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

by

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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.

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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.

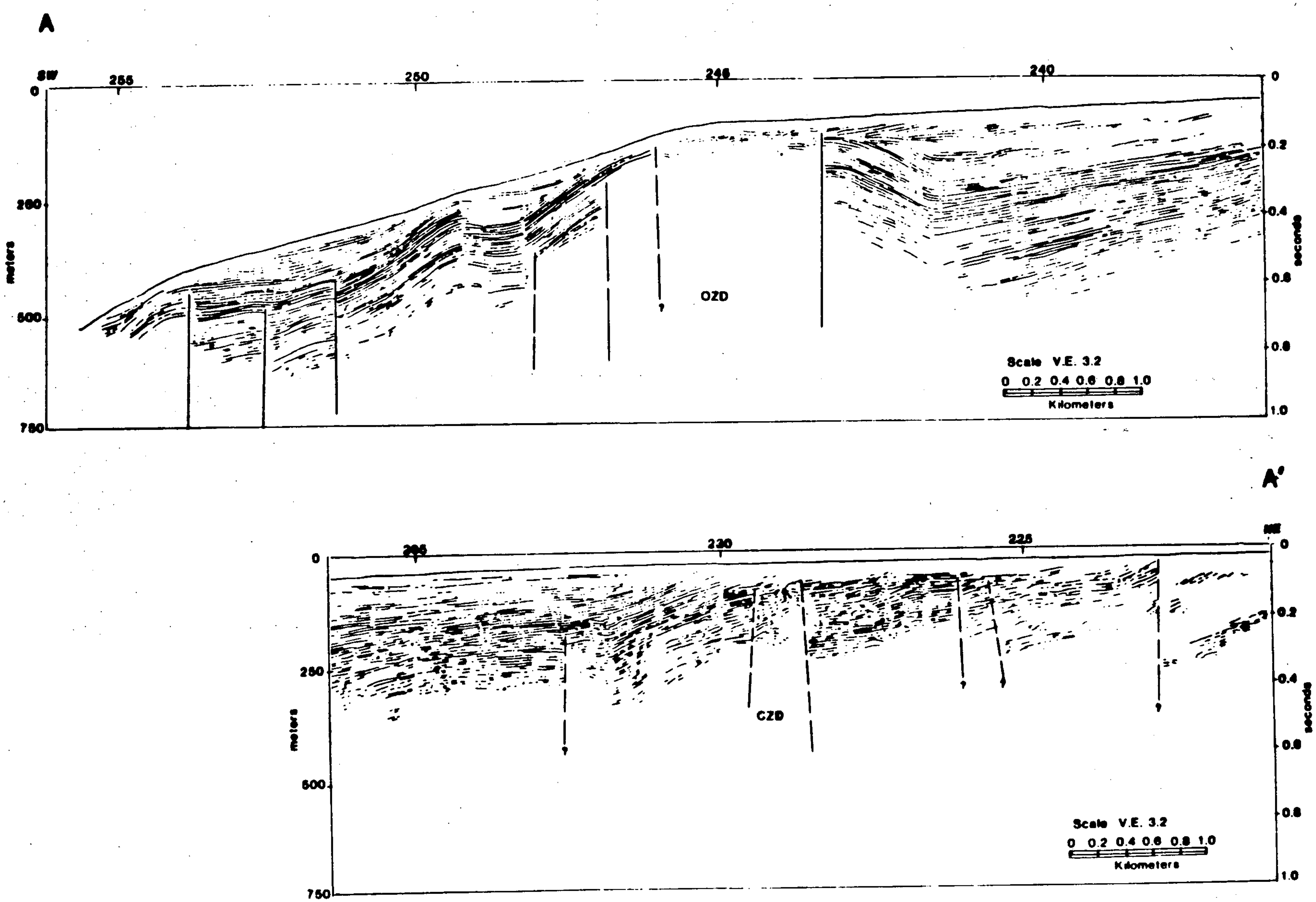


Figure 1.--Line drawing Marine Advisor's seismic reflection profile S-22 showing location of the OZD and CZD. See Plates 1 and 2 for location.

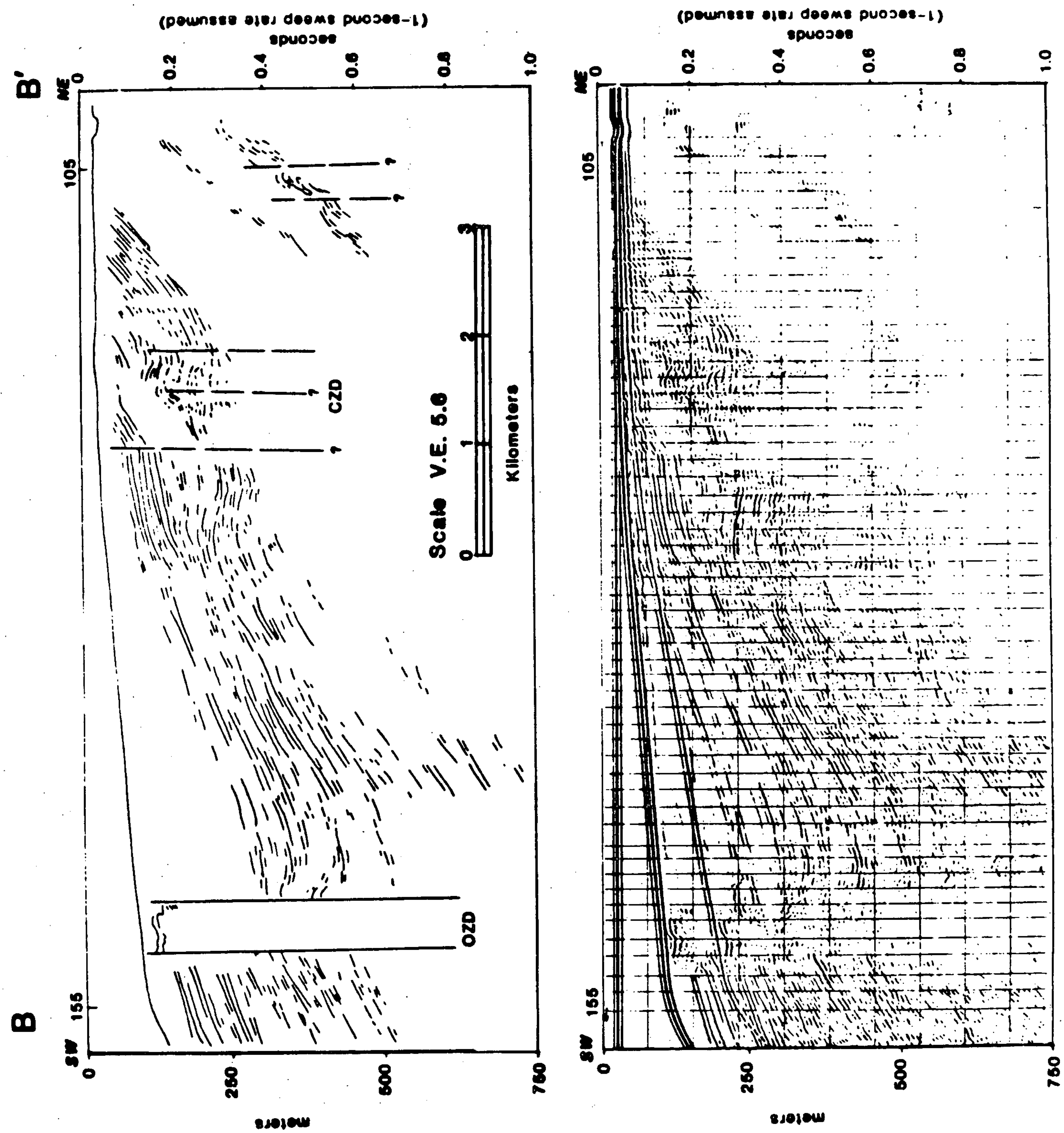


Figure 2.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 845 showing OZD and CZD. See Plates 1 and 2 for location.

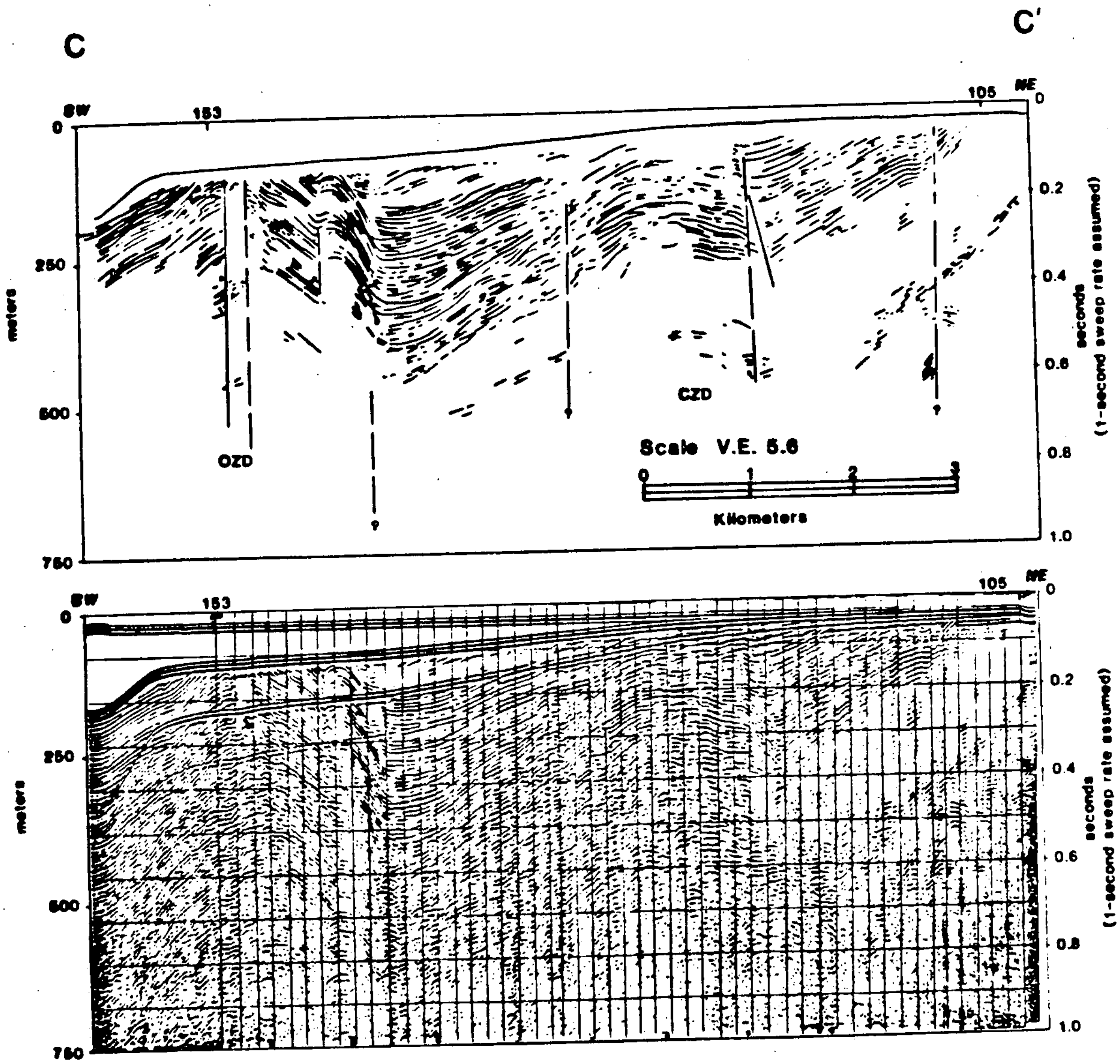


Figure 3. Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 836 showing OZD and CZD. See Plate 1 and 2 for location.

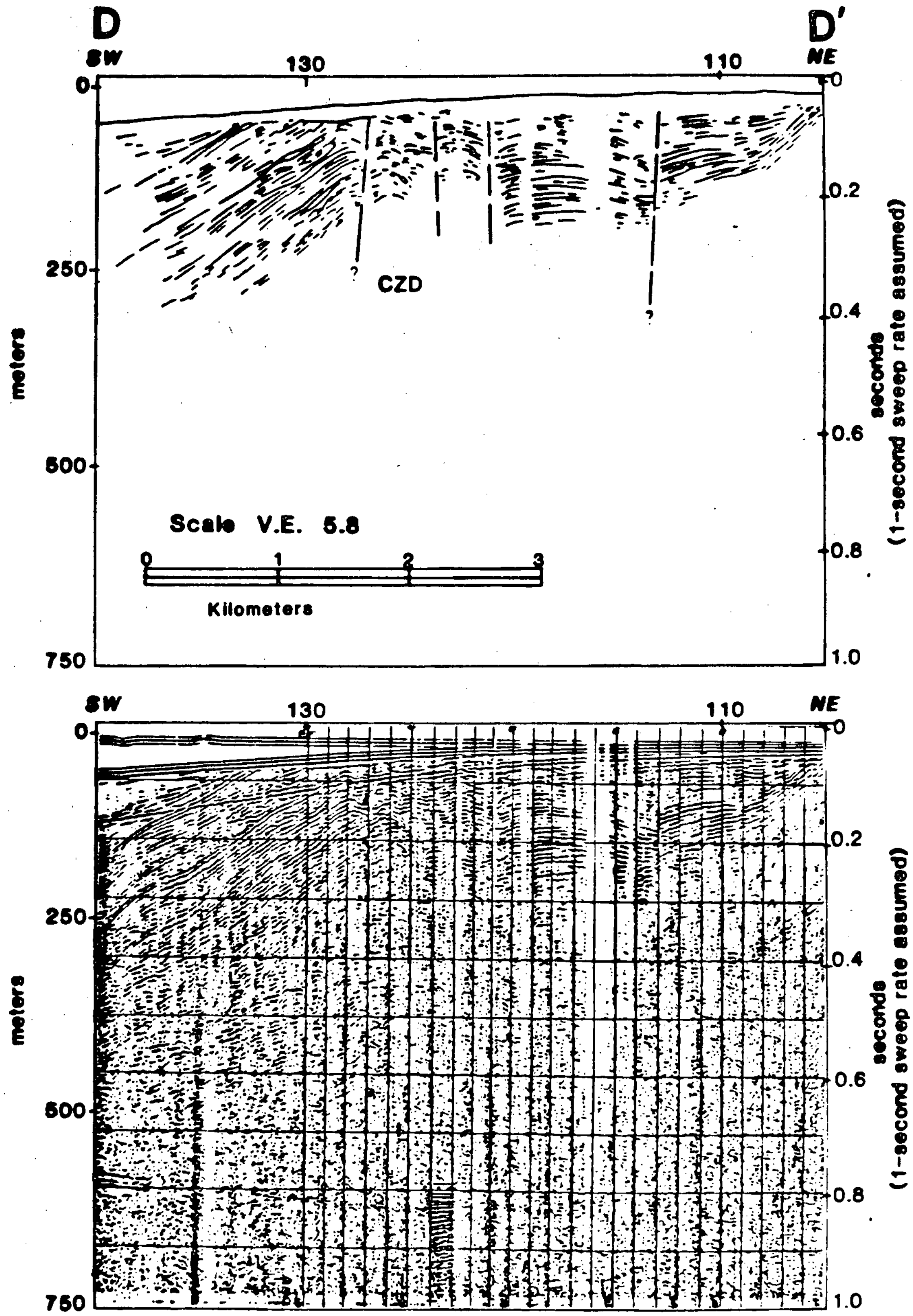


Figure 4.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 822 showing CZD and inshore fault. See Plate 1 and 2 for location.

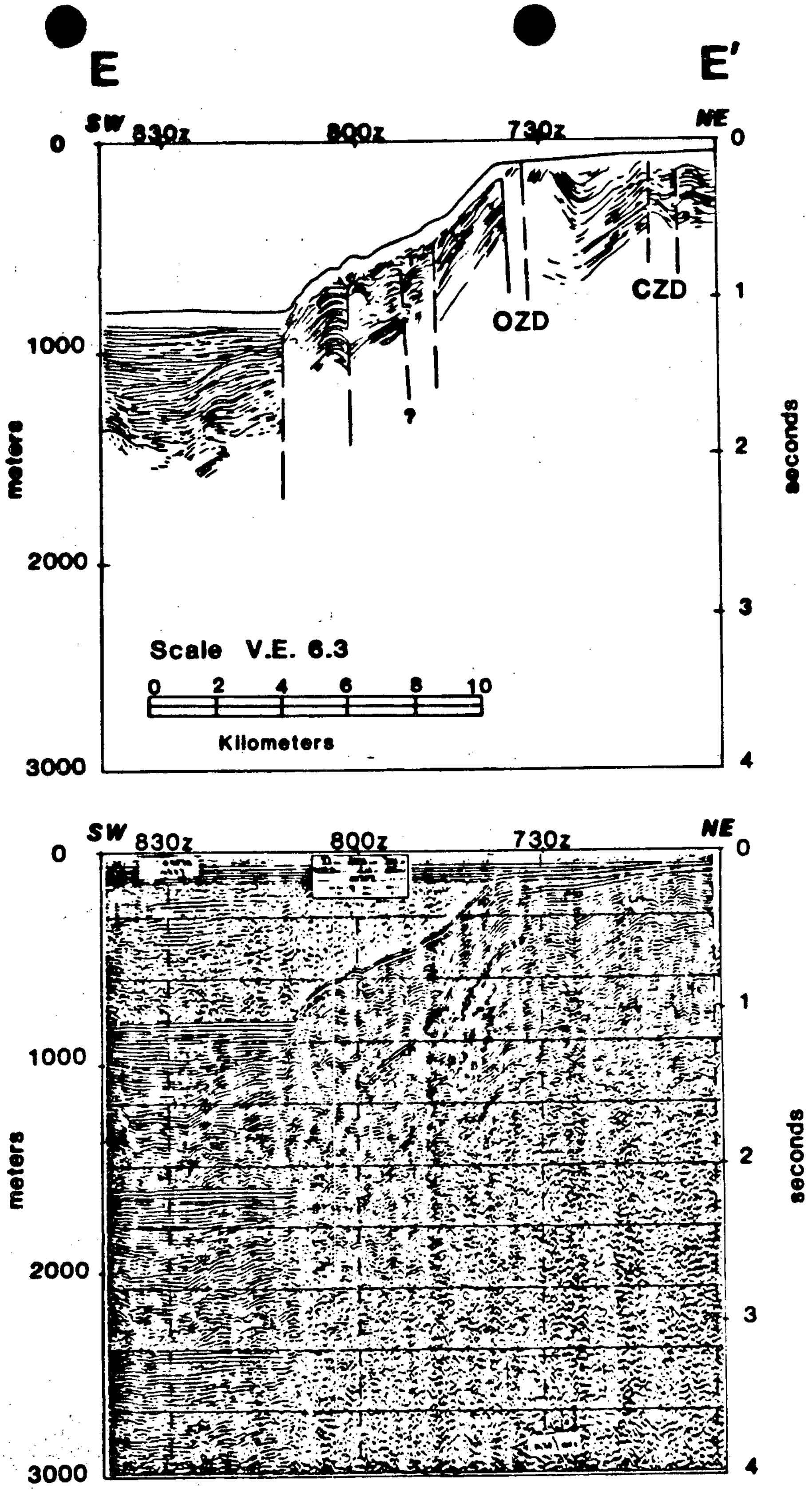


Figure 5.--Line drawing and seismic reflection profile of USGS SEA SOUNDER Line 58 (S2-79-SC) showing OZD, CZD, and other faults seaward of the study area. See Plates 1 and 2 for location.

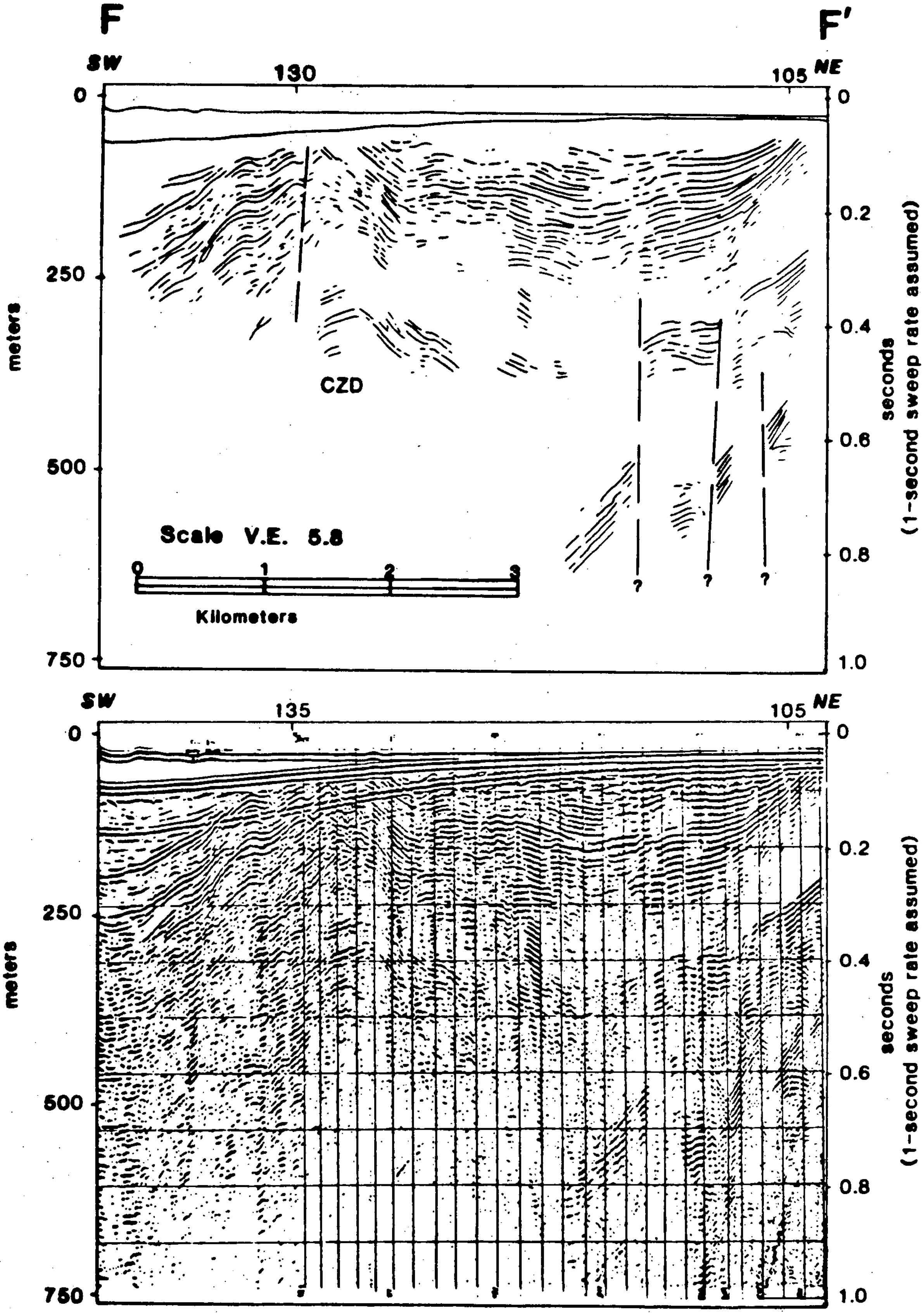


Figure 6.--Line drawing and seismic reflection profile of Woodward-Clyde Consultant's Line 816 showing CZD and deep faults nearshore. See Plates 1 and 2 for location.

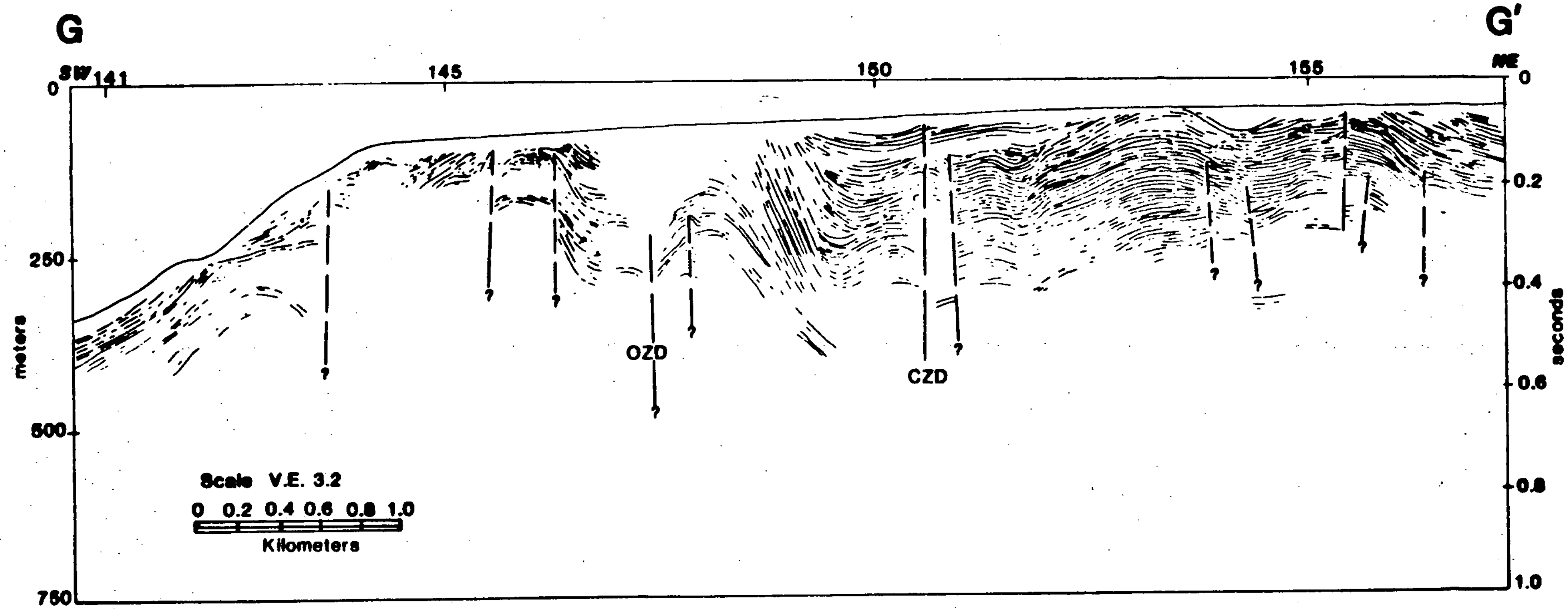


Figure 7.--Line drawing of Marine Advisor's seismic reflection profile S-16 showing OZD, CZD, and other structure in study area. See Plates 1 and 2 for location.

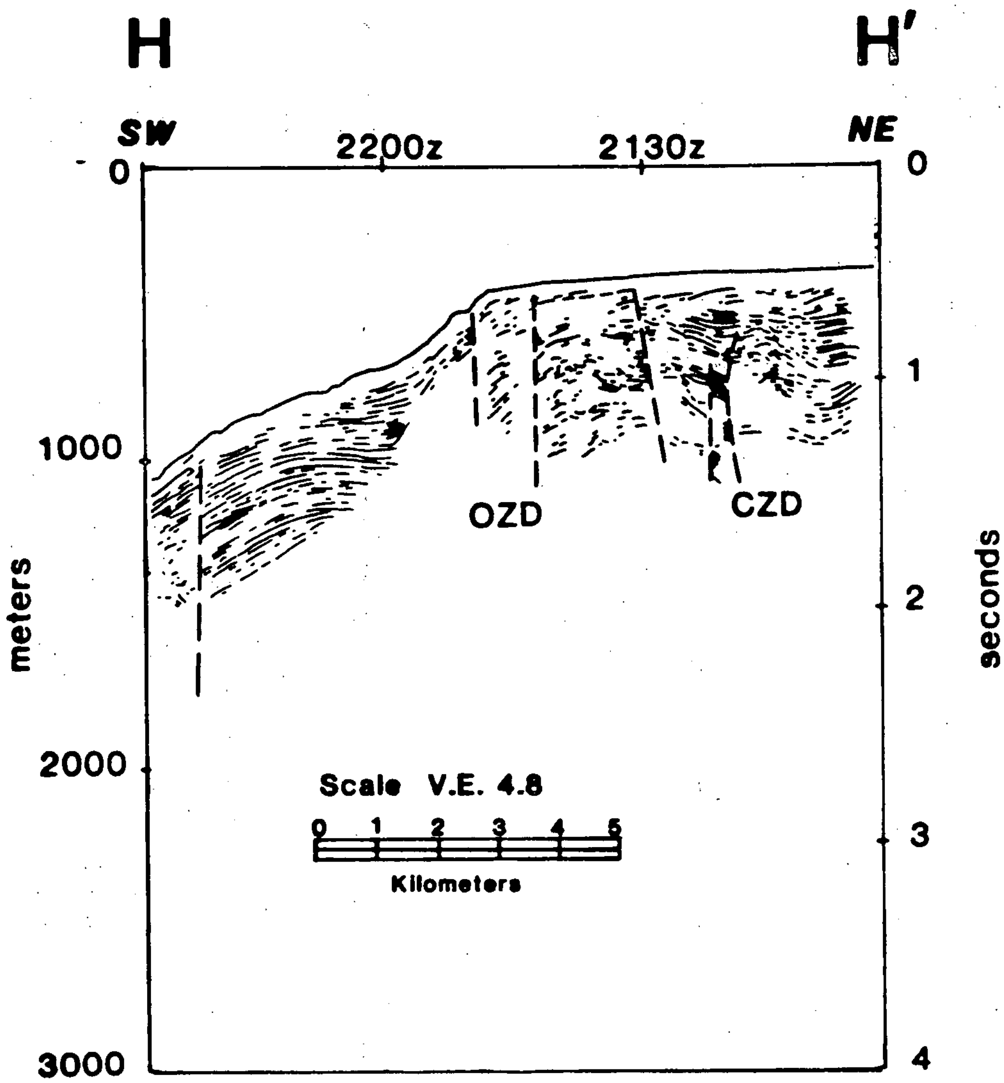


Figure 8.--Line drawing of USGS seismic reflection profile 33 (S2-78-SC) showing OZD and CZD. See Plates 1 and 2 for location.

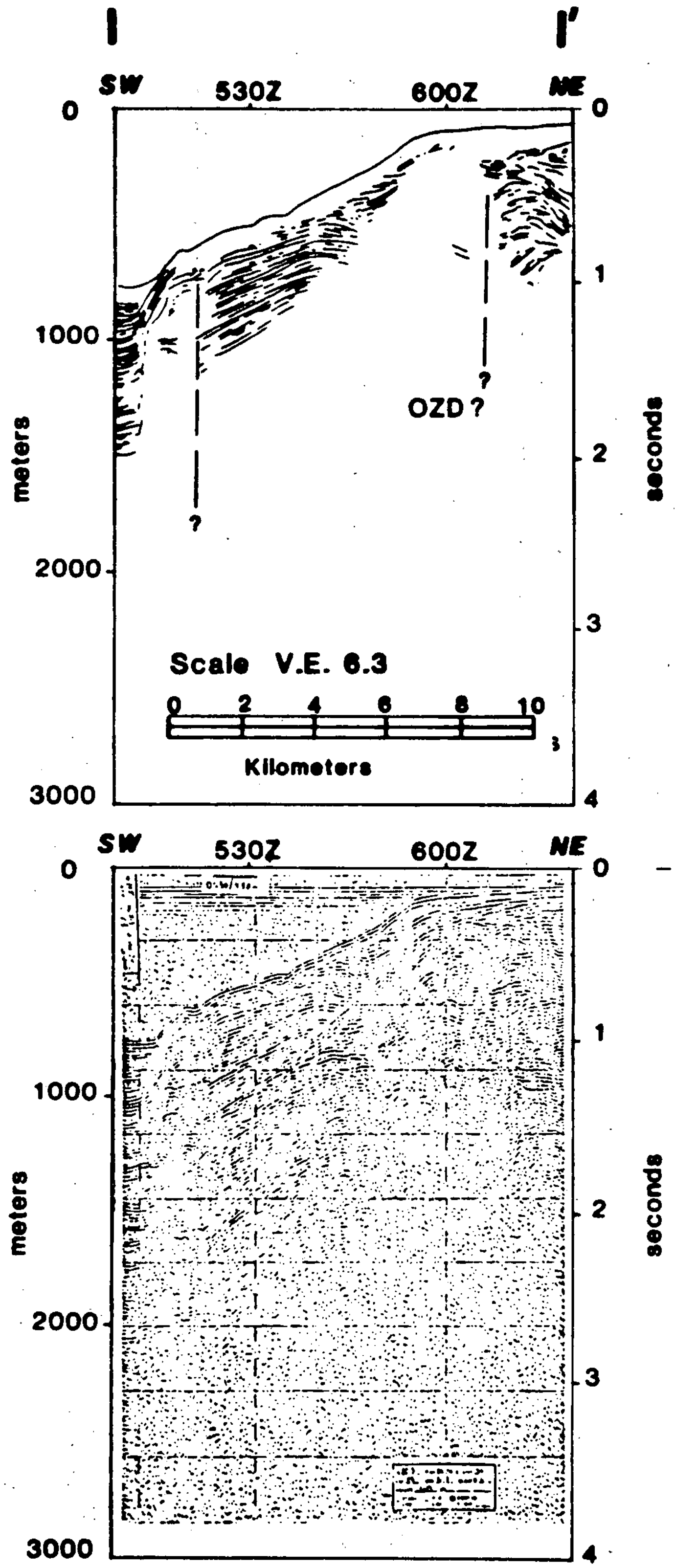


Figure 9.--Line drawing and seismic reflection profile of USGS SEA SOUNDER (S2-79-SC) Line 56 showing OZD. See Plates 1 and 2 for location.

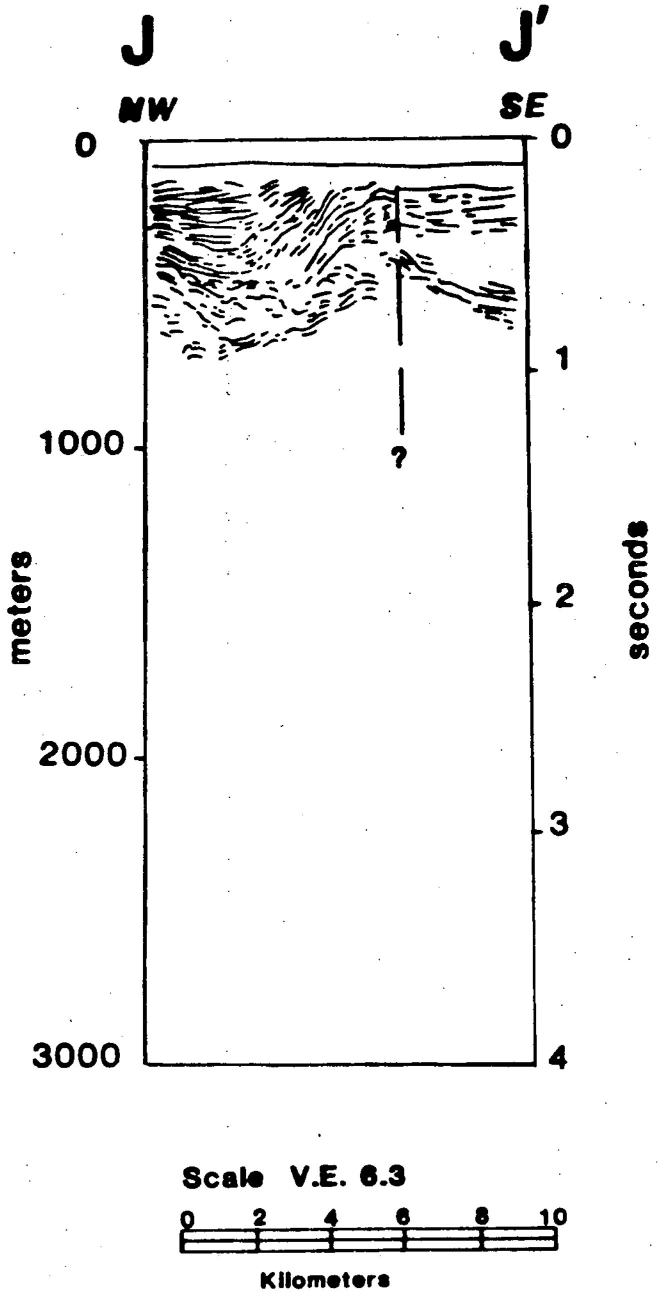
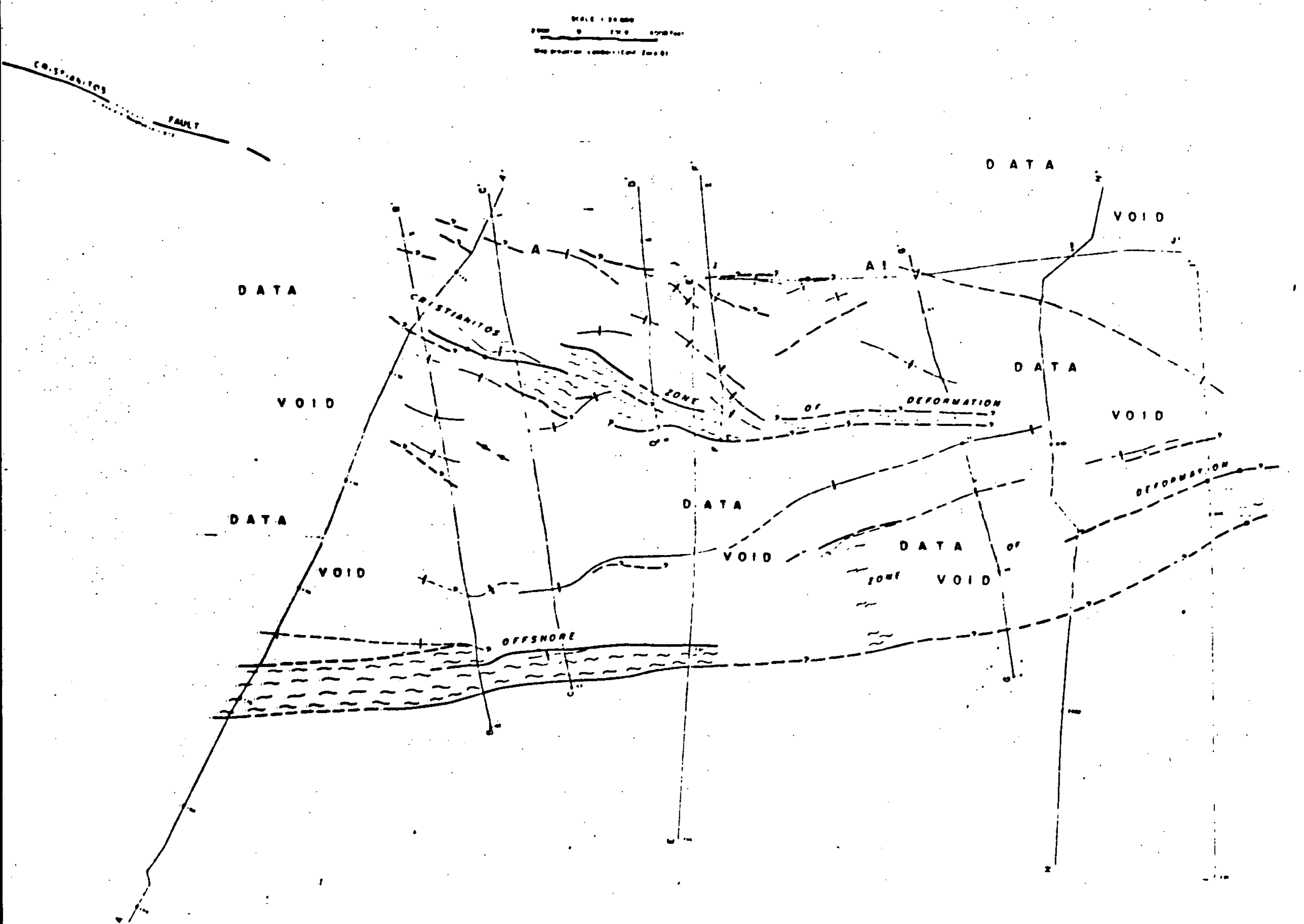
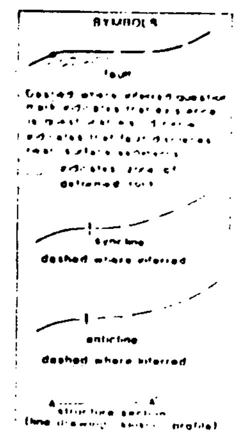


Figure 10.--Line drawing of USGS seismic reflection profile 57 (S2-79-SC) showing fault inshore of CZD. See Plates 1 and 2 for location.

Plate 1





GEOLOGIC STRUCTURE MAP - SAN ONOFRE OFFSHORE

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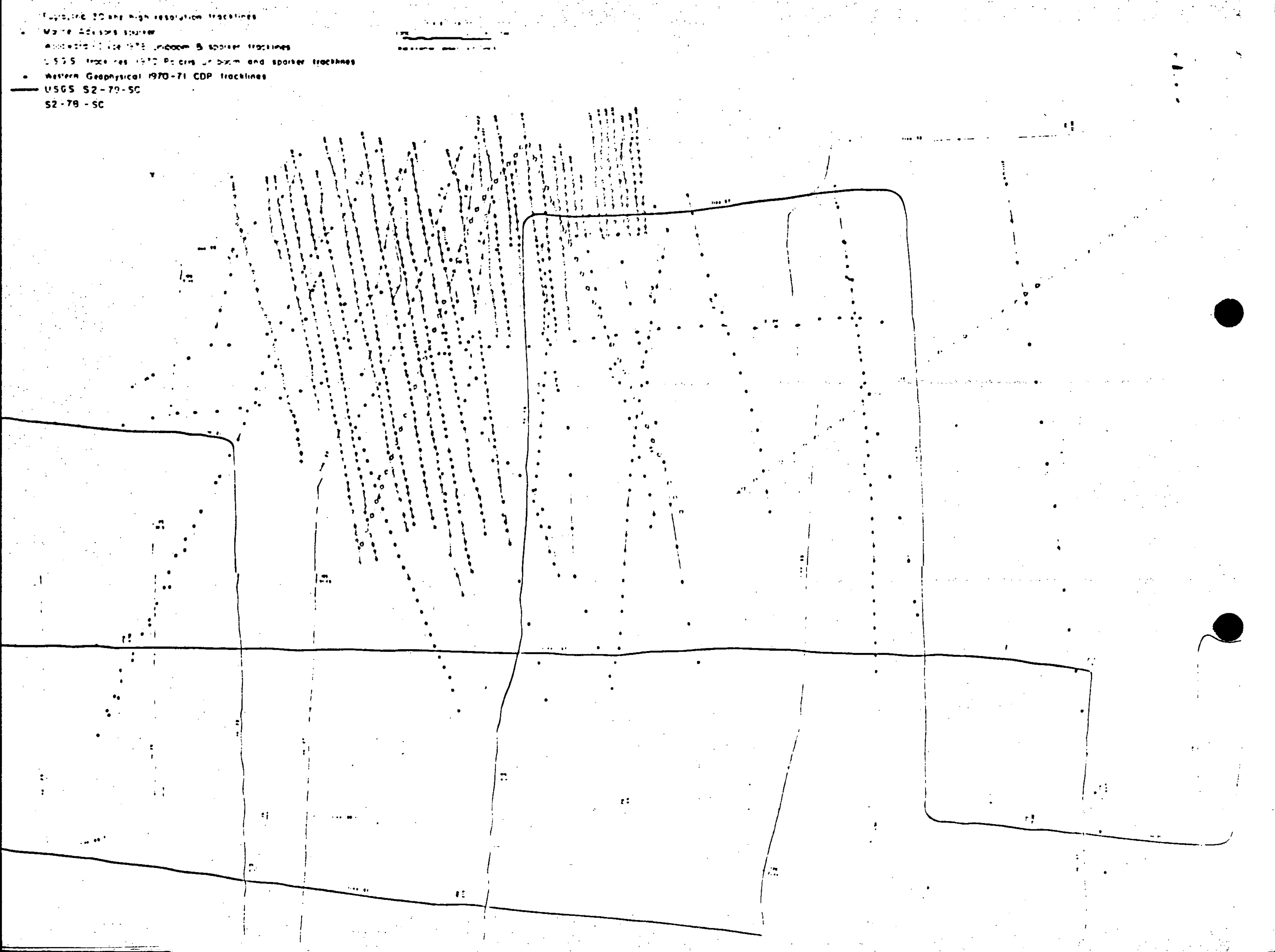
Bathymetry in meters - after Fisher, 1980 (SCIMAP)
Map projection Lambert (Calif. zone 6)

A review for NRC


Western Geophysical 1970-71 CDP tracklines
USGS S2-79-SC
S2-78-SC