianitos fault indicates to us that two structural zones of deformation are present in this area. The first and most well defined zone is a segment of the "OZD," a recognized Quaternary fault zone (Greene and others, 1979; Hileman, 1979; Legg and Kennedy, 1979). The second is less well defined but nevertheless exhibits characteristics similar to those of the "OZD." This second zone, the "CZD," consists principally of a highly fractured and faulted asymmetrical anticlinal structures.

The "CZD" and associated folds to the east combine to form a broad structural zone (up to 3 km in width) which projects onshore to the north. The southeast end of the "CZD" could become incorporated with a major syncline of the "OZD", however, the structural relationship of the "CZD" with the "OZD" is unconfirmed because of a "data void" (Plate 1).

The age of most recent faulting along the "CZD" is unknown. All seismic profiles examined show that faults associated with the "CZD" end at or near the surface of an apparent wave-cut platform that is overlain by acoustically transparent sediment. Nowhere within the "CZD" is there evidence of seafloor displacement.

It is our conclusion that a structurally deformed zone consisting of correlatable en echelon faults and folds, many extending into shallow subsurface strata (probably Neogene in age), is present along the expected offshore extension of the "CZD." The seismic reflection data reviewed here show that a fairly continuous fault zone extends south to southeastward offshore from SONGS to within 1 km of the "OZD," where a projected connection is possible.

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TABLE 1*

DATA EXAMINED

1. Marine Advisors intermediate penetration sparker profiles 5-9, 11, 12, 13, 14, 16, 18, 20, 25, and 26.
2. Woodward-Clyde intermediate penetration sparker and high-resolution UNIBOOM profiles numbers 801 to 807, 809-812, 814, 816, 818, 819, 821, 822, 825, 828, 830, 832, 834, 836, 839, 841, 843, 845, 847, 849, 850, and 852.
3. Fugro Sonia profile SNO-5.
4. Western Geophysical deep-penetration CDP profiles numbers 106 (S. P. 359-191), 117 (S. P. 231-27D), 119 (S. P. 65-29D), 121 (S. P. 165-33D), 123 (S. P. 171-27D), and 145 (S. P. 195-39D).
5. USGS, 1970 POLARIS intermediate penetration sparker and high-resolution mini-sparker profiles numbers 18, 23F, 24, and 25.
6. USGS, 1978 and 1979 SEA SOUNDER (S2-78-SC and S2-79-SC) intermediate to deep-penetration and high-resolution UNIBOOM profiles: S2-78-SC lines 27, 28, 31, and 33; S2-79-SC lines 56 and 58.

*See Plate 2 for location of profiles.

ILLUSTRATIONS

Figure 8. Line drawing of USGS seismic reflection profile 33 (S2-78-SC) showing OZD and CZD. See Plates 1 and 2 for location.

Figure 9. Line drawing and seismic reflection profile of USGS SEA SOUNDER (S2-79-SC) Line 56 showing OZD. See Plates 1 and 2 for location.

Figure 10. Line drawing of USGS seismic reflection profile 57 (S2-79-SC) showing fault inshore of CZD. See Plates 1 and 2 for location.

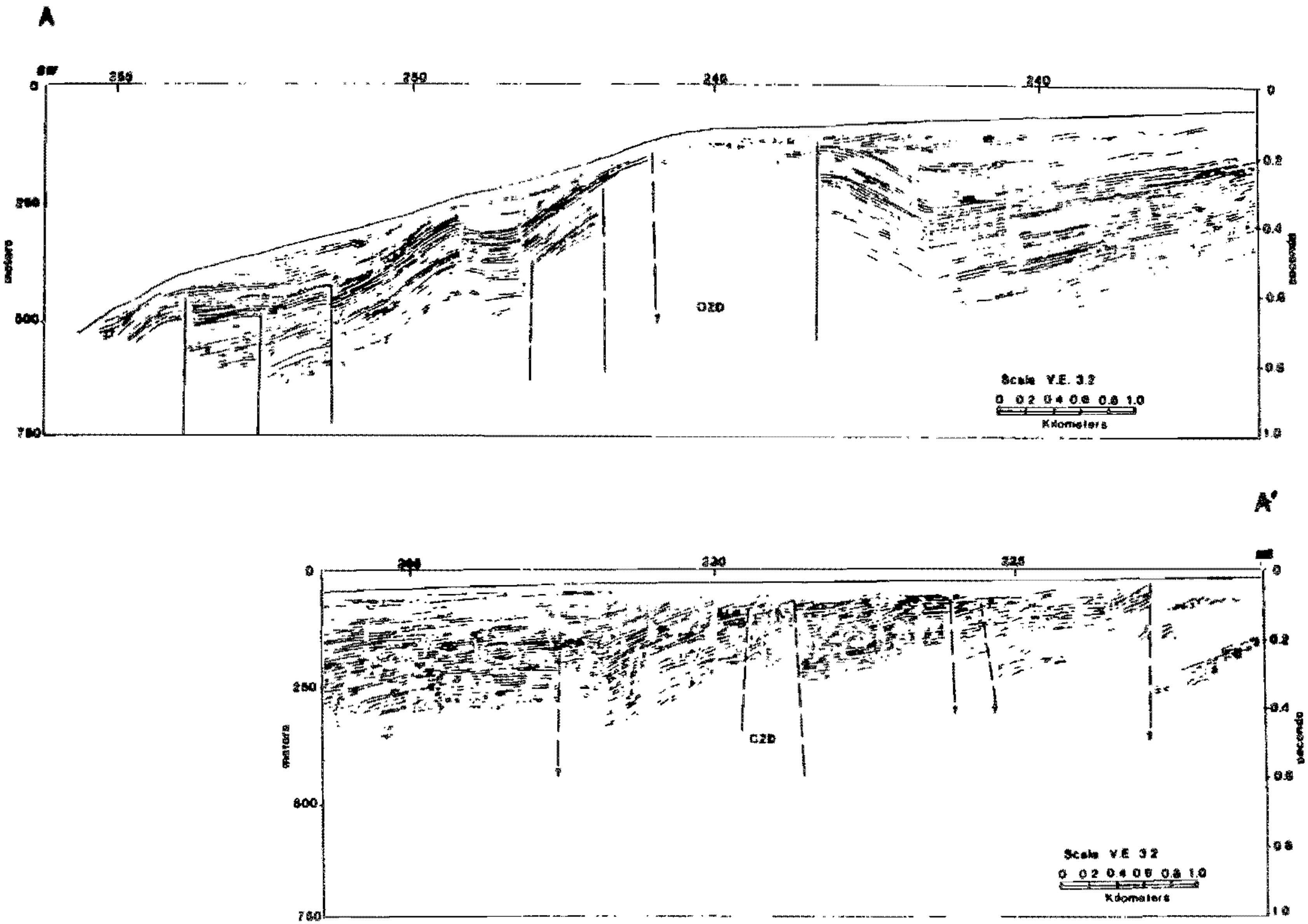


Figure 1.--Line drawing Marine Advisor's seismic reflection profile S-22 showing location of the OZD and CZD. See Plates 1 and 2 for location.

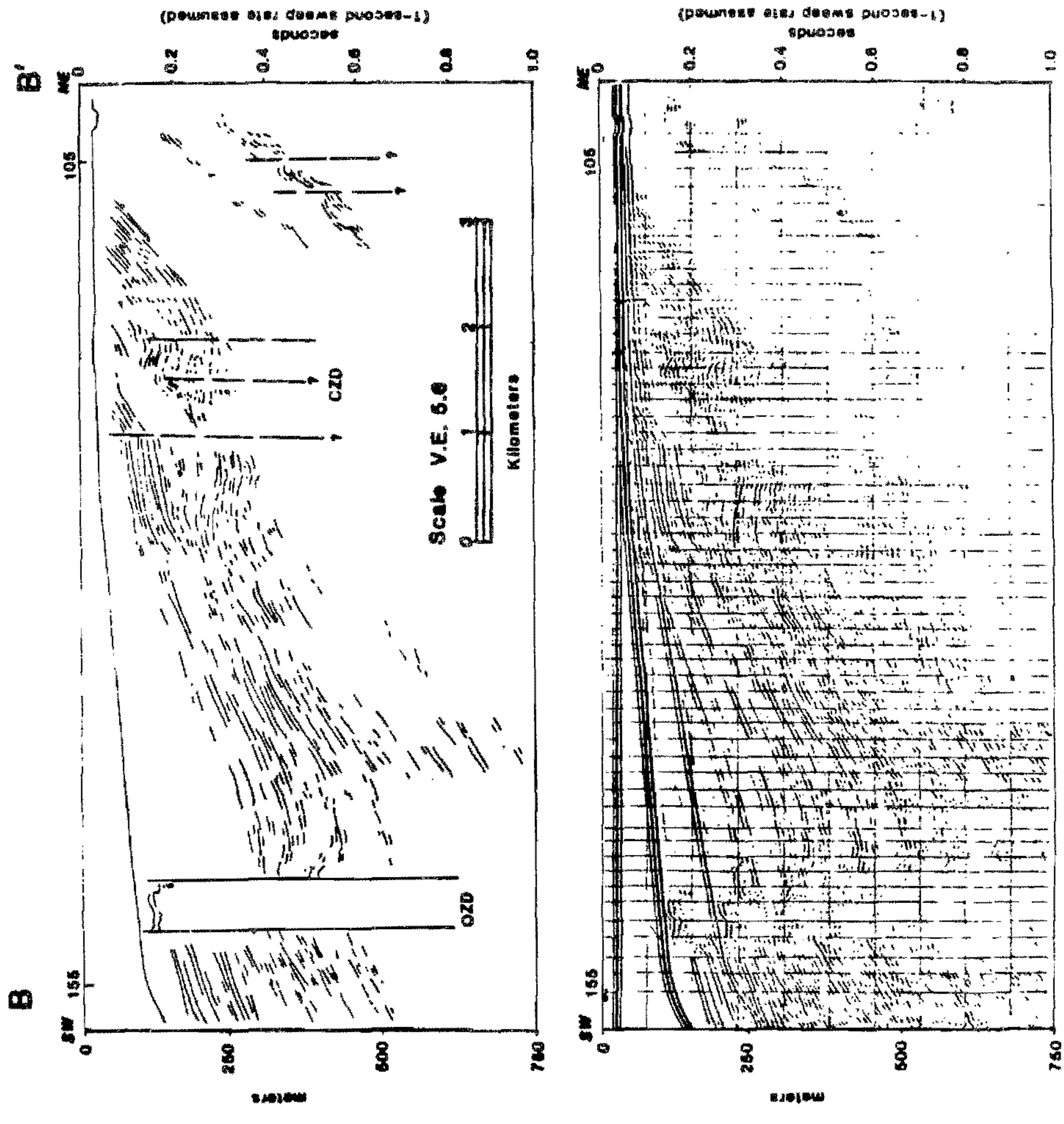


Figure 2.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 845 showing OZD and CZD. See Plates 1 and 2 for location.

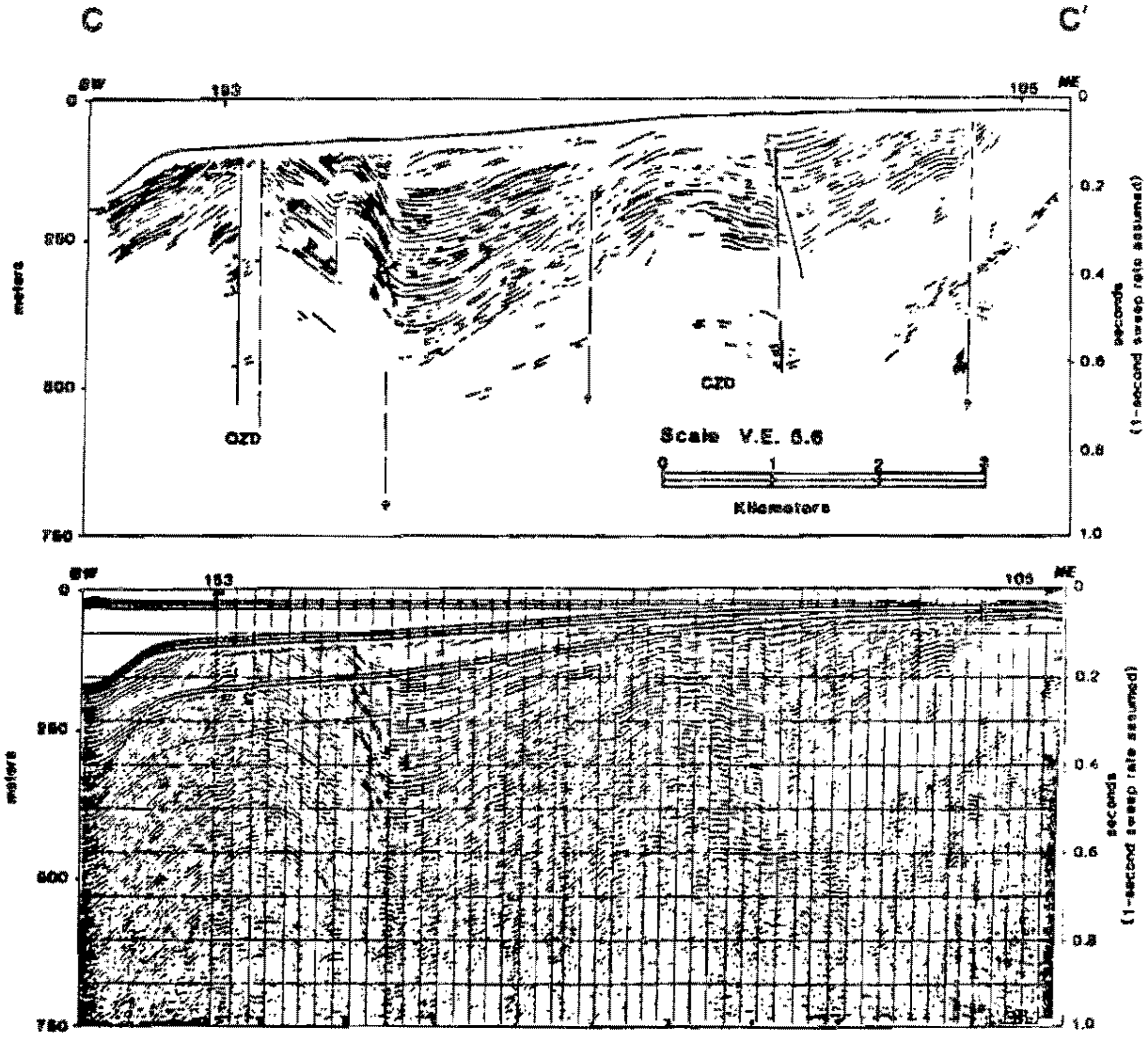


Figure 3. Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 836 showing OZD and CZD. See Plate 1 and 2 for location.

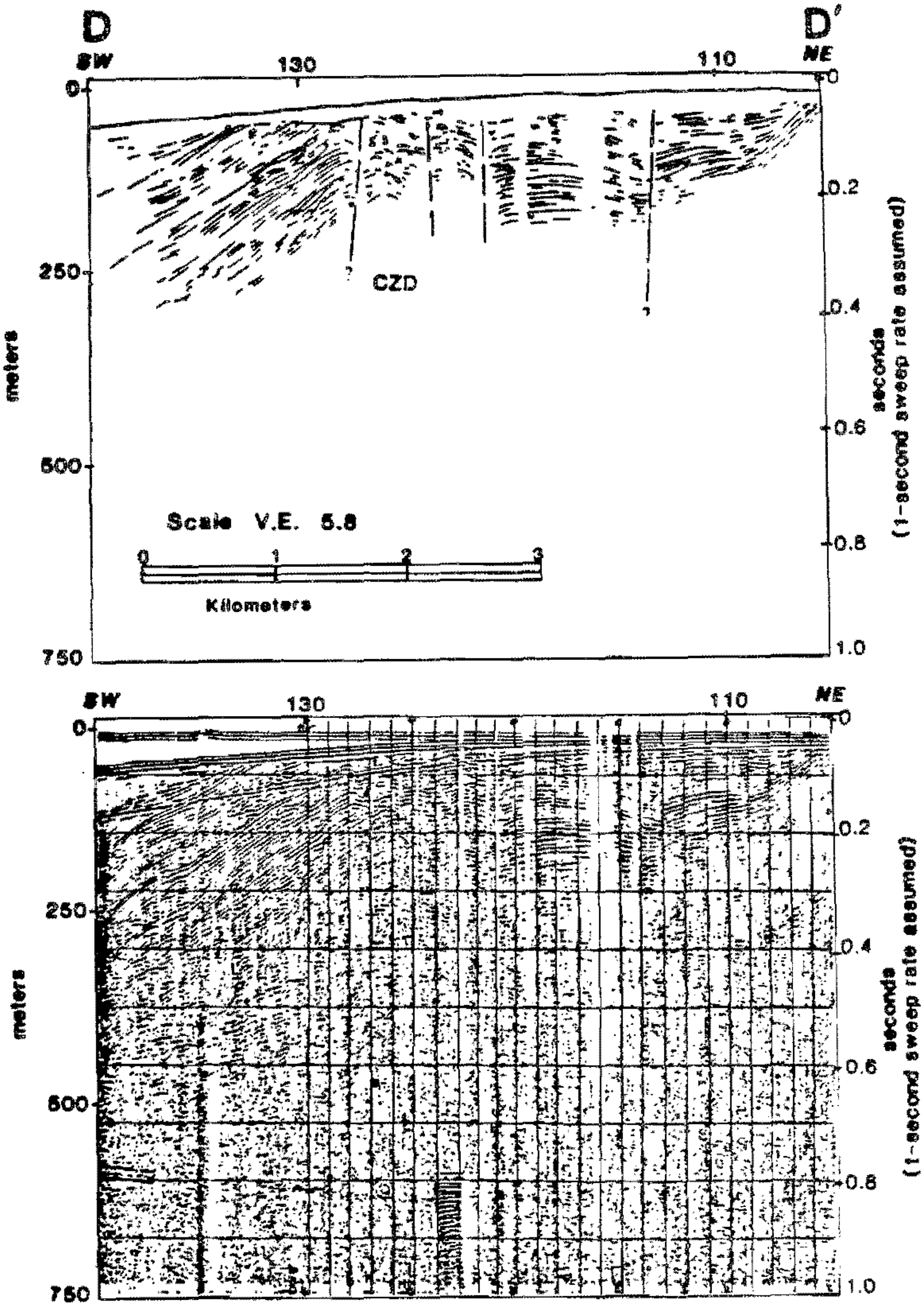


Figure 4.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 822 showing CZD and inshore fault. See Plate 1 and 2 for location.

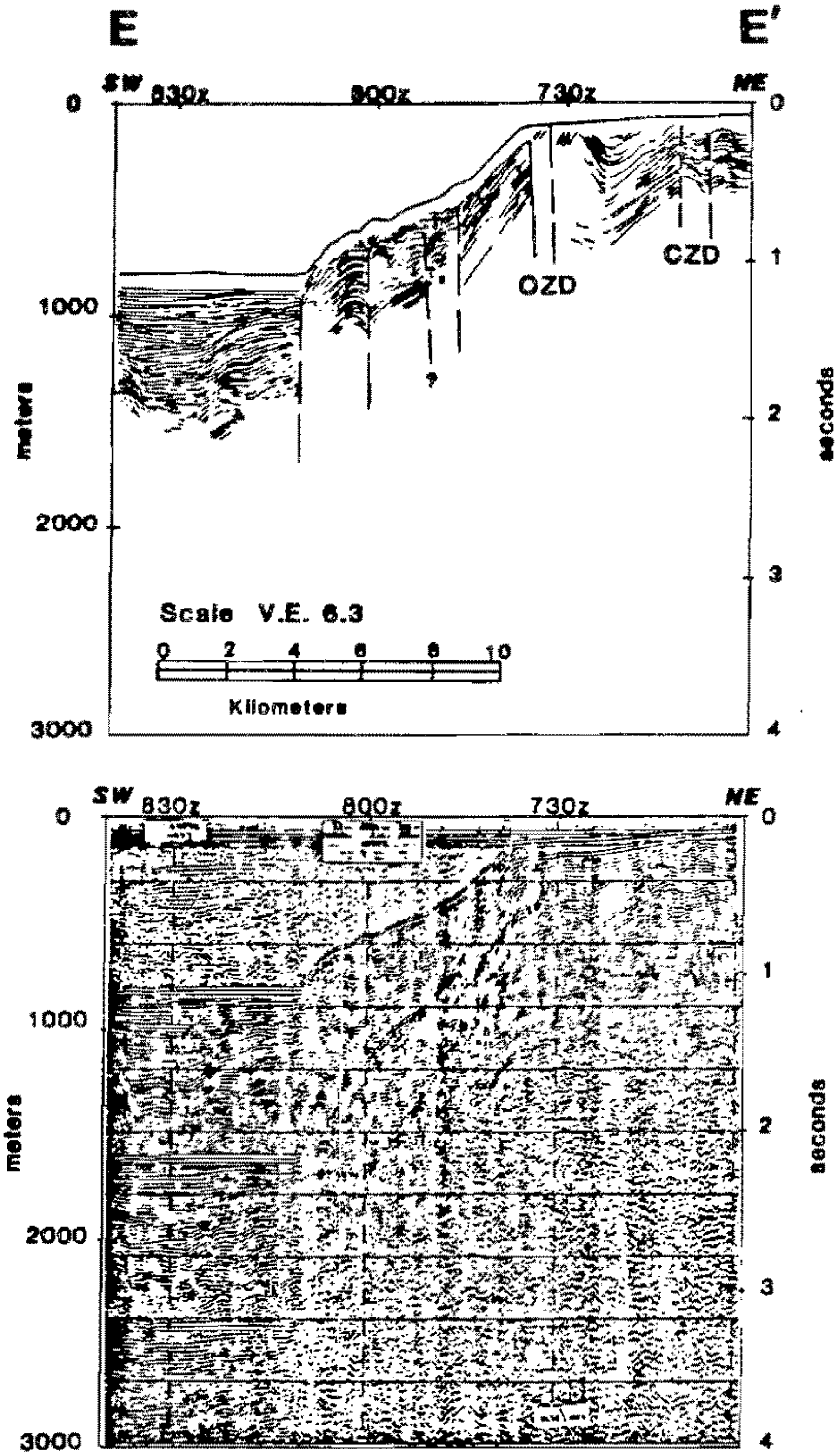


Figure 5.--Line drawing and seismic reflection profile of USGS SEA SOUNDER Line 58 (S2-79-SC) showing OZD, CZD, and other faults seaward of the study area. See Plates 1 and 2 for location.

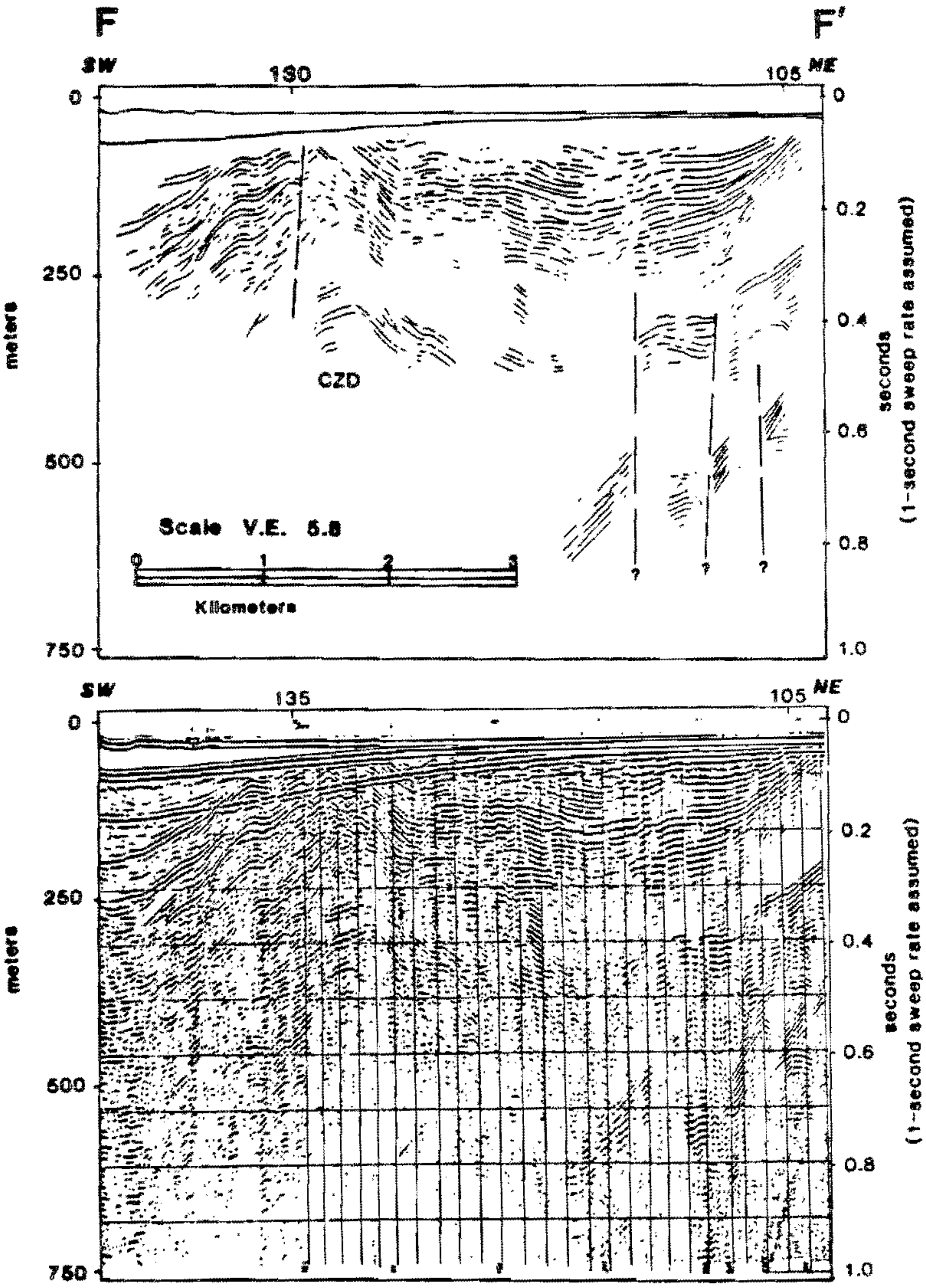


Figure 6.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 816 showing CZD and deep faults nearshore. See Plates 1 and 2 for location.

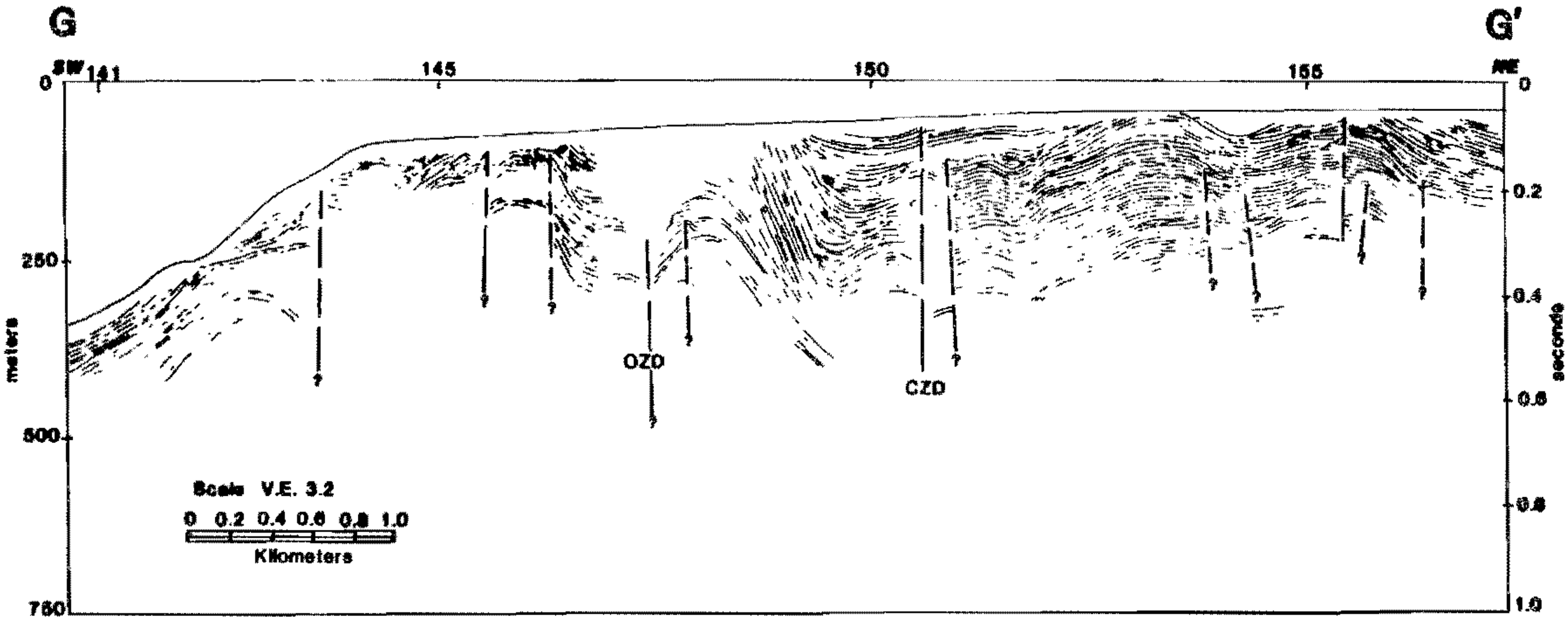


Figure 7.--Line drawing of Marine Advisor's seismic reflection profile S-16 showing OZD, CZD, and other structure in study area. See Plates 1 and 2 for location.

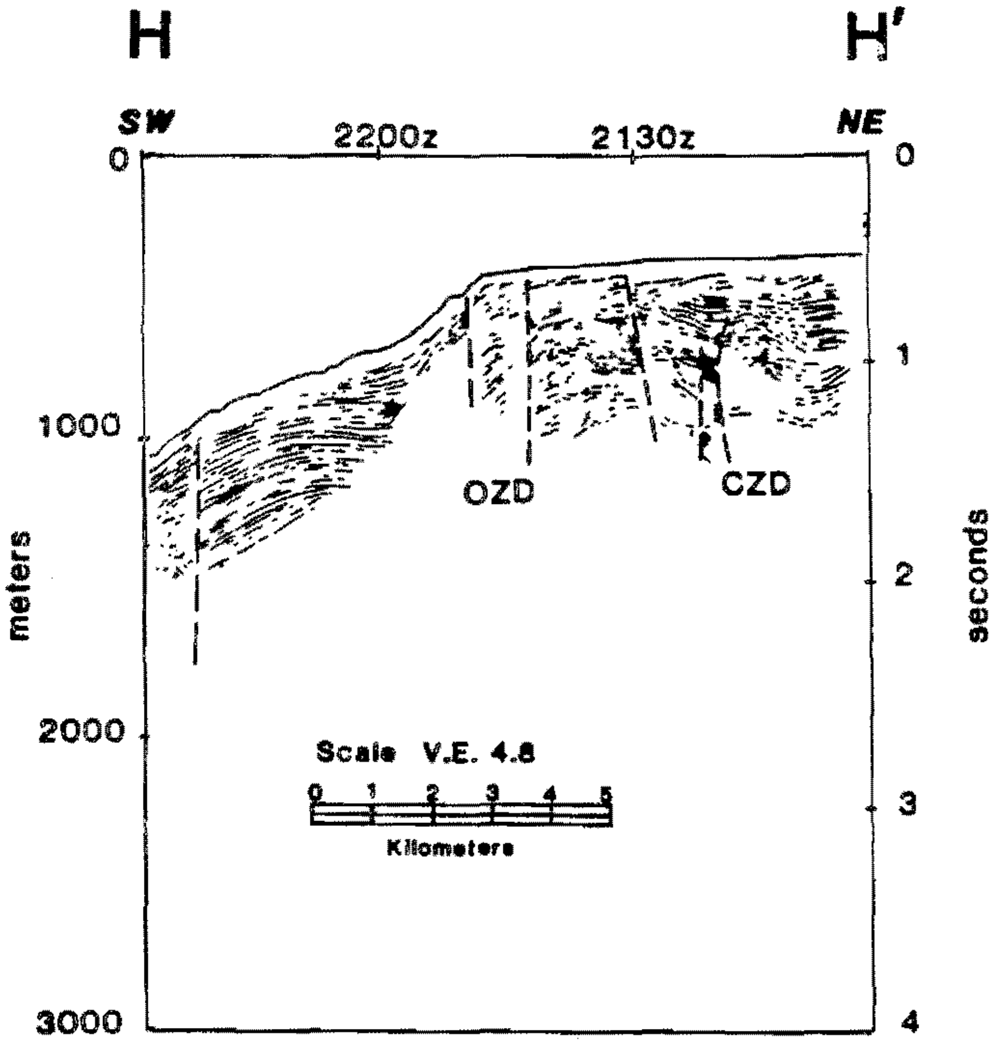


Figure 8.--Line drawing of USGS seismic reflection profile 33 (S2-78-SC) showing OZD and CZD. See Plates 1 and 2 for location.

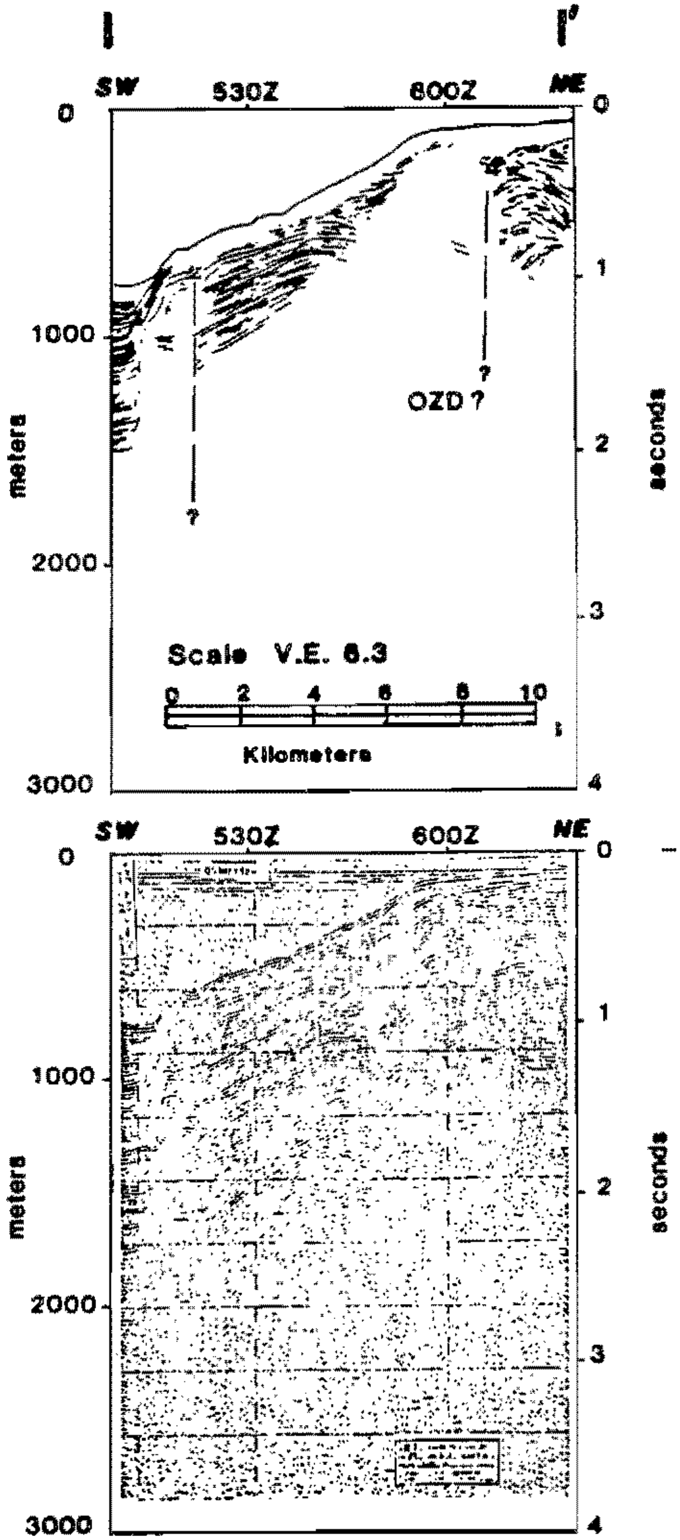


Figure 9.--Line drawing and seismic reflection profile of USGS SEA SOUNDER (S2-79-SC) Line 56 showing OZD. See Plates 1 and 2 for location.

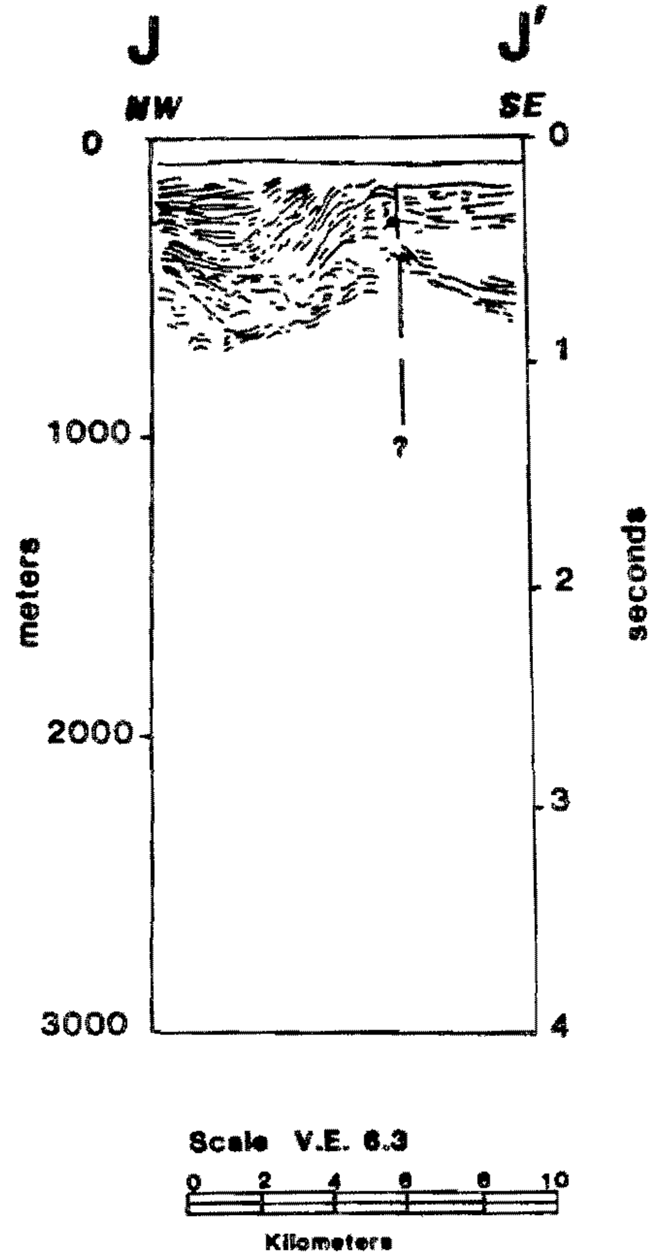


Figure 10.--Line drawing of USGS seismic reflection profile 57 (S2-79-SC) showing fault inshore of CZD. See Plates 1 and 2 for location.

APPENDIX G

Letter from H. William Menard, USGS, to

Harold R. Denton, NRC, dated November 26, 1980

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

OFFICE OF THE DIRECTOR

In Reply Refer To:
EGS-Mail Stop 106

NOV 26 1980

Mr. Harold R. Denton, Director
Office of Nuclear Reactor
Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Denton:

Transmitted herewith, in response to the requests of your staff, is a review of the geologic and seismologic data submitted by the Southern California Edison Company in support of its position concerning the San Onofre Nuclear Generating Station Units 2 and 3 (SONGS 2 and 3).

This review was prepared by Mr. Robert H. Morris and Mr. James F. Devine. Assistance was provided by Dr. H. Gary Greene and Dr. Joseph S. Andrews.

We have no objection to your making this review part of the public record.

Sincerely yours,

James F. Devine
for H. William Menard

Enclosure

Review of Geologic and Seismologic Data Relative to the San Onofre Units 2 and 3 Operating License Application

On August 13, 1980, the U.S. Geological Survey (USGS) transmitted to Dr. Robert E. Jackson in response to his request dated July 2, 1980, an Administrative Report entitled "Review of Offshore Seismic Reflections Profiles in the Vicinity of the Cristianitos Fault, San Onofre, California" by H. G. Greene, USGS, and Mr. M. P. Kennedy, California Division of Mines and Geology (CDMG). Since that transmittal, additional reflection profiles have been submitted by the applicant for the San Onofre Nuclear Generating Station Units 2 and 3 (SONGS). On September 23, 1980, a meeting was conducted in Menlo Park, California, during which the applicant, Southern California Edison (SCE), presented their interpretation of the Nekton survey. The USGS, in collaboration with M. P. Kennedy of the CDMG, has completed review of the Nekton data. This review constitutes an addendum to their earlier report and is being made available as an Administrative Report with the title "Addendum to Review of Offshore Seismic Reflections Profiles in the Vicinity of the Cristianitos Fault, San Onofre, California" by H. G. Greene and M. P. Kennedy (attached). In this addendum, Greene and Kennedy conclude that the Cristianitos Zone of Deformation (CZD) merges with or is truncated by the Offshore Zone of Deformation (OZD) and that generally faults within the CZD, with few exceptions, displace shallow stratified sedimentary rock that lies beneath a prominent unconformity and younger, poorly stratified sediments.

The significance of the above described studies on the earthquake potential at the SONGS site has been studied extensively by the applicant. On October 8, 1980, the USGS received edited transcriptions of some of the September 23, 1980, presentations made by SCE and its consultants. Included were the following:

1. Discussion of Geologic Setting, SONGS area, September 23, 1980, Dr. Perry Ehrlig.

2. Discussion of Offshore Recent Seismic Reflection Profiles, September 23, 1980, Dr. David Moore.

3. A description of the A, B, C, and D features at the site.

4. Amended response to NRC question 361.54.

The full set of these presentations represent the most complete summary of the applicant's analysis of this earthquake potential. The transcriptions of September 23, 1980, did not include the discussion by Dr. Roy Shleman, consultant to SCE, whose interpretation of the geomorphology and Holocene history of the area contributed significantly to the interpretation of the ages represented by various marine terrace sequences. The importance of this information is demonstrated by the application of these data to the interpretation of the marine profiles described by Dr. David Moore, and this, in turn, reflects the manner in which projection of the Cristianitos Fault to the south has been made. In assessing the conclusions drawn by the applicant's consultants in contrast with those by Greene and Kennedy, there emerges a difference in the use of certain named structures. Apparently, the applicant's consultants restrict the use of the term "Cristianitos Fault" to a single fault structure, i.e., a west-dipping normal fault. However, Greene and Kennedy use the terms "Cristianitos Zone of Deformation" (CZD), to refer to a zone of short discontinuous faults and folds. The applicant's consultants conclude that the Cristianitos fault dies out to the south whereas Greene and Kennedy project the Cristianitos Zone of Deformation southward to the OZD. SCE recognizes the southward projection by Greene and Kennedy but state in their conclusion that it does not represent an interconnection between the Cristianitos fault and the OZD. Both parties recognize younger undeformed, probably marine terrace, deposits capping the structures near shore. The range in age of these capping deposits is stated by Dr. Shleman (oral discussion, September 23, 1980, and viewgraph) to be from 80,000 years before present (YBP) to 8,500 YPB. The 8,500 YBP date was obtained by C14 method and the 80,000 YBP was inferred based upon geomorphology and late Pleistocene history. Assuming the inferred age is a reasonable conclusion, then the applicant's contention that the Cristianitos Fault (restricted use) is not capable is permissive. On land, the Cristianitos Fault is capped by the 125,000 year-old marine terrace, and the above conclusion then is consistent with that evidence.

Applicant's consultant, Dr. Perry Ehlig, discussed the origin of the Cristianitos Fault (restricted use) and concluded that the fault originated from 10 to 4 million years ago during a period of crustal extension and that the present stress régime of generally northeast-southwest compression represents a significant change; therefore, movement on the OZD would not trigger movement on the Cristianitos Fault.

The USGS, in general, concurs with the conclusions stated by the applicant and its consultants regarding the history and age of last movement of the Cristianitos Fault, its relation as one of several faults of the CZD of Greene and Kennedy, and its apparent lack of potential for movement in response to movement on the OZD.

The extensive investigations and studies by the applicant and its consultants to develop an estimate of the proper magnitude of the Safe Shutdown Earthquake have been reviewed. The techniques discussed in these studies have value but also limitations and shortcomings. Consequently, uncertainty still remains as to just which magnitude number is the "correct" one. Some of this uncertainty results not from the tools for deriving a specific magnitude number but from the limited relevance of such a number as a primary avenue through which ground motion values are estimated for sites near to the earthquake source structures. It is our judgment that a single magnitude value alone is an insufficient basis for assessing the consequence of the occurrence of an earthquake. Instead, it is necessary to include the entire tectonic package in three dimensions and in time sequence and the engineering considerations in order to develop appropriate seismic design numbers. Continued efforts to define a specific "magnitude" have, in our judgment, rapidly diminishing returns.

One could argue even today that reasoned judgment of the amount of ground shaking from many large earthquakes as indicated by the observed response at or near the fault structure may still be the most useful tool for estimating future ground motions very near to the fault. To the extent that that is the case, the previous estimates of shaking "intensity" and resulting estimated seismic design values, as used in the process leading to the seismic design of the SONGS facilities, still appear to be valid and appropriate to the SONGS 2 and 3 facilities.

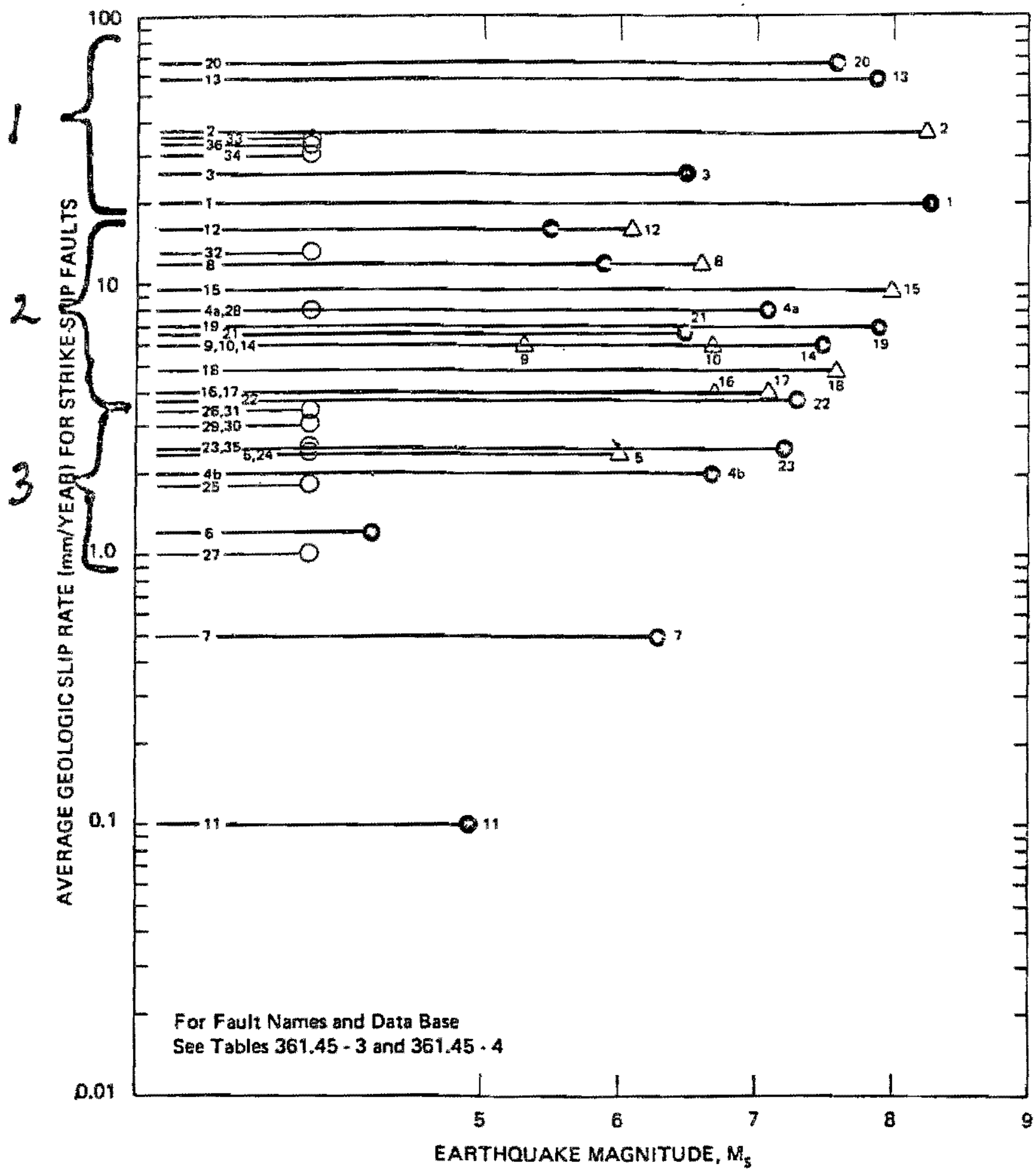
However, in an effort to be responsive to your requests to review the material submitted by the applicant, we offer the following comments concerning the primary technique discussed by the applicant, slip-rate versus magnitude study.

On the question of the statistical significance of the slope of a line bounding points on the log slip-rate versus magnitude plot, the applicant's consultants point out that while a single fault with low slip-rate is unlikely to have a "maximum" earthquake in historic time, a group of low-slip-rate faults has a significance proportional to their moment-rate sum. This same reasoning can be applied quantitatively.

There are 14 faults in Group 2 (see attached figure) with slip-rates ranging from 3.5 to 17.5 mm/yr. Seven of these faults have had historic earthquakes within one magnitude unit of the proposed "maximum earthquake limit" (MEL) line, and two have had earthquakes within 1/2 magnitude unit of the proposed MEL line.

There are 11 faults in Group 3 with slip-rate of 0.7 to 3.5 mm/yr. It is stated on p. 361.51-2 of the SCE report of February 1980 that "The total moment rate for group 3 is roughly equal to the average rate for group 2." Therefore, the faults of group 3 collectively have the statistical weight of a single fault of group 2. The probability that any earthquake in group 3 is within one magnitude unit of a properly-drawn "maximum earthquake limit" line is 7/14 = 0.5, and the probability that any earthquake on any fault in group 3 is within 1/2 magnitude unit of the MEL is 2/14 = 0.14. Therefore, there is a substantial probability that the MEL line should be steeper than shown in Figure 361.45-4, and earthquake magnitudes at smaller geologic slip-rates could be larger. During discussion the applicant made the observation that there are probably many faults with small geologic slip-rates and no historic earthquakes which are not shown on the plot and that these should be included in an estimate of statistical significance. It remains to be shown that the number of such faults increases inversely with decreasing geologic slip-rate. Consequently, an imperical technique based on such limited data cannot be considered definitive in assessing maximum magnitude. However, this technique is helpful, when considered along with other procedures for estimating earthquake size to assess the potential impact of earthquakes on the SONGS site.

A comment is in order relative to other regional and areal studies prepared for a variety of uses that have listed estimates of the magnitude of the maximum earthquake on the various faults in southern California and elsewhere. Such studies are based on a variety of generalized geologic and seismologic assumptions that may be adequate for the purposes for which those reports are intended but quite inappropriate for other purposes such as the development of the seismic design criteria for a specific site. Such specific site design criteria usually require detailed studies with the particular needs and requirements for that site as a basis for the studies. Consequently, the very extensive studies and evaluations accomplished for the particular purpose of assessing the earthquake safety at the SONGS site should provide the bases upon which seismic safety issues relative to that site are resolved.



EXPLANATION

- ● Maximum instrumental recording
- △ Maximum pre-instrumental estimates
- — Range over which smaller earthquakes occur
- ○ No maximum magnitude from instrumental or pre-instrumental data.

Figure 361.45 - 1 Empirical Plot
Geologic Slip Rate VS Historical
Magnitude for Strike–Slip Faults

ADDENDUM TO:
REVIEW OF OFFSHORE SEISMIC REFLECTION PROFILES IN THE VICINITY OF THE CRISTIANITOS FAULT, SAN ONOFRE, CALIFORNIA

by

H. Gary Greene[1] and Michael P. Kennedy[2]

INTRODUCTION

On May 8, 1980 the U.S. Nuclear Regulatory Commission (NRC) requested that a comprehensive review by made of all marine geophysical data relevant to the character and recency of faulting along the offshore extension of the Cristianitos fault in the vicinity of the San Onofre Nuclear Generating Station (SONGS) in northwestern San Diego county, California. This request was made to the U.S. Geological Survey (USGS) and was concerned specifically with a proposed structural relationship between the Cristianitos zone of deformation (CZD) and the Newport-Inglewood-Rose Canyon fault zone (Greene et al., 1979) or the Offshore Zone of Deformation (OZD) of Southern California Edison (SCE) Company. H. G. Greene of the U.S.G.S. suggested to the NRC that this review be made jointly by himself and M. P. Kennedy of the California Division of Mines and Geology. This suggestion was made because of the extensive joint research effort then underway between Greene and Kennedy on aspects of the structural geology of the southern California borderland. The NRC agreed to Greene's suggestion and a review and report were completed on July 18, 1980.

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[1]U.S. Geological Survey, Menlo Park, California
[2]California Division of Mines and Geology, La Jolla, California

Following the completion of this review and report an additional data set was forwarded for the authors consideration. This data set was collected in June 1980 by NEKTON Inc. for SCE. It consists of about 90 km of high resolution water gun and 3.5 kHz seismic reflection profiles and side-scan sonographs collected within the area of earlier studies (plate 2). The 3.5 kHz data is generally good to moderately good and the penetration is on the order of 10-20 ms. The side-scan data is generally poor and for the most part unuseable for our purpose.

PURPOSE OF NEKTON DATA COLLECTION

The June 1980 NEKTON survey was aimed specifically at collecting data in the vicinity of the proposed intersection of the CZD and the Newport-Inglewood-Rose Canyon fault zone (Greene et al., 1979) or OZD. This relationship was explained in detail by H. G. Greene in a meeting with the NRC and SCE held May 21, 1980. The objectives of the survey as defined by NEKTON, Inc. (1980) were (1) to identify, if possible, the seaward extension of the Cristianitos fault that is mapped onshore 0.8 kilometers southeast of SONGS within our Cristianitos zone of deformation, (2) to determine if the Cristianitos fault connects with the OZD, (3) to identify and map other faults and folds in the area, and (4) to determine whether any faults show evidence of Holocene movement.

DISCUSSION

Although no seismic lines collected by NEKTON in the June 1980 survey actually cross the proposed CZD-OZD intersection of Greene and Kennedy (1980) the CZD can be extended by way of this data (June 1980

NEKTON data) to an area where we interpret it to merge with a synclinal fold and adjoining fault associated with the OZD.

With the exception of minor and consistant navigational errors between the earlier data studied and the June, 1980 NEKTON data nearly all of the geological structures identified correlate with those noted previously (Greene and Kennedy, 1980). Several faults that were inferred and shown in areas labeled "data void" have been confirmed with the June 1980 NEKTON data set. As in the original review no geological features have been shown on plate 1 that cannot be correlated between two or more lines.

The June 1980 NEKTON data suggest that the CZD narrows to the south and merges with a syncline that marks the landward boundary of the OZD. This syncline in turn is truncated by a fault that lies parallel or subparallel to this syncline (plate 1).

In the area of the proposed CZD-OZD intersection the OZD is wide (6.4 km) but appears on the bases of the June 1980 NEKTON data to narrow or trend out onto the continental slope southeast of the intersection (plate 1). Components of the OZD southeast of the proposed CZD-OZD intersection consist primarily of a single continuous fault. At the locality where the OZD is represented by a single fault a scarp on the seafloor suggests recent fault movement. The seafloor scarp is at the intersection of two very continuous faults within the central part of the OZD (plate 1).

Structure noticeably changes southeast of the OZD-CZD intersection. Northwest of this intersection structural components mapped on the shelf are plentiful and relatively complex while southeast of the intersection the structural components are reduced in number and complexity (plate 1).

The geological structure mapped from the total review process, with only a few exceptions are confined to a section of well stratified sedimentary rock that lies wholly beneath a prominent unconformity and a thin sequence of poorly stratified, locally acoustically transparent (poorly consolidated and possibly water saturated) sediment. The exceptions noted are faults that displace near surface bedrock or sediment in the vicinity of (1) the proposed intersection of the CZD and OZD, (2) along the eastern margin of the CZD at a single locality and (3) centrally in the CZD at four separate localities that lie between approximately 4.5 - 6 km south of SONGS (plate 1).

CONCLUSIONS

The CZD merges with or is truncated by the OZD in the area offshore from SONGS (plate 1). Generally faults within the CZD with few exceptions (plate 1) displace shallow stratified sedimentary rock that lies beneath a prominent unconformity and younger poorly stratified sediments. The June 1980 NEKTON data support the conclusions reported previously by Greene and Kennedy (1980).

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Docket Nos. 50-361 and 50-362

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The Safety Evaluation Report (geologic and seismic aspects) for the application filed by Southern California Edison Company, et al for licenses to operate the San Onofre Nuclear Generating Station (Docket Nos. 50-361 and 50-362) located in San Diego County, California has been prepared by the Office of Nuclear Reactor Regulation of the Nuclear Regulatory Commission. Other aspects of the safety review are still in progress. When review of the other areas is complete, a complete Safety Evaluation Report will be issued, which will incorporate the material included in this report.

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SAN ONOFRE NUCLEAR GENERATING STATION, UNITS 2 AND 3

DECEMBER 1980