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NUCLEAR REGULATORY COMMISSION

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In the Matter of:

SOUTHERN CALIFORNIA EDISON COMPANY, ET AL., (SAN ONOFRE NUCLEAR GENERATING STATION, UNITS 2 AND 3) DOCKET NOS. 50-361, OL and 50-236, OL

DATE: June 22, 1981, ff. PAGES: ______

AT: San Diego, California

APPLICANTS' DIRECT TESTIMONY

ON

CONTENTION NO. 4

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ADD:
M. MOE/OGC 881 SS
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original to:
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TESTIMONY OF DR. PERRY L. EHLIG

Q. Would you please state your name?

A. Dr. Perry L. Ehlig.

Q. By whom are you presently employed?

A. I am a professor of geology at California State University at Los Angeles.

Q. In what manner are you associated with the Applicants in this proceeding?

A. Over the past four years I have been retained by the Applicants as a consulting geologist. I have conducted several geologic studies of the area around San Onofre involved with local stratigraphy; regional and local structure and tectonics.

Q. Would you please describe your formal training in geology?

A. I received a B.A. and Ph.D in geology from the University of California at Los Angeles (UCLA) in 1952 and 1958, respectively.

Q. What professional positions have you had in the area of geology?

A. I have been a consulting engineering geologist since 1954 to private consulting firms, the U.S. Army Corps of Engineers, Southern California Edison, City of Rancho Palos Verdes, and a member of Los Angeles County Engineering Geology and Soils Review and Appeals Board.

Q. Have you been associated with any educational institutions?

A. Yes, I was a teaching assistant in geology at UCLA in 1953-1954, a field geology instructor in 1956 and 1958 at UCLA and at Louisiana State University in 1957, and I have been a professor in geology at California State University at Los Angeles since 1956.

Q. Do you hold any professional registrations in the State of California or any other state?

A. Yes, I am a Registered Geologist, No. 1692, and a Certified Engineering Geologist, No. 533, in the State of California.

Q. What are your pertinent professional or organizational memberships?

A. I am a member of the American Association for the Advancement of Science; American Association of Petroleum Geologists; Association of Engineering Geologists; Geological Society of America; Mineralogical Society of America; Sigma Xi; Society of Economic Paleontologists and Mineralogists; and National Association of Geology Teachers.

Q. Have you written or published articles in the field of geology?

A. Yes, I have authored or co-authored numerous papers and reports dealing with applied igneous and

metamorphic petrology, structural geology and engineering geology. A list of published reports is appended hereto.

Q. Have you presented expert opinion or testimony?

A. Yes. I presented expert opinion to the Advisory Committee on Reactor Safeguards ("ACRS") in this proceeding. In addition, I presented expert opinion before the Riverside, California Superior Court about 1970. This testimony dealt with the volume of hard rock likely to have been present in an area requiring blasting.

Q. What is the purpose of your testimony in this proceeding?

A. One of the issues in this proceeding is whether based on the geologic characteristics of the OZD, including its length, assignment of M 7 as the maximum magnitude earthquake for the OZD renders the seismic design basis inadequate. The purpose of my testimony is to establish the regional geologic setting and the evolution of the relevant geologic structures and stratigraphy in the San Onofre region.

Q. Have you investigated or studied the geologic evolution of the San Onofre region including the OZD?

A. Yes.

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Q. Would you describe the basic geologic evolution of the San Onofre region up to the time of development of the OZD?

A. My studies indicate the geologic evolution of the San Onofre region began about 200 million years ("m.y.") ago when the western edge of the continental crust terminated near the eastern margin of the present Peninsular Ranges and sedimentary strata of Triassic and Jurassic age, referred to as the Bedford Canyon Formation near SONGS, were accreted against it, presumably as a result of eastward subduction of oceanic crust (Hamilton, Warren, "Mesozoic Tectonics of the United States" and Criscione and others, "The Age of Sedimentation/ Diageneis for the Bedford Canyon Formation and the Santa Monica Formation in Southern California; A Rb/Sr evaluation," Mesozoic Paleography of the Western United States: Pacific Section, So. Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, Howell, D.G. and McDougall, K.A., eds., pp. 385-396 (1978).) Volcanic and volcaniclastic rocks were emplaced on top of the accretionary wedge along the western side of the Peninsular Ranges during the Late Jurassic and Early Cretaceous (Gastil, Morgan, G. J. and Krummenacher, "Tectonic History of Peninsular

California and Adjacent Mexico", in The Geotectonic Development of California, 284-305 (Ernst, W.G. ed. 1981); Gastil and others, "Reconnaissance Geology of the State of Baja California." Geological Society of America, Mem. 140, (1975).) Batholithic rocks intruded the accretionary wedge during the Cretaceous. The initial batholiths were emplaced across the western half of the Peninsular Ranges starting about 120 m.y. ago. The locus of magmatism was nearly static until about 105 m.y. ago when it began migrating eastward and eventually passed east of the Peninsular Ranges 85-90 m.y. ago (Silver and others, "Some Petrological and Geological Observations of the Peninsular Ranges Batholith Near the International Border of the U.S.A. and Mexico," in Mesozoic Crystalline Rocks Peninsular Ranges Batholith and Pegmatites Point Sal Ophiolite: Depart. of Geological Sciences San Diego State University, Abbott, P.L. and Todd, V.R., eds., pp. 83-110, (1979).) Batholithic emplacement was accompanied by uplift and erosion, but, by Late Cretaceous, subsidence along the western margin of the Peninsular Ranges permitted the sea to transgress eastward to form a rugged shoreline near the western margin of the batholithic intrusions (Figure PLE-A, "Block Diagram of Peninsular Ranges

During Cretacous"). As seen today, the eastern limit of Upper Cretaceous marine strata forms a relatively straight line from the Santa Ana Mountains at the northwest corner of the Peninsular Ranges to the Vizcaino Peninsula in Baja, California. Gastil and others (supra at 47) refer to this as the Santillan and Barrera line (Figure PLE-B, "Location of Santillan and Barrera Hinge Line"). The line was originally thought of as the eastern edge of a geosynclinal basin analogous to the Great Valley of California but in terms of modern nomenclature we would refer to it as a forearc basin. The Santillan and Barrera line is a tectonic hinge line separating the thick, buoyant, dominantly batholithic continental crust to the east from the westward-thinning, accretionary wedge which adjoins oceanic crust to the west. Downwarping to the west of this line was probably controlled primarily by isostatic adjustments and proceeded gradually through time, probably in response to loading by sediments eroded from the continent to the east of the line.

During the period 90-20 m.y. ago, from the Late Cretaceous through the Early Miocene, the position and configuration of the coastline varied slightly, probably as a result of fluctuations in

relative sea level and minor crustal warping. During the Eocene approximately 40 m.y. ago the coast transgressed landward across the Santillan and Barrera line but most of the time it was on the seaward side of the line. During the Early Miocene (about 20 m.y. ago) the shoreline was immediately west of SONGS and trended north-northwesterly across the present Capistrano Embayment as shown diagramatically in Figure PLE-C, "Location of Coastline During Early Miocene About 20 m.y. Ago" (see Campbell, R.H. and Yerkes, R.F. "Cenozoic Evolution of the Los Angeles Basin Area - Relation to Plate Tectonics": Pacific Section of American Association of Petroleum Geologists and Petrologists: Misc. Pub. 24, pp. 541-558, (1976).) At that time the Vaqueros Formation was deposited under shallow marine conditions on the seaward side of the shoreline while the continental Sespe Formation was deposited on the landward side.

At the beginning of the Middle Miocene (about 16 m.y. ago) conditions changed radically along the southern California coast and adjacent offshore borderland. The change may have been brought on by passage of the East Pacific Rise beneath this part of the continental margin or by divergent transform faulting postdating the overriding of the rise.

The major changes included: 1) the sudden appearance of Catalina Schist at the surface in the area offshore from the present coast with local shedding of schist debris in a northerly to easterly direction to form the onshore occurrences of the San Onofre Breccia; 2) widespread volcanism including volcanic intrustions within and to the north of the San Joaquin Hills; and 3) crustal extension and fragmentation causing the initial opening of the Los Angeles Basin (Figure PLE-D, "Paleogeography in Middle Miocene About 15 m.y. Ago"; (see Stuart, C.J. "Middle Miocene Paleogeography of Coastal Southern California and the California Borderland -- Evidence from Schist-bearing Sedimentary Rocks", in Cenozoic paleogeography of the Western United States, Pacific Section, SEPM, pp. 29-44, (Armentrout, Cole and Terbist, eds., 1979) and the development of northwest-trending ridges and basins in the Southern California Continental Borderland. PLE-E, "Known Distribution of San Onofre Breccia and Probable Northeastern Limits of Catalina Schist Basement" shows the distribution of San Onofre Breccia which consists of Catalina Schist debris and the probable landward limit of schist bedrock. The juxtaposition of the schist against Peninsular Range basement is significant because the two formed in very different

environments. The juxtaposition is important because the two formed in very different environments and were probably brought together by lateral faulting. Whereas the Peninsular Ranges basement formed in a shallow continental environment by emplacement of batholithic magma believed to be derived from a subduction zone undergoing partial melting at a depth of 125 to 175 km below the surface, the Catalina Schist experienced low temperature, high pressure metamorphism characteristic of a subduction zone at a depth of 30 to 40 km (Platt, J.P., "The Petrology, Structure, and Geologic History of the Catalina Schist Terrane, Southern Terrain, Southern California"; in 112 Univer. Calif. Publ. Geol. Sci., (1976)). The limited available data indicates the schist was metamorphosed synchronous with emplacement of batholithic rocks (Platt, J.P., Stuart, C.J., Suppe, J. and Armstrong, R.L., "Potassium Argon Dating of Franciscan Metamorphic Rocks: 272 American Journal of Science, 217-233, (1972)).

In the area offshore from SONGS the contact between the two terranes is likely to lie along the OZD but the presence of a thick sedimentary cover inhibits verification. The greatest known thickness of San Onofre Breccia is exposed on San Onofre

Mountain east of SONGS where it was deposited on a piedmont alluvial fan (Figure PLE-F, "Idealized Block Diagram, Deposition of the San Onofre Breccia"). Details of its depositional environment in the SONGS area are described by me in "Miocene Stratigraphy and Depositions, Environments of the San Onofre Area and Their Tectonic Significance" (in Stuart, C.J., A Guidebook to Miocene Lithofacies and Depositional Environments, Coastal Southern California and Northwestern Baja California, pp. 43-51, (1979)) and by Stuart, C.J., in "Middle Miocene Paleography of Coastal Southern California and the California Borderland - Evidence from Schist-Bearing Sedimentary Rocks", (in Cenozoic Paloegeography of the Western United States, Pacific Section, SEPM, pp. 29-44 (Armentrout, Cole and Terbest, eds., (1979)).

Volcanism was wide spread within southern California during the Middle Miocene but in the region around SONGS it occurred mainly within and to the north of the San Joaquin Hills. Here, the volcanic rocks occur as flows and pyroclastic debris interbedded with the Topanga Formation and as intrusions along faults (Vedder and others, "Geologic Map and Cross Section of the San Joaquin Hills - San Juan Capistrano area, California; U.S.

Geological Survey Open - File Maps 75-552, (1975)). A southward plunging domal uplift developed in the San Joaquin Hills and the area to the north simultaneous with emplacement of volcanic rocks. McCulloh has mapped a steep-gradient positive gravity anomaly over this area. (McCulloh, T.H., "Gravity Variations and the Geology of the Los Angeles Basin of California," U.S. Geological Survey Research, Professional Paper 400-B, p. B-325, (1960)). Although McCullch suggested the anomaly might be caused by a gabbro intrusion in the underlying basement, it appears more likely that the area is underlain by a shallow laccolith of Middle Miocene age.

A microfaunal analysis of the Topanga Formation in the northwestern San Joaquin Hills indicates water depths increased from about 250 m (800 ft.) at the start of the Middle Miocene (16 m.y. ago) to about 1800 m (5900 ft.) in late Middle Miocene (about 14.5 m.y. ago) as determined by Ingle (Ingle, J.C., "Biostratigraphy and Paleoecology of Early Miocene through Early Pleistocene Benthonic and Planktonic Foraminifera, San Joaquin Hills - Newport Bay - Dana Point Area, Orange County, California," in Stuart, C.J., supra, pp. 53-78, (1979).) (Figure PLE-G "Bonita Canyon -

Paleobathymetry Correlation"). This reflects the initial opening of the Los Angeles Basin. As subsidence progressed throughout the area and a silled basin with oxygen-deficient bottom water developed, sedimentation changed to the laminated diatomaceous shale of the Monterey Formation and the paleobathymetry changed as shown in Figure PLE-H "Newport Bay - Paleobathymetry Correlation". Along the coast southeast of SONGS, shale in the Monterey Formation interfingers with massive sandstone deposited as small submarine fans. This reflects the presence of a relatively steep submarine slope along the western margin of the Peninsular Range perhaps controlled isostatically by a thinner crust west of the OZD.

Q. Subsequent to the Middle Miocene period, described above, were there any significant changes in geologic structure or stratigraphy?

A. Yes.

Q. Would you describe those changes?

A. During the Late Miocene, (approximately 10 m.y. ago) the Cristianitos fault began to move in association with subsidence in the Capistrano Embayment as described by me in "The Late Cenozoic Evolution of the Capistrano Embayment" (<u>Geologic Guide of San Onofre Nuclear Generating Station and Adjacent</u>

Regions of Southern California, Pacific Sections AAPG, SEPM, and SEG, Fife, D.L., ed., pp. 38-47, (1979)). The surface trace of the Cristianitos fault is subparallel to the Santillan and Barrera line and lies at an average distance of about 6 miles (10 km) west of it. As interpreted here, the Cristianitos fault is a westward-facing listric, normal fault which passes downward into a bedding-plane fault within the lower part of the post-batholithic Cretaceous strata or underlying Santiago Peak Volcanics which contain interfingered marine shale. Structural factors controlling the Cristianitos fault would be the westward dip of the deep strata and the eastward pinchout of clay-rich strata which might serve as surfaces of low shear strength during gravity gliding. The dip of the strata would be essentially perpendicular to the Santillan and Barrera line and the dips would be steeper at the base of the sedimentary sequence than near the top because of progressive westward tilting through time.

Movement on the Cristianitos fault started when the area was below sea level and is marked by a change in sedimentation from the dominantly laminated diatomaceous strata of the Monterey Formation to the poorly bedded mudstone, siltstone

and sandstone of the Capistrano Formation. Beds within the two formations are concordant and are gradational in lithology within the interior of the embayment but are discordant and change abruptly from shale to sandstone adjacent to the Cristianitos fault. During deposition of the Capistrano Formation, two large submarine fans had their heads along the base of a west-facing submarine scarp along the Cristianitos fault. One is in the northeastern part of the Capistrano Embayment and is represented by massive sandstone of the Oso Member of the Capistrano Formation. Here, conglomeratic sandstone of the Oso Member rests upon a scoured surface cut on slightly upturned beds of Monterey shale. The sand of the Oso Member was probably fed into the area by the ancestral Trabuco Creek which probably drained a large area some 50 km northeast of SONGS, in the Perris region. The second submarine fan had its head along the Cristianitos fault in the area between SONGS and San Mateo Creek and, although its massive sandstone is referred to as the San Mateo Formation, it interfingers with and is part of the Capistrano Formation. The coarsest part of the fan-head deposits is restricted to a small area between San Onofre and San Mateo Creeks. This suggests that the fan was fed by a submarine

canyon cut into the fault scarp along the Cristianitos, probably by the ancestral San Mateo Creek which may have drained a large area extending some 50 km northeast of SONGS in the Perris region during the Late Miocene.

Simultaneous with the development of the Capistrano Embayment, the Los Angeles Basin deepened rapidly in the vicinity of Newport Bay on the west side of a submarine ridge which occupied the present position of the San Joaquin Hills. Faunal analyses by Ingle (supra) indicate water depths were at least 3,000 m (9840 ft.) in the Newport Bay area during the Late Miocene (PLE-H). At the same time water depths were a maximum of 2,500m (8,200 ft.) in the Dana Point-Capistrano area at the mouth of the Capistrano Embayment (Figure PLE-I, "Capistrano-Dana Point-Paleobathymetry Correlation"). The paleogeography for this period is shown in Figure PLE-J, "Paleography of Capistrano Embayment Area About 8 m.y. Ago". The arrangement of the Doheny and San Mateo submarine fans indicates a relatively steep south-facing submarine slope existed at the mouth of the Capistrano Embayment with a deep ocean basin to the south.

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Q. Would you please discuss the development of the Cristianitos fault in the context of the regional geology?

A. Movement on the Cristianitos fault and extension within the Capistrano Embayment is also probably the result of gravity gliding in a westward direction into the Los Angeles Basin. That the Cristianitos fault is a west-facing normal fault can readily be seen in the coastal exposure southeast of SONGS. Here, the fault dips 57 degrees west with slickensides oriented down the dip. The west side is down and reverse drag on the downthrown side indicates a flattening of the fault plane with depth (Ehlig, P.L., "Geotechnical Studies Northern San Diego County, October, 1977, Consultants Report to Southern California Edison Company and San Diego Gas and Electric Company," (1977)). (Figure PLE-K, "Reverse Drag Features at the Cristianitos Fault".) Similar features exist along the fault within the Capistrano Embayment. For example, cross section C-B by West (West, J.C., "Generalized Sub-Surface Geological and Geophysical Study, Capistrano Area, Orange County, California": Consultants Report to Southern California Edison Company and San Diego Gas and Electric Company, (1975)) Figure PLE-L, ("A Portion of a Geologic Section Across the Capistrano

Area") shows reverse drag on the down side (west) of the fault. Figure PLE-L indicates bedding has a regional dip of about 15 degrees west along the base of the Cretaceous to the east of the Cristianitos fault thus providing a structure suitable for westward sliding. Although Figure PLE-L indicates gentle dips along the base of the Cretaceous beneath the Capistrano Embayment, structural control is restricted to the upper half of the sedimentary sequence. The base of the Cretaceous sediments is likely to continue to dip westward beneath the Capistrano Embayment as a result of westward thickening and the addition of older strata at the base of the sequence in the seaward direction from the Santillan and Barrera line. The base of the Cretaceous may also dip westward beneath the San Joaquin Hills structural high if the domal uplifting of the high was the result of a Middle Miocene laccolithic intrusion as appears likely.

The Cristianitos fault is likely to flatten with depth and become a bedding plane fault near the base of the Cretaceous sediments. Movement on the Cristianitos fault was probably caused by gravity gliding of the hanging wall block and was the result of inadequate lateral support within the Los Angeles Basin where the ocean floor was very deep and where

the westward continuation of the Middle Miocene and older rocks of the Peninsular Ranges had been removed by crustal extension and/or strike-slip faulting.

It should be noted that Los Angeles Basin had a different configuration during the Late Miocene and Early Pliocene than at present. A deep trough extended southward across the present coast to the west of the San Joaquin Hills structural high whereas a northwest-trending structural high was subsequently developed along the landward slide of the coast to the west of the San Joaquin Hills. This is shown by the fact that Upper Miocene strata exposed above sea level on the west side of San Joaquin Hills were, according to Ingle, supra, deposited at an ocean depth of about 10,000 feet (3,000 m) whereas strata of the same age and probably deposited at about the same depth are presently 20,000 fee below sea level within the deepest part of the modern Los Angeles Basin. Vertical relief between the Capistrano Embayment and the Los Angeles Basin probably provided the driving force for the gravitational gliding. A contributing factor may have been loss of lateral support by deep-seated extension beneath the Los Angeles Basin.

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Q. Would you describe the amount of movement that is evident along the Cristianitos?

A. The displacement along the Cristianitos fault is greatest near the center of the Capistrano Embayment where West (supra) indicates the top of the Cretaceous strata have a stratigraphic separation of about 3500 feet with the west side down and decreases both to the north and to the south.

At the south end of the embayment near SONGS the Monterey Formation has a dip separation of about 600 feet across the Cristianitos fault as seen in Figure PLE-M, "Geologic Cross Section Between Onshore Borings". Displacement appears to die out completely several thousand feet offshore from SONGS.

Q. Are there other instances in the vicinity of San Onofre where faults were formed as a result of gravity gliding during the same time period?

A. Yes. The San Joaquin Hills to the west of the Capistrano Embayment contain several westward-facing normal faults which were active at the same time as the Cristianitos fault. A good example is the Pelican Hill fault shown in Figure PLE-N, "Cross-Section Showing Pelican Hill Fault", by Vedder and others (Vedder, J.G., et al., "Preliminary Report of the Continental Borderland of Southern California," United States Geol. Survey,

Misc. Field Studies, Map MF-624, (1974)). The diagnostic features are: (1) the west side of the fault is down; (2) the fault surface dips westward and the dip of the fault surface flattens with depth, and (3) there is reverse drag along the down thrown side of the fault. In essence, the fault functioned as the base of a large landslide with the overlying strata sliding westward toward the Los Angeles Basin.

Q. Is there a structural relationship between the Cristianitos Fault and the OZD?

A. No. The Cristianitos fault dies out in the near shore area before reaching the OZD. A likely mechanical reason for its dying out is because of a change in the physiographic and geologic structure which existed in the vicinity of the present coast during the Late Miocene and Early Pliocene. In the inland area to the east of the Cristianitos, exposed bedrock consists mainly of Eocene and Cretaceous strata striking nearly parallel to the fault and dipping gently in a westerly to southwesterly direction. To the east of the fault near the coast the San Onofre Breccia forms the principal exposed bedrock. It strikes in northwesterly to westerly directions and dips seaward at angles typically ranging betwen 35 and 45 degrees along the south

flank of the San Onofre Mountains (Ehlig, supra). If a similar change in structure is present at depth to the west of the surface trace of the Cristianitos fault, it would tend to prevent gravity gliding toward the Los Angeles Basin in the area south of the present coast and the steep dip would tend to cause the Cretaceous beds to be buttressed in the offshore area. An alternate or complimentary possibility is that the downwarping of the coastal area southeast of the Cristianitos fault tended to reduce the gravitational driving force along the southern edge of the gravity glide block thereby causing displacement to die out in the offshore area.

Q. Have you reviewed the earthquake potential of the OZD?

A. Yes. I have reviewed it from the standpoint of what I consider to be the maximum earthquake likely to occur along it based on its features, geologic strain rate, and regional tectonic setting.

Q. One of the issues is whether M_s 7 is an appropriate maximum magnitude for earthquakes on the OZD. Do you believe M_s 7 is adequate?

A. Yes, I do for the following reasons:

1. The absence of extensive and/or throughgoing fault ruptures in near-surface strata along much of the OZD is typical of faulting associated with

earthquakes of less than about M_s 7. For larger earthquakes the high rate and large amount of ground displacement during such an earthquake would favor propagation of faults to the surface and would also favor extensive secondary faulting and lurching near the surface. For example, there is a lack of near-surface faulting in the vicinity of Dominguez Hill near the center of the NIZD. If M_s 7 or greater earthquakes had occurred in this area, I would expect extensive evidence of near-surface faulting.

2. As I interpret the regional tectonic setting, north-south compression and right lateral drag along the Big Bend in the San Andreas fault is causing widespread deformation within the upper crust to the west of the San Andreas. Displacement along the OZD is only one aspect of this deformation. Folding, broad arching, and other faulting is also occurring over a wide area. Because of this and the variability of rock types and geologic structures along the OZD, I would expect variations in the orientation and intensity of the stress field along the OZD. Because its strain rate is only about 0.5 mm per year, only a relatively small segment of the OZD is likely to have shearing stress at or near the elastic limit at any given time. Consequently,

I would expect strain release by localized earthquakes of less than M_s 7.

Q. Are you familiar with present-day theories of what is commonly called wrench tectonics?

A. Yes.

Q. Would you please describe your understanding of wrench tectonics theory?

A. The current theories of wrench tectonics are described by Wilcox, Harding and Seely in "Basic Wrench Tectonics", 57 American Assoc. Petroleum Geologists Bull., p. 74-96 (1973). They attempt to relate certain types and patterns of shallow folding and faulting to horizontal shearing strain within the underlying crystalline crust. Their interpretations are based on the deformation produced in clay models by moving tin sheets beneath a clay cake. Different styles of deformation are achieved by varying the sense and amount of strike-slip movement and by combining divergent or convergent motion with strike-slip motion.

The basic concepts of wrench tectonics have been known for several decades in association with studies of strike-slip faults but wrench terminology has become popular only recently, particularly among petroleum geologists. An understanding of the terminology is essential in order to comprehend the

strengths and weaknesses of the concepts. Some of the most important terms used by Wilcox and others, supra, are:

Wrenching - the process of deforming near surface rocks by horizontal shearing strain along a steeply inclined zone or fault within the underlying basement.

Wrench fault - a high-angle strike-slip fault of great linear extent which involves basement deformation.

Wrench zone - a swath of terrane deformed by wrenching prior to and concurrently with strike-slip along the throughgoing wrench fault.

The principal strength of the concepts and a significant reason for the present day interest in them is that they may permit the identification of zones of deformation along which petroleum-bearing structures may occur in a systematic pattern. The principal weakness of the concepts is that, aside from establishing a sense of shear, they do not deal with the nature, origin and causes of the deepseated basement deformation.

Among the most controversial aspects of wrench fault tectonics is the theory proposed by J. D. Moody and M. J. Hill (Moody, J. D. and Hill, M. J., "Wrench-fault tectonics", 67 Geol. Soc. America

Bull., p. 1207-1246 (1956)). According to their theory, the earth has been broken into major blocks bounded by first-order conjugate wrench faults formed by north-south (equator to pole) crustal compression. The major blocks were then broken into progressively smaller blocks by second-order and third-order conjugate wrench faults caused by reorientation of the stress field within blocks. Other types of deformation including thrust faults, compressional folds and drag folds are associated with the wrench faults. Their theory assumes (1) that crustal blocks are mechanically homogeneous with conjugate wrench faults forming at an angle of 30 degrees to the axis of compression and (2) that the local stress field has a constant orientation through time except for changes brought about by progressive development of higher order wrench faults. The weaknesses of this theory are discussed by Badgley (Structural and Tectonic Principles, p. 261-272 (1965)). The major weaknesses include:

(1) The basic premise of north-south global compression is incompatible with modern knowledge of plate tectonics.

(2) Local stress fields change orientation through time due to interactions between crustal plates. As a result, faults and folds formed during

one stage in the tectonic evolution of a region may be inactive during a later stage when other types of deformation may be taking place along new orientations.

(3) Most of the earth's crust is inhomogeneous with new ruptures tending to follow surfaces of weakness. Thus the geometry of the faulting is influenced by the fabric of the crust and not just the orientation of the stress field. Also, the assumed orientation of wrench faults at 30 degrees to the axis of compression requires crustal rocks to have a constant angle of internal friction of 30 degrees. Measured values are variable.

(4) The theory of Moody and Hill requires wrench faults to form as a result of horizontal compression in a system of non-rotational pure-shear. Wrench faults associated with plate boundaries, such as those in California, tend to form by simple-shear and may be associated with rotational and dilational motion.

Thus, although wrench tectonic concepts and models may be used to identify wrench zones underlain by deepseated strike-slip faults, the concepts are of little value when interpreting regional tectonic history.

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Q. Would you discuss how the OZD fits into the wrench tectonic system?

A. Assuming the OZD marks the boundary between the Peninsular Range basement and the Catalina Schist, the OZD originated about 15 or 16 m.y. years ago during the Middle Miocene. As indicated in my earlier testimony, the difference between the two basement terranes seems to require them to have formed at a considerable distance from each other and to have been brought together by faulting. Based on our knowledge of regional geology and plate tectonic reconstructions by Tanya Atwater ("Implications of Plate Tectonics for the Cenozoic Tectonic Evolution of Western North America", 81 Geol. Soc. America Bull. 3513-3536 (1970)), the OZD was probably part of a system of right-lateral faults which formed the Pacific-North American plate boundary within the California Continental Borderland during Middle Miocene. Thus, the OZD probably originated as a wrench fault. However, the San Andreas fault and its branches constitute the present plate boundary. Assuming the OZD is active, it is probably responding to the effects of crustal compression along the Big Bend in the San Andreas fault or to drag along the plate boundary. In either case, Quaternary deformation along the OZD is

a secondary effect of interaction between the Pacific and North American crustal plates and the theory of wrench-faulting is not applicable.

Q. Given your understanding of wrench tectonics do you see any basis for relating the onshore Cristianitos fault with the OZD?

A. No not at present, however, an indirect relationship may have existed when the Cristianitos was active 4 to 10 m.y. ago insofar as there may have been an inter-relationship between the OZD and faults involved in the opening of the Los Angeles Basin. However, as previously described by me, the Cristianitos fault is a westward dipping normal fault which developed as a result of the hanging wall block undergoing gravity gliding toward a deep submarine depression located in the vicinity of the present Los Angeles Basin. The submarine depression was formed by east-west crustal extension caused by divergent motion between the Pacific and North American crustal plates. The Los Angeles Basin stopped opening during the Pliocene about the same time that the Gulf of California began to open and the San Andreas fault began to take up most of the Pacific North American interplate motion in southern California. The Los Angeles Basin has subsequently filled with sediment and is currently experiencing

crustal shortening in a northeast and southwest direction. In the vicinity of the Capistrano Embayment shortening is causing upwarping near the coast and downwarping within the inland area as shown in Figure PLE-O, "Location of Axes of Quaternary Upwarping and Downwarping". Under existing conditions the Cristianitos fault is buttressed and cannot move. Consequently movement on the OZD would not cause movement on the Cristianitos fault.

Q. Have you investigated the onshore area between the Rose Canyon fault and the northern extent of the Vallecitos fault?

A. Yes. I have reviewed the literature, examined aerial photographs, and have made a limited geologic reconnaissance of the area.

Q. Do you have an opinion as to whether there is an association between those faults in that location?

A. My opinion is that there is no apparent association between the Rose Canyon fault and the Vallecitos fault. The northern end of the Vallecitos fault either dies out or is overlapped by Eocene conglomerate as reported by Gastil, Kies and Melius, ("Active and potentially active faults: San Diego County and northermost Baja California", in <u>Earthquakes and Other Perils, San Diego region: San</u>

Diego Assoc. of Geologists and Geol. Soc. America, Field Trip Guidebook, Abbott, P.L., and Elliott, W.J., eds., pp. 47-60 (1979)). I have examined aerial photographs of the 30 km interval between the most northerly mapped position of the Vallecitos fault and the U.S. border and find no lineament or other feature suggestive of a through-going fault along the projected trend of the Vallecitos fault as mapped in Plate 1-A by Gastil, Phillips and Allison in their book, "Reconnaissance Geology of the State of Baja California", Geological Society of America, Memoir 140, 1975. In a few places northeast-trending features, such as the margin of a batholithic intrusion, extend across the projected trend of the Vallecitos fault without visible offset.

Gastil, Kies and Melius, supra, discuss evidence for the "Tijuana lineament" which might be used to infer the presence of a concealed fault along the Tijuana Valley subparallel to, but northeast of, the Vallecitos fault. All of the evidence is equivocal and may result from causes other than a hypothesized fault along the Tijuana Valley. An examination of aerial photographs reveals no northwest trending feature where the hypothetical fault would have to pass through exposed basement terrane southeast of Rodriquez

Reservoir. This suggests the Tijuana lineament is not a fault-controlled feature.

Q. Have you investigated the area between the southern extent of the Vallecitos fault and the San Miguel fault?

A. Yes. I have reviewed geologic literature, examined aerial photographs, and made a field reconnaissance of selected parts of the area.

Q. In your opinion is there an association between those two faults in that location?

A. There is no apparent relationship between the Vallecitos fault and the San Miguel fault. The two faults have subparallel trends but remain about 7 km apart at their closest approach, Figure PLE-P. ("A Portion of A Geologic Map of Northern Baja California" [reference: Gastil, Phillips, and Allison, supra].) Although neither fault appears to have a maximum displacement of more than a few hundred meters, the Vallecitos fault appears to have little or no displacement along it opposite to where the San Miguel fault dies out north of Valle San Rafael. The Vallecitos fault appears to be an old inactive fault with no evidence of cutting anything younger than Mesozoic basement rocks as has also been pointed out by Gastil, Kies and Melius, supra.

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My investigation indicates that the San Miguel fault terminates near the northwest corner of Valle San Rafael. The fault trends northwestward into this area as seen in aerial photographs and on Figure PLE-P. The fault is within schist terrane bounded on the northeast and southwest by elliptically-shaped granitic intrusions. Several northward-trending, steeply-inclined Mesozoic dikes are present within the schist terrane. One dike was traced for 8 km in the field. The overlapping arrangement of the dikes precludes the existance of northwest-trending strike-slip faults of significant displacement within the area between the two granitic intrusions. The granitic intrusion to the southwest contains northeast-trending joints and minor faults along with other structural features which indicate no northwest-trending faults extend across the granitic intrusion's 10 km width.

The granitic intrusion to the northeast of the terminous of the San Miguel fault lacks northwest-trending features suggestive of faults except in the northeastern part where the linear arrangement of erosional features marks the location of the Vallecitos fault as mapped by Gastil, Phillips and Allison (supra). Their map (supra, 1975, Plate 1-A) shows a 3 km right-separation of

the intrusion's northern margin where it is cut by the Vallecitos fault. In order to verify the displacement, I traversed along more than 10 km of the fault in this area. Although the mapped trace of the fault is well marked by canyons and other topographic features, geologic contacts appear to extend across the trace without detectible offset. Along the north side of the intrusion in the area shown as schist in Figure PLE-P, the area is underlain by granitic rocks, including numerous dikes. On the east side of the intrusion, granitic dikes interspersed with gabbro appear to extend without interruption across the mapped trace of the fault. A strong linear color contrast visible on aerial photographs of this area marks the contact where old deeply weathered alluvial deposits abut against bedrock along the former margin of a steep-sided valley. Thus, on the basis of my observations, the Vallecitos fault lacks significant displacement in this area.

In summary, my findings based on photointerpretation and field observations not only indicate that there is no relationship between the Vallecitos and San Miguel faults but also indicate an absence of significant strike-slip faults crossing this part of Baja California.

DR. PERRY L. EHLIG

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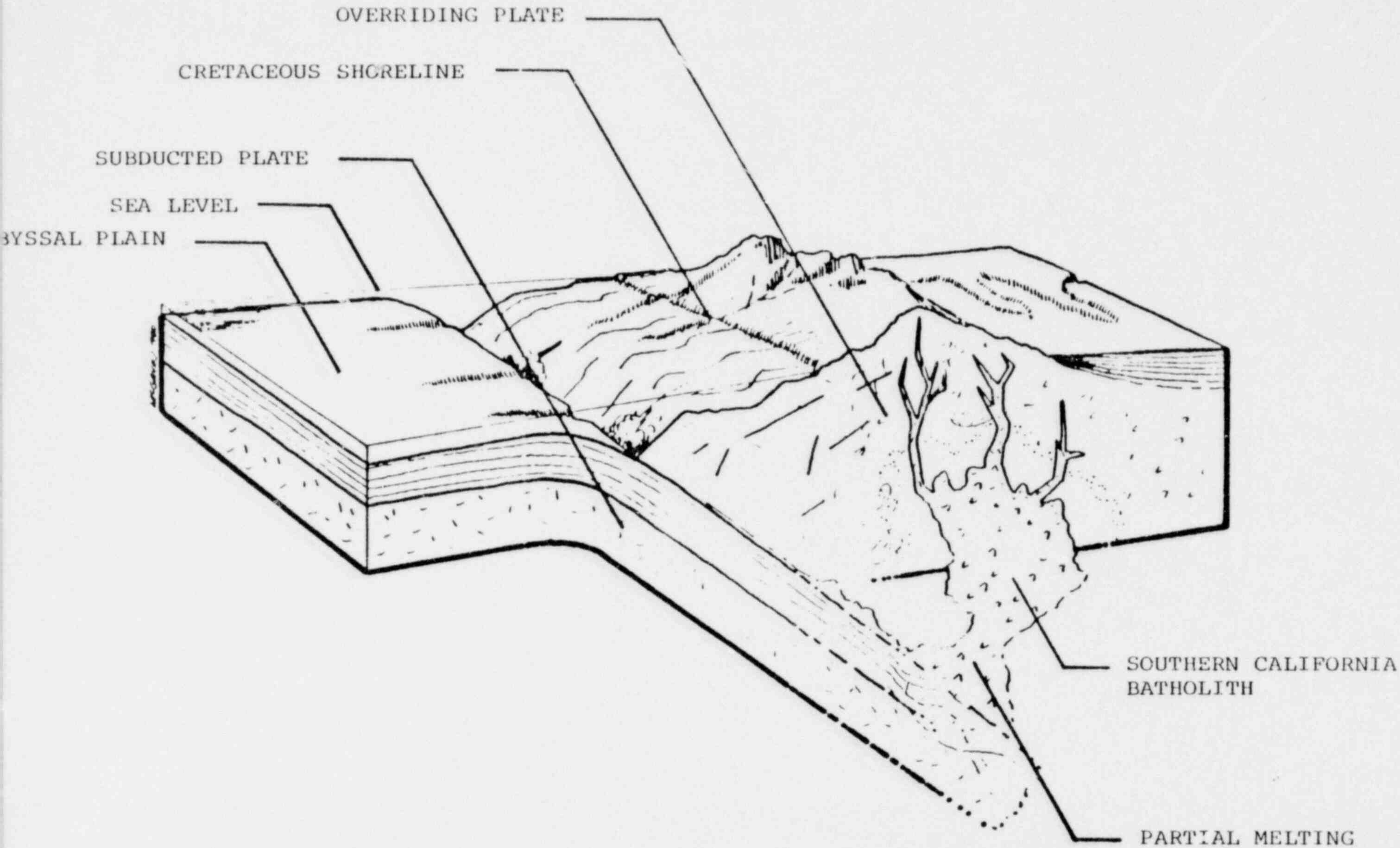
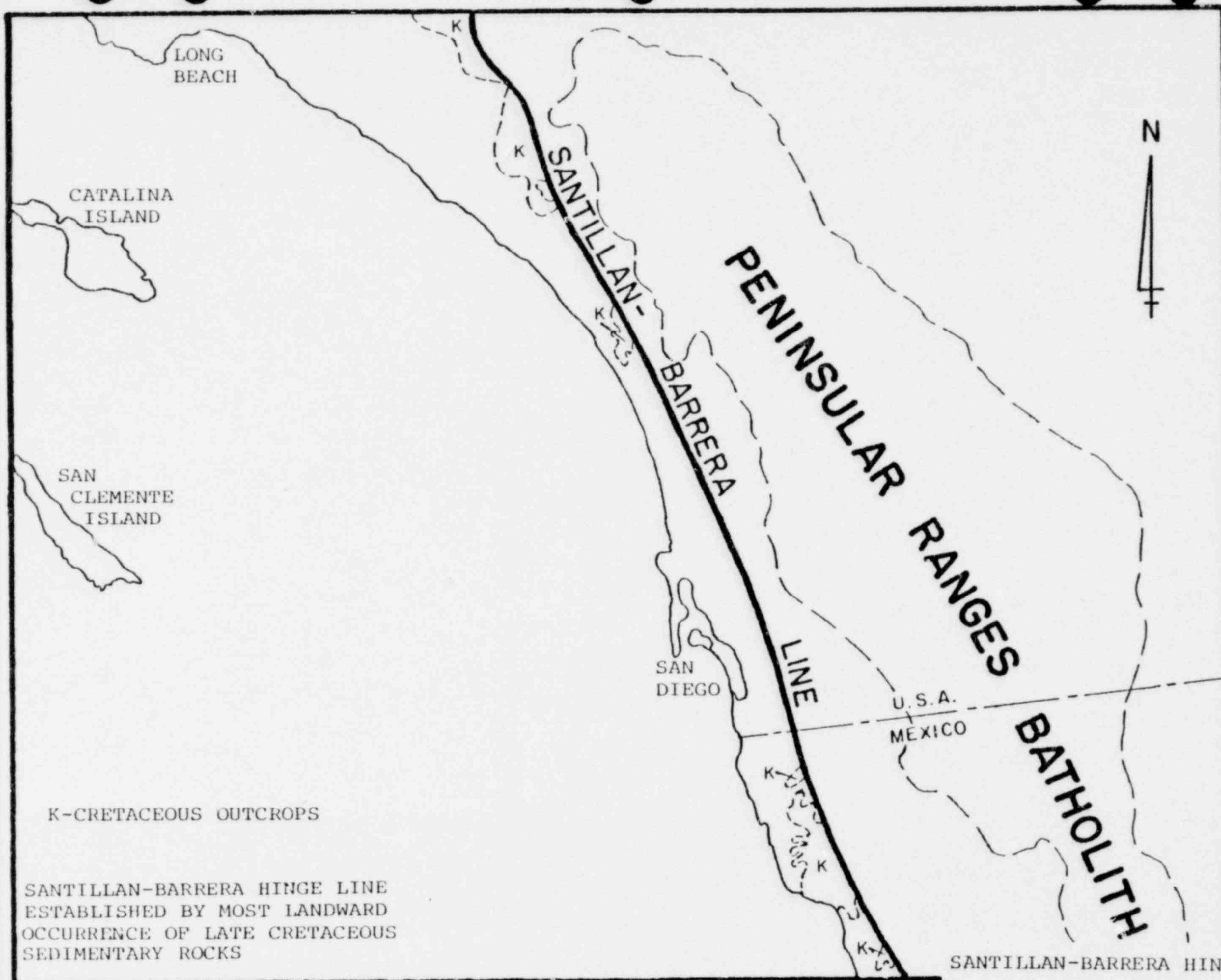


IDEALIZED BLOCK DIAGRAM
CRETACEOUS TIME

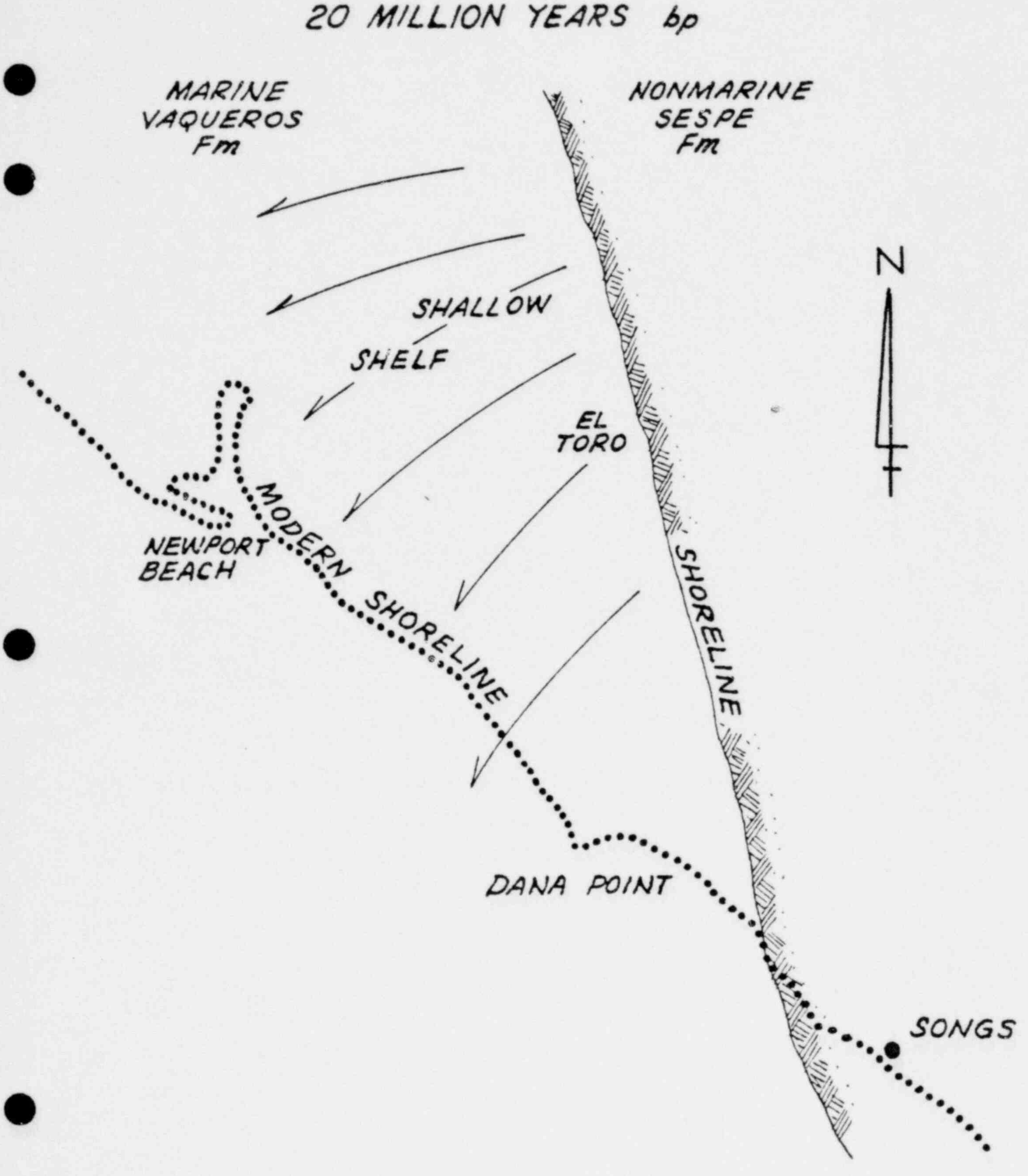
BLOCK DIAGRAM OF PENINSULAR RANGES DURING
CRETACEOUS (VERTICAL SCALE EXAGGERATED)

FIGURE PLE-A



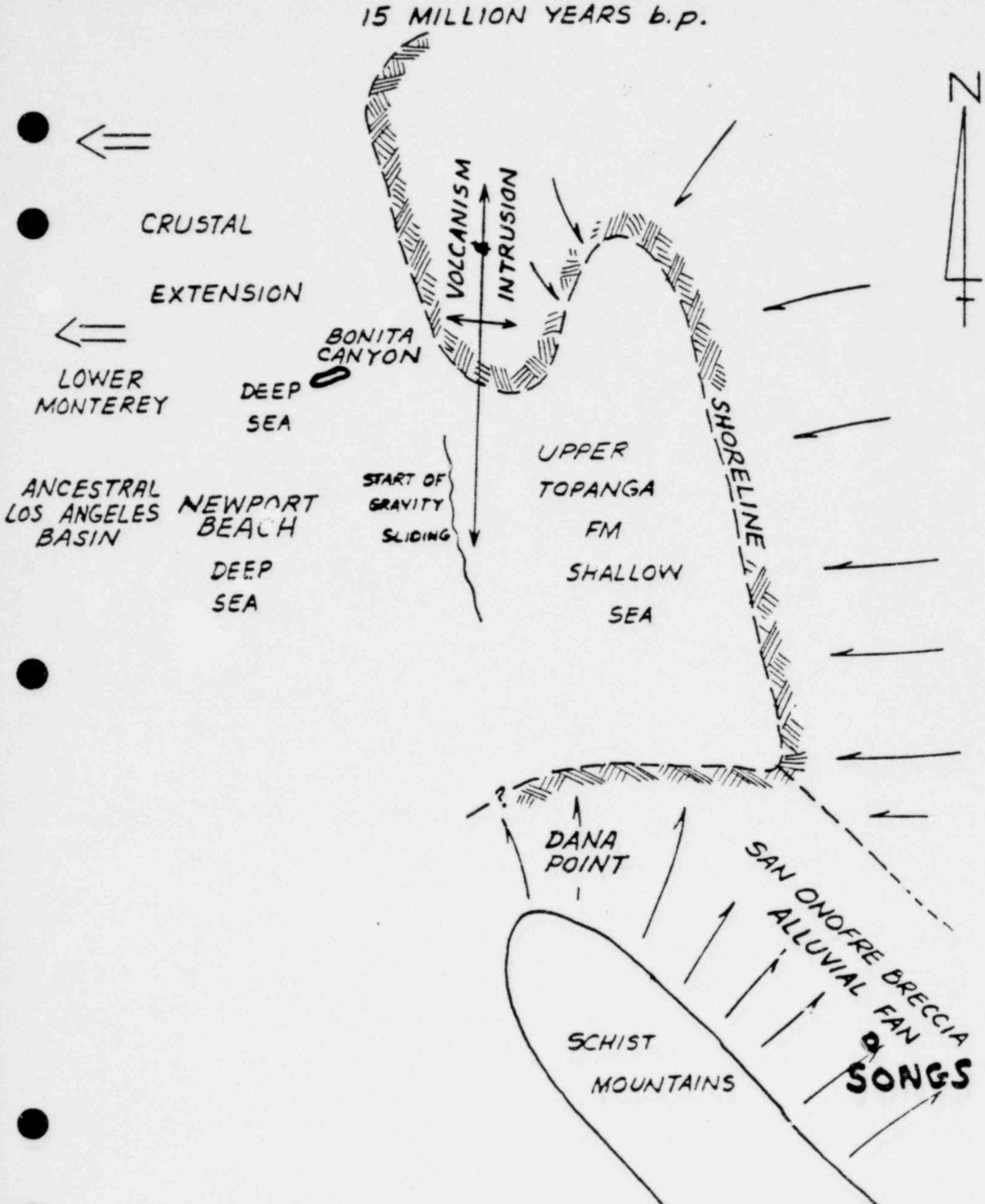
SANTILLAN-BARRERA HINGE LINE

Figure PLE-B



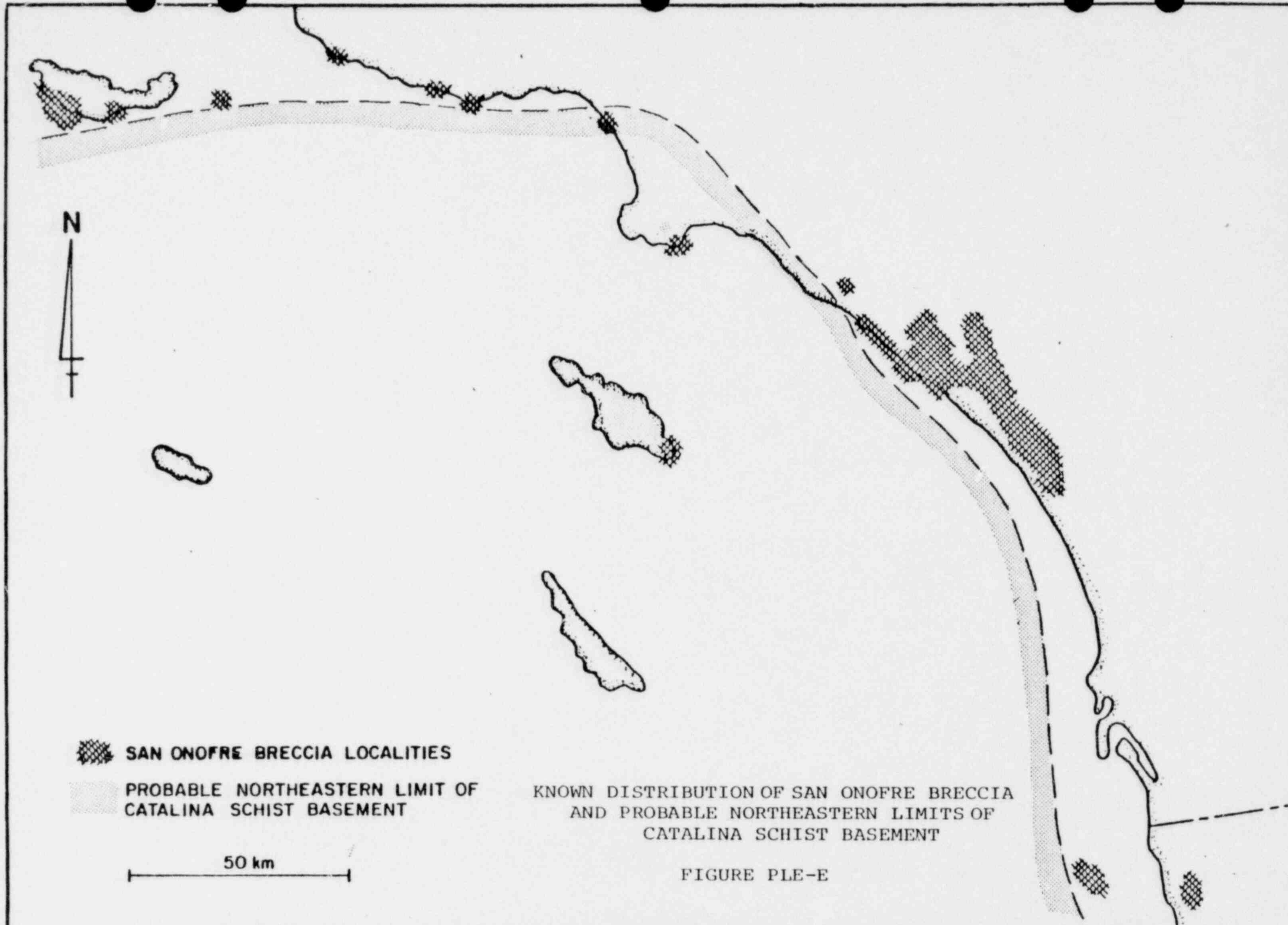
LOCATION OF COASTLINE DURING EARLY MIOCENE, ABOUT 20 M.Y. AGO

FIGURE PLE-C



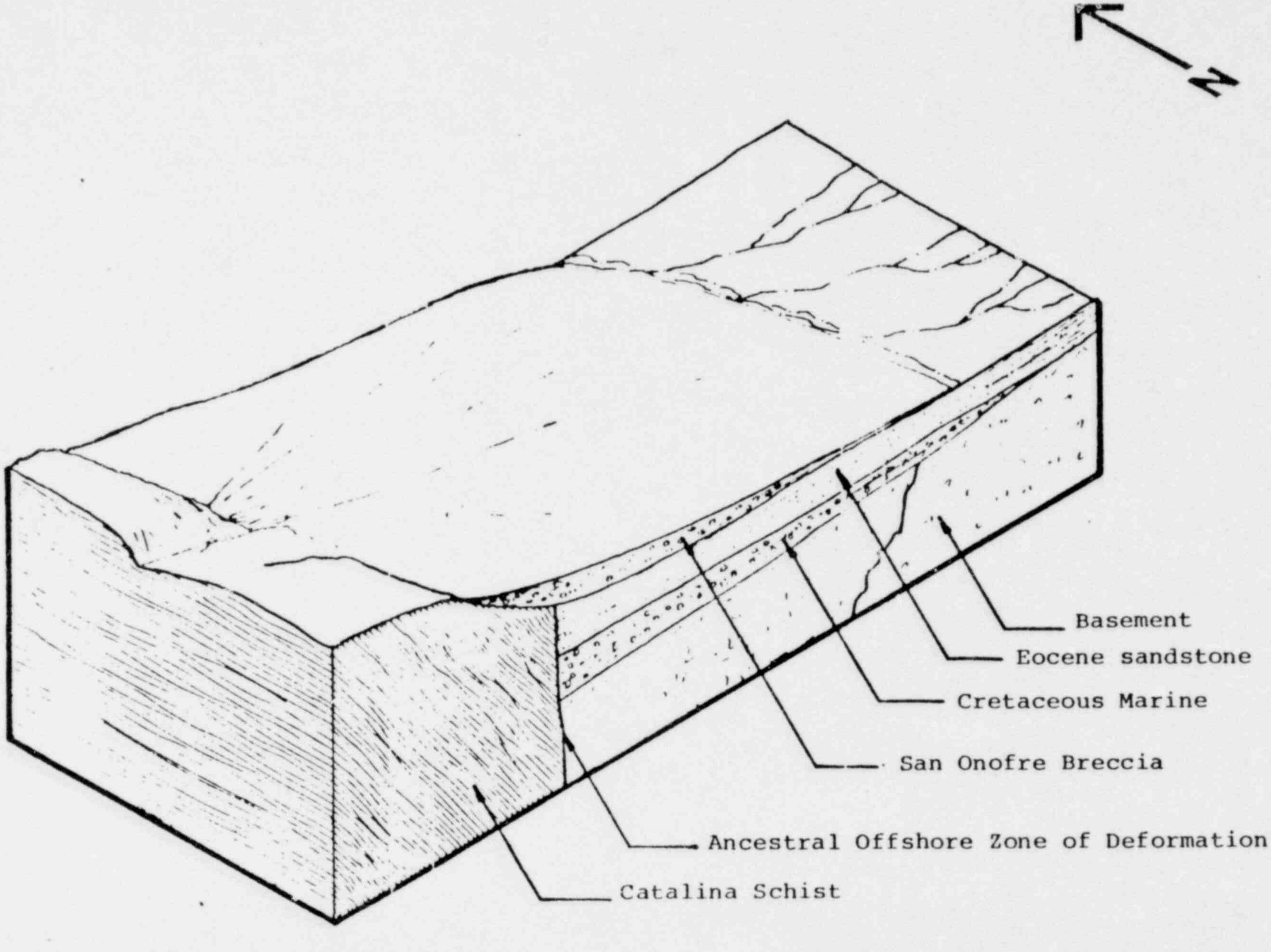
PALEOGEOGRAPHY IN MIDDLE MIOCENE
ABOUT 15 M.Y. AGO

Figure PLE-D



KNOWN DISTRIBUTION OF SAN ONOFRE BRECCIA AND PROBABLE NORTHEASTERN LIMITS OF CATALINA SCHIST BASEMENT

FIGURE PLE-E

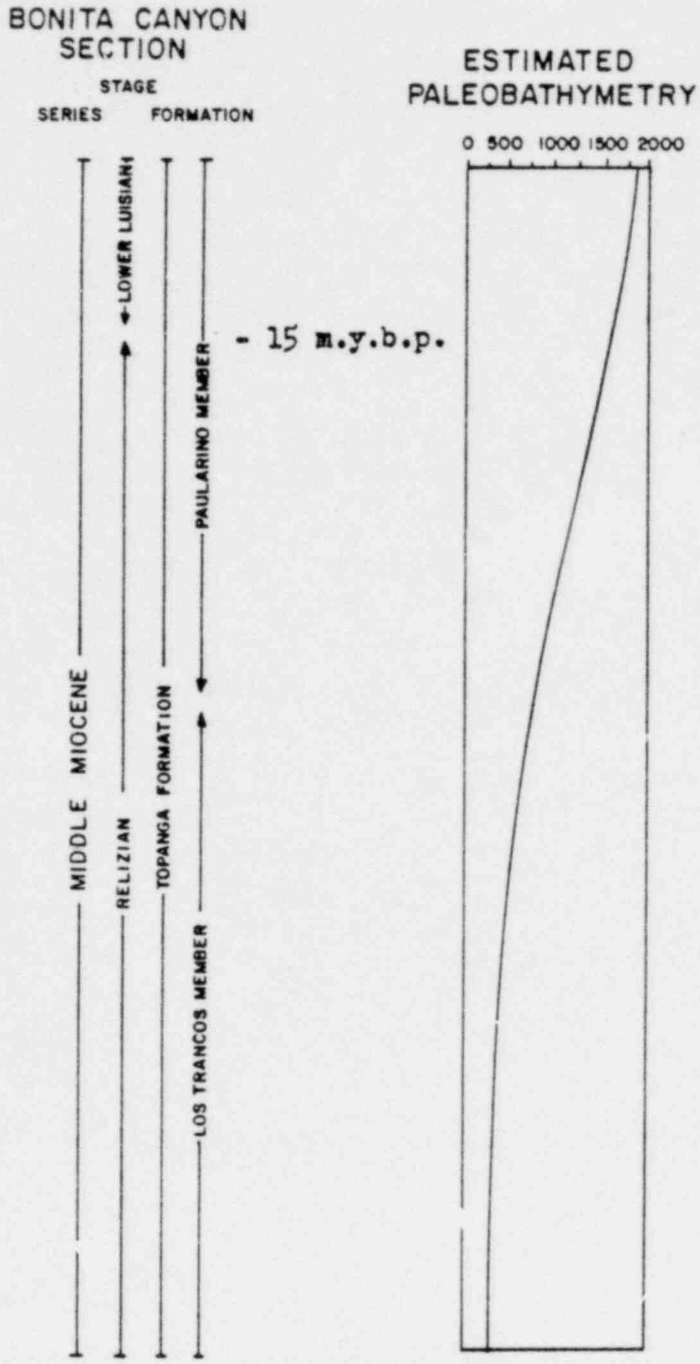


IDEALIZED GEOLOGIC BLOCK DIAGRAM
DEPOSITION OF THE SAN ONOFRE BRECCIA

IDEALIZED GEOLOGIC BLOCK DIAGRAM,
DEPOSITION OF THE SAN ONOFRE BRECCIA

FIGURE PLE-F

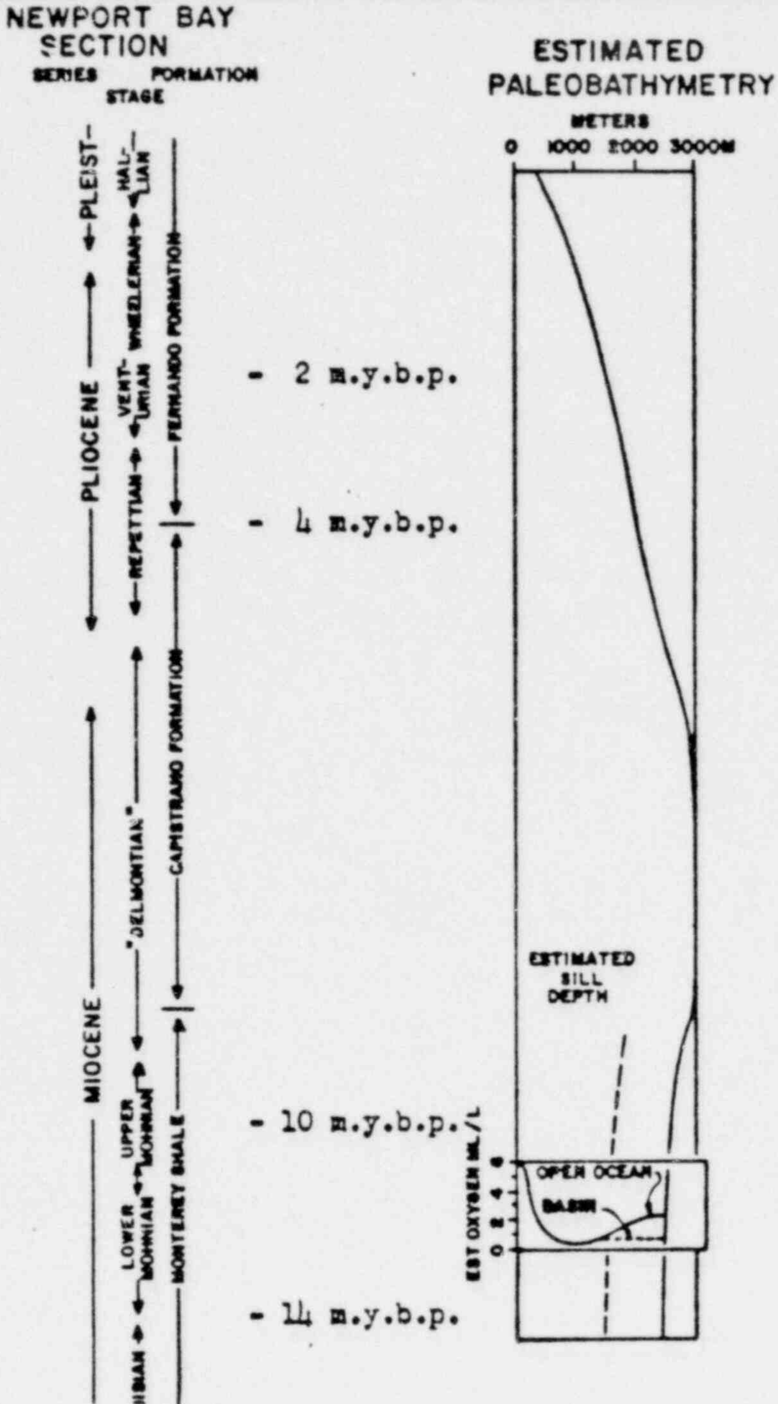
WESTERN SAN JOAQUIN HILLS



(after Ingle, 1979)

BONITA CANYON-PALEOBATHYMETRY
CORRELATION

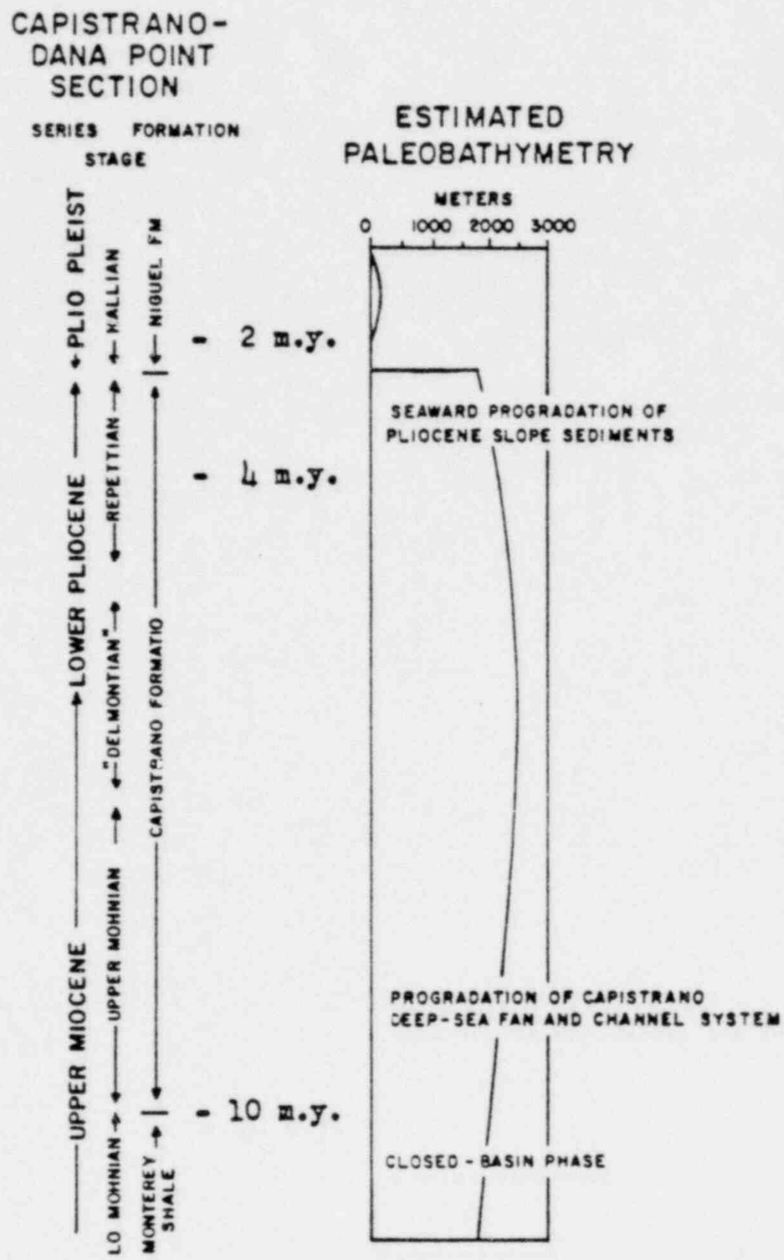
FIGURE PLE-G



(after Ingle, 1979)

NEWPORT BAY-PALEOBATHYMETRY CORRELATION

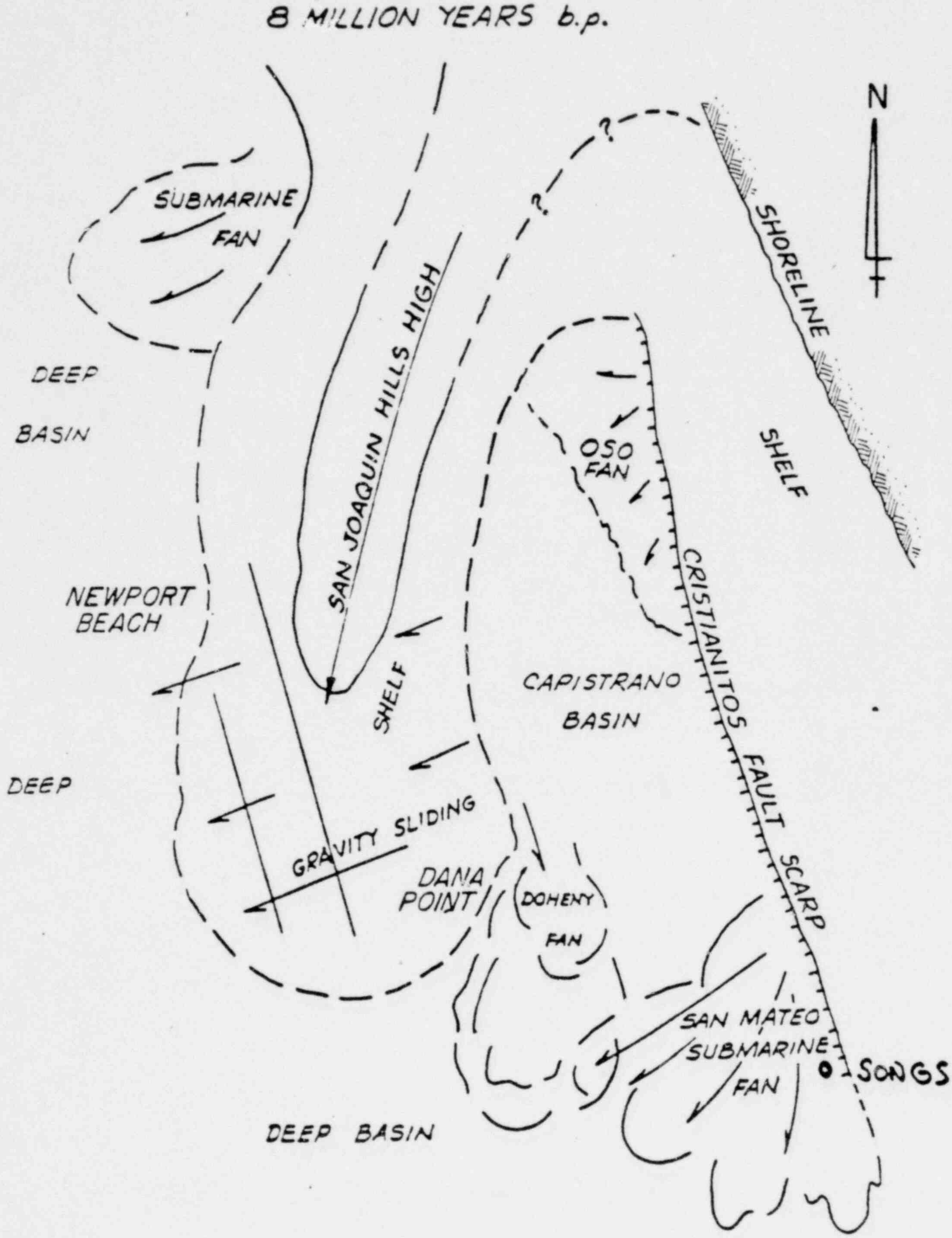
FIGURE PLE-H



(after Ingle, 1979)

CAPISTRANO-DANA POINT PALEOBATHYMETRY CORRELATION

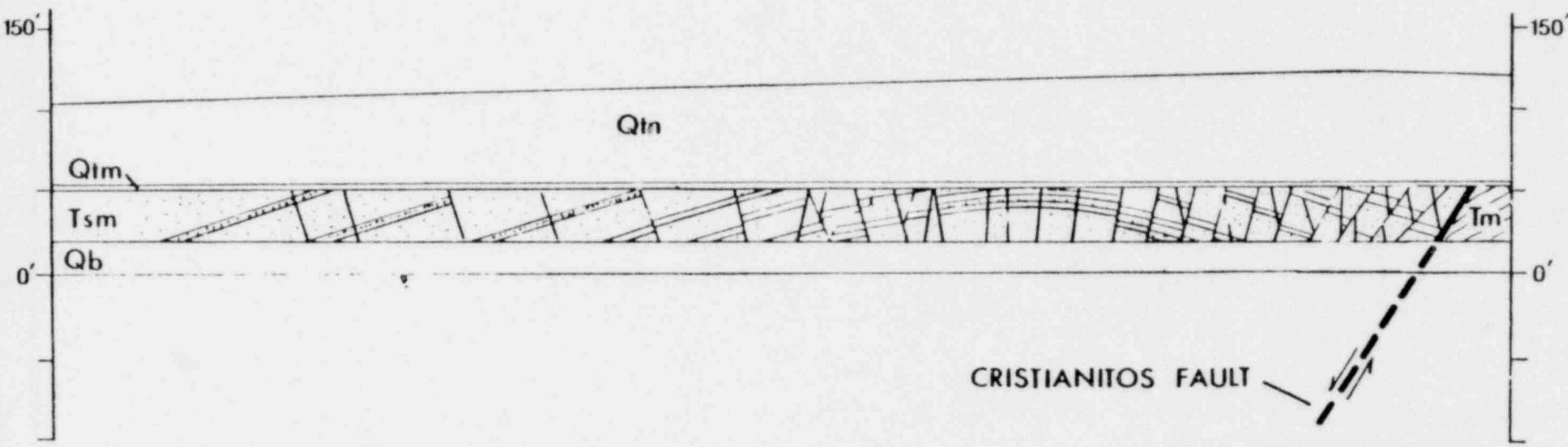
FIGURE PLE-I



PALEOGEOGRAPHY OF CAPISTRANO
EMBAYMENT AREA ABOUT 8 M.Y. AGO

FIGURE PLE-J

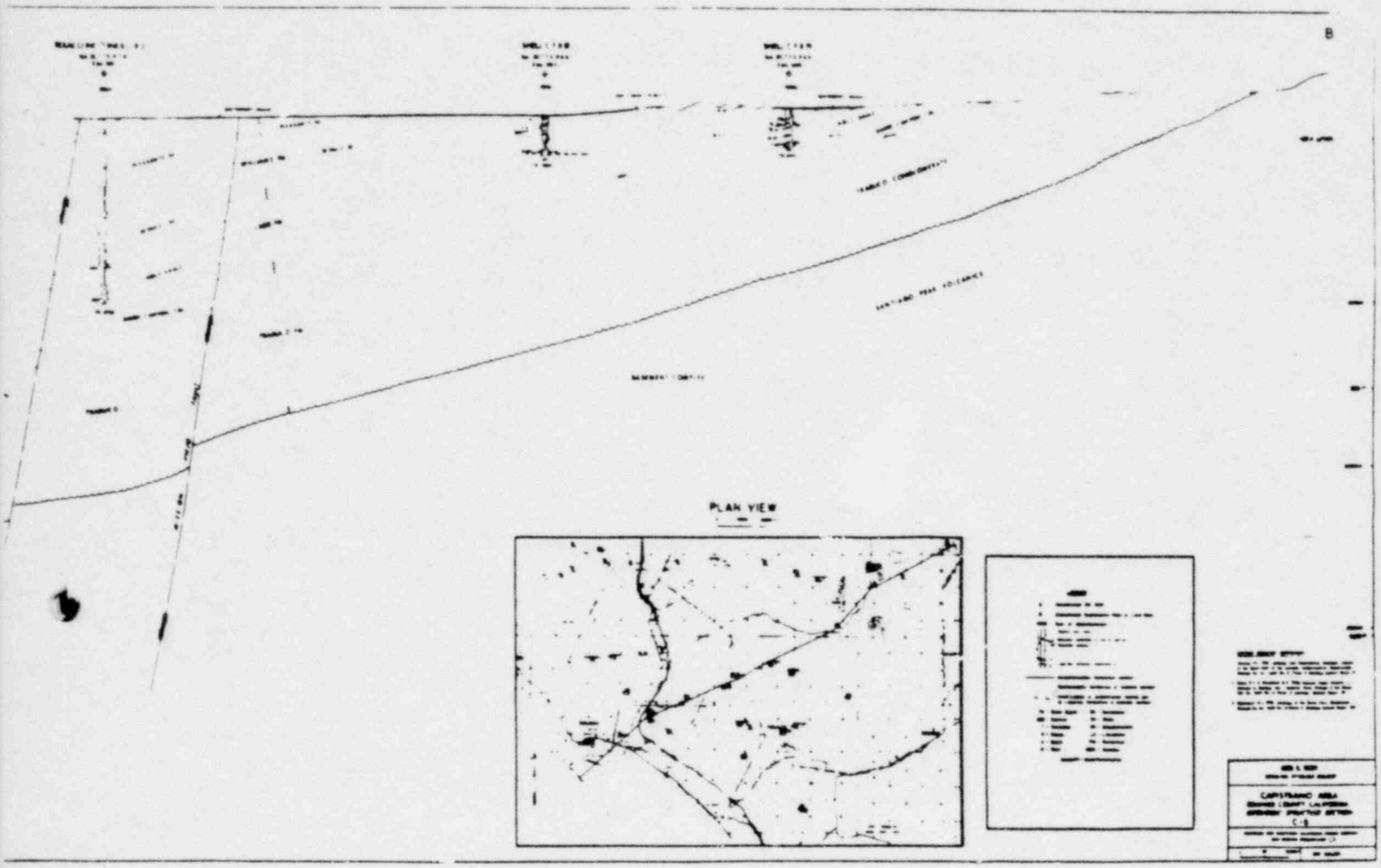
REVERSE DRAG FEATURES AT THE CRISTIANITOS FAULT
LOOKING NORTH



SCALE: 1" = 100'

REVERSE DRAG FEATURES AT THE
CRISTIANITOS FAULT

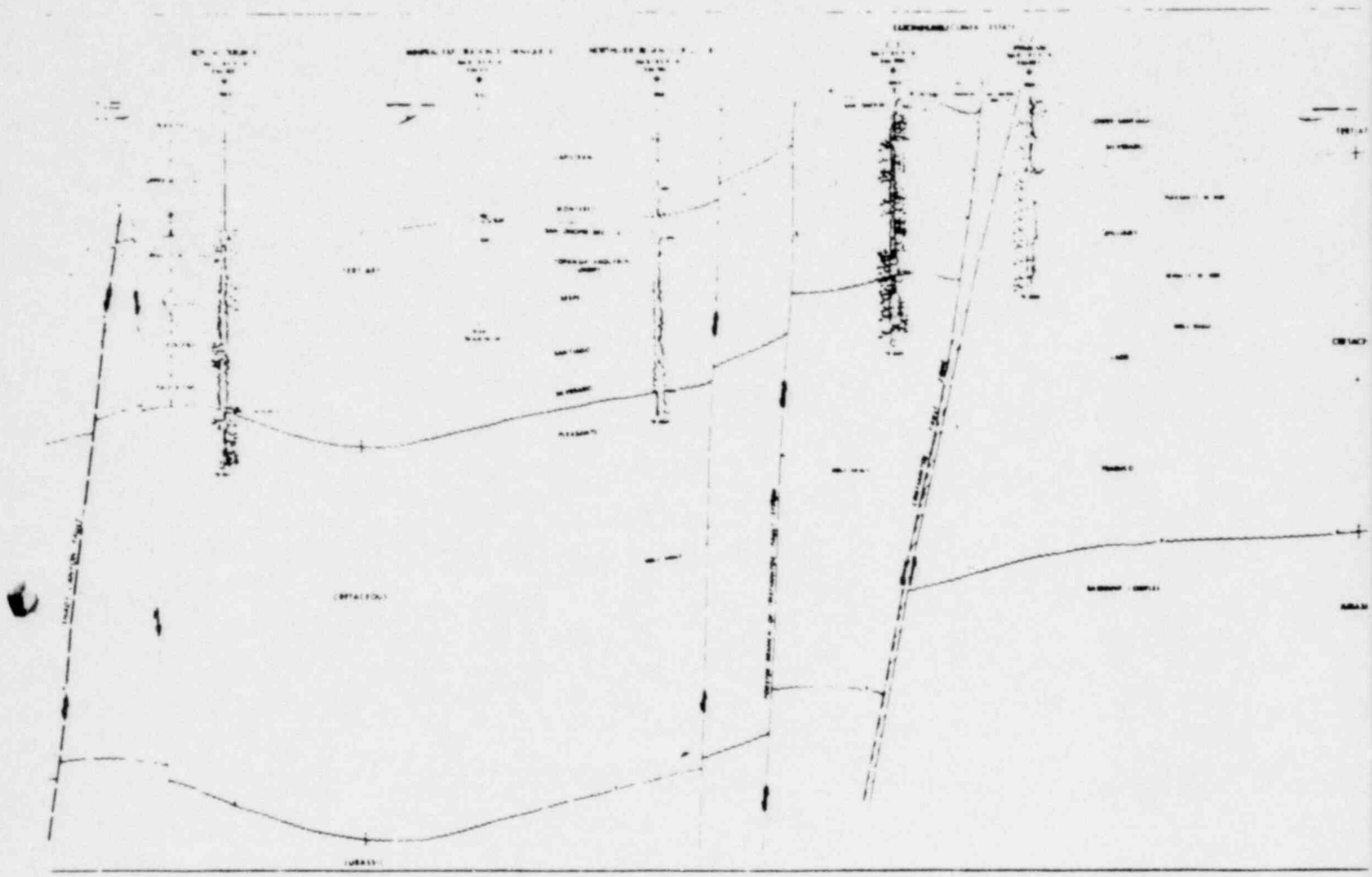
FIGURE PLE-K

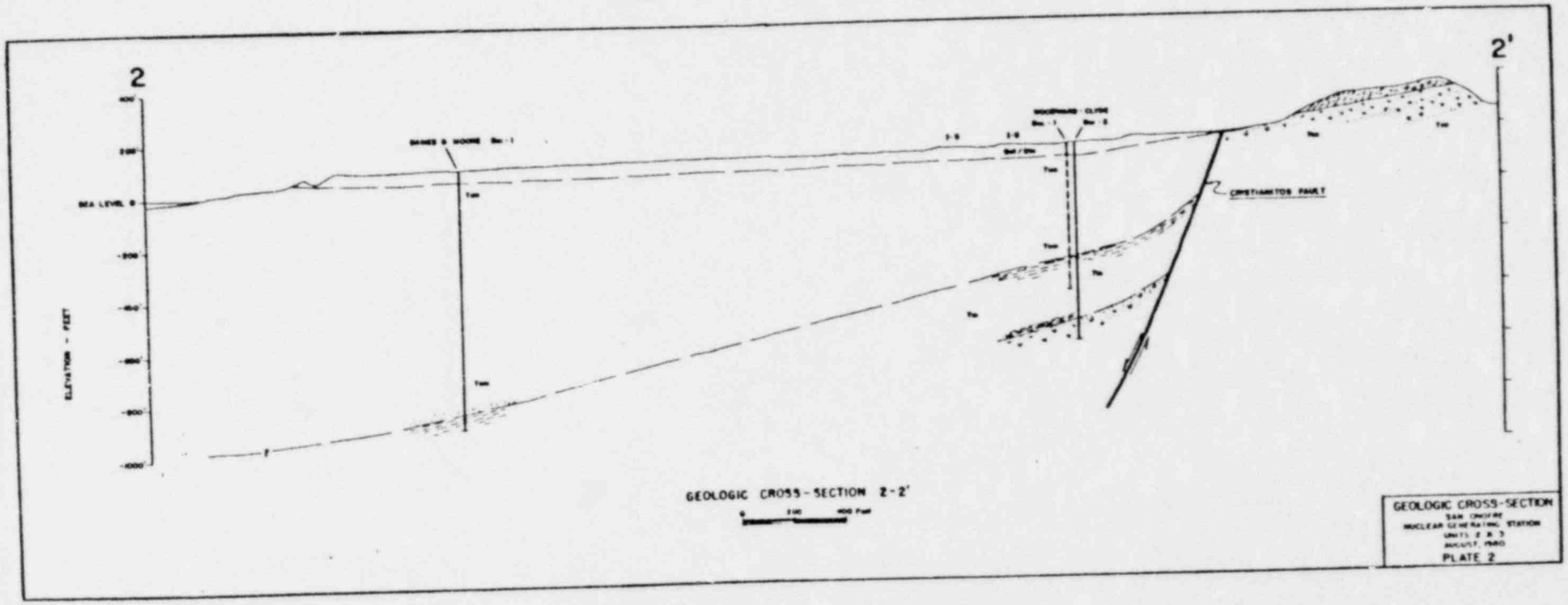


A PORTION OF A
GEOLOGIC SECTION ACROSS
THE CAPISTRANO AREA

FROM WEST, 1975

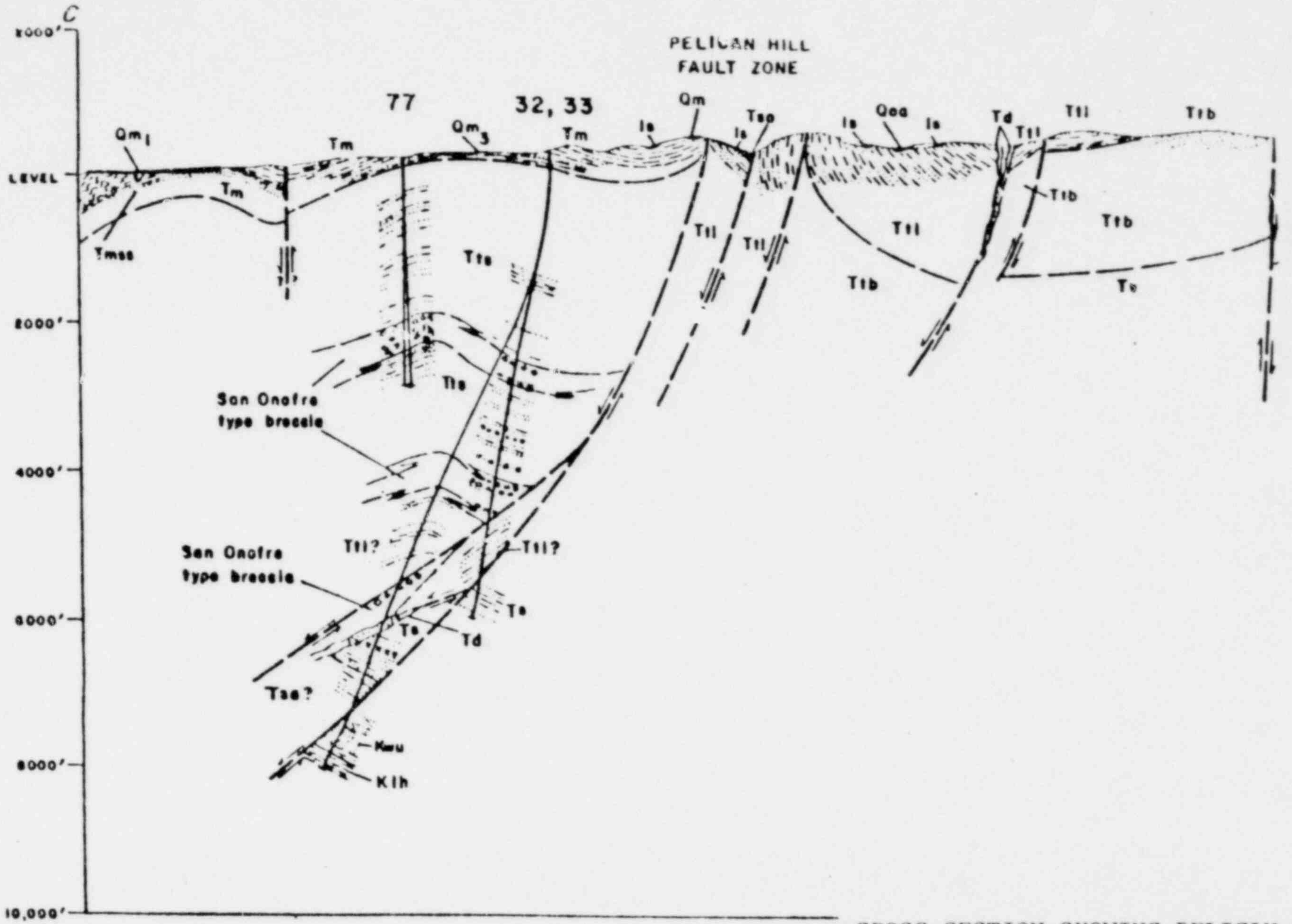
Figure PLE-L





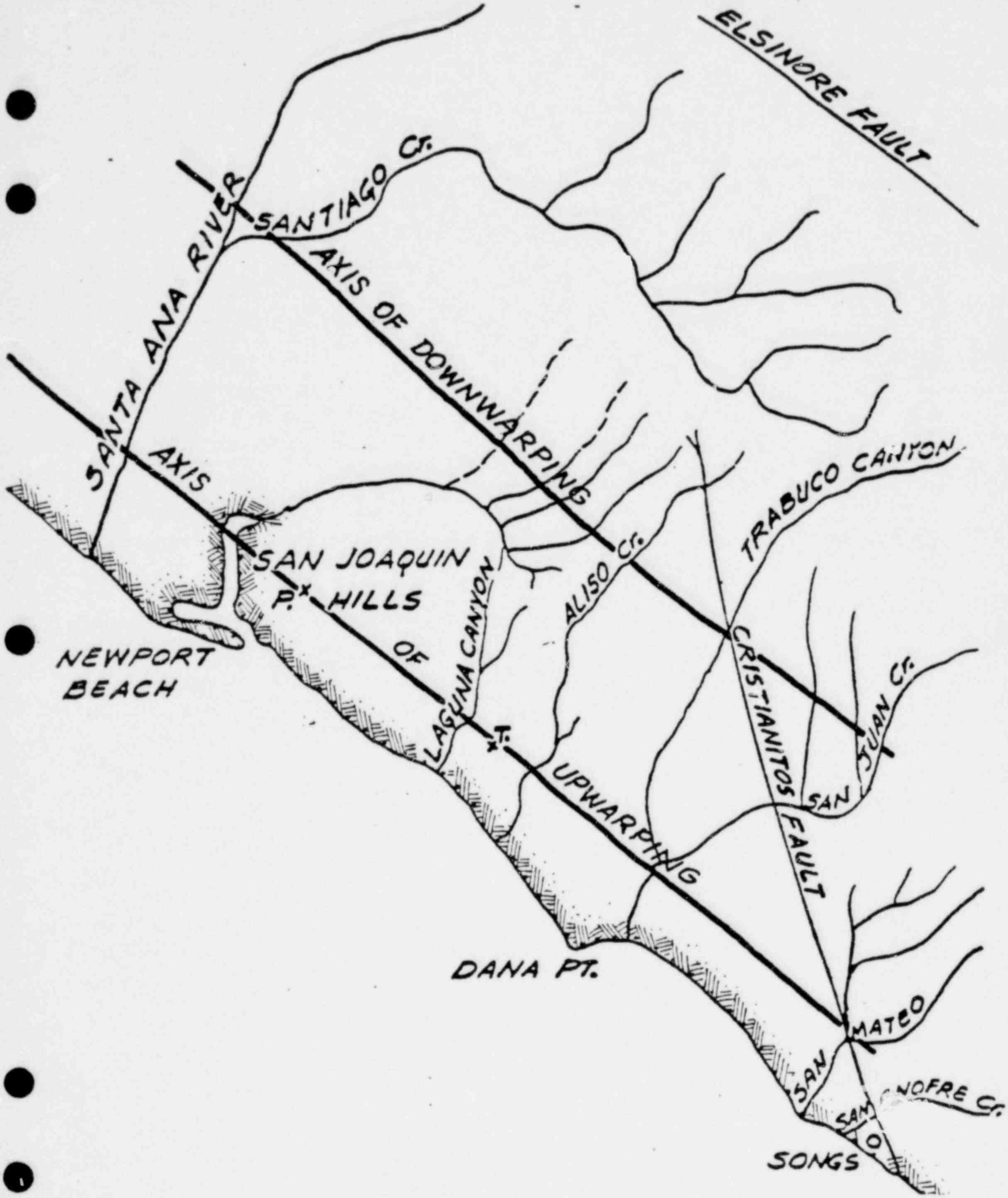
GEOLOGIC CROSS-SECTION BETWEEN
ONSHORE BORINGS

FIGURE PLE-M



CROSS-SECTION SHOWING PELICAN HILL FAULT

FIGURE PLE-N



LOCATION OF AXES OF QUATERNARY
UPWARPING AND DOWNWARPING

A PORTION OF A GEOLOGIC MAP OF NORTHERN BAJA

FROM GASTIL, 1975, PLATE 1-A

Figure PLE-P

TESTIMONY OF EDWARD G. HEATH

Q. Would you please state your name?

A. Edward G. Heath

Q. By whom are you presently employed?

A. I am a geologist employed by Woodward Clyde Consultants ("WCC"). I am currently a Project Manager and Senior Project Geologist with WCC in their Orange/Los Angeles facility.

Q. In what manner are you associated with the Applicants in this proceeding?

A. I am responsible for all WCC geologic studies related to the development of a maximum magnitude for the hypothesized Offshore Zone of Deformation ("OZD").

Q. Would you please describe your formal education?

A. I received my Master of Arts degree in Geology from the Claremont Graduate School, Claremont, California in 1954 and my Bachelor of Arts Degree in Geology from Pomona College, Claremont, California in 1952.

Q. What professional positions have you had in the area of Geology?

A. I have 27 years of experience in geology with major emphasis in the last 13 years on engineering and seismic geology. I have been with WCC since 1973.

From 1968 to 1973 I was with F. Beach Leighton and Associates, consulting geologists, in LaHabra, California as a project geologist and Vice President. I

was a research geologist with the Shell Development Co. in Houston, Texas from 1966 to 1968 and was the Chief Geologist with the Hydrocarbon Mining group of the Shell Oil Co. in Los Angeles from 1965 to 1966. Prior to that I was a Production Geologist with the Shell Oil Co. in Los Angeles from 1954 to 1966.

Q. Have you been associated with any educational institutions?

A. I have taught field geology at Whittier College and made presentations in seismic geology to several meetings of the Geologic Society of America and other professional societies.

Q. Do you hold any professional registrations in the State of California or any other state?

A. I am a Certified Engineering Geologist and a Registered Geologist in the State of California. I am a Certified Petroleum Geologist in the American Association of Petroleum Geologists. I am also currently serving as a Reviewer for the Professional ethics review Committe of the Board of Registration of Geologists and Geophysicists for the State of California.

Q. What are your pertinent professional or organizational memberships?

A. I have membership in the following professional organizations:

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American Association of Petroleum Geologists

Association of Engineering Geologists

Earthquake Engineering Research Institute

Geologic Society of America

South Coast Geological Society

Q. Have you written or published articles in the field of geology?

A. I have published several papers in the field of geology. Those related to seismic geology are listed as follows:

"Evidence of Faulting Along a Projection of the San Andreas Fault, south of the Salton Sea," in Geology and Mineral Wealth of the California Desert, South Coast Geological Society, 1980.

"Slip Rates Along the Newport-Inglewood Fault Zone, Los Angeles, California," Geological Society of American Cordilleran Section, Abstracts with Programs, San Jose, California, Vol. 11, No. 3, February 1979, with P. Guptill, R. Sugiura, G. Linkletter, and G. Hawkins.

"A Geological-Geophysical Approach Toward Re-Analysis of Existing Dam Foundations," Association of Engineering Geologists, Program Abstracts, 1978 Annual Meeting, Hershey, Pennsylvania, 1978, with D. D. Pieratti and D. E. Jensen.

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"Subsurface Investigation of Ground Rupturing During San Fernando Earthquake," San Fernando, California, Earthquake of February 9, 1971, National Oceanic and Atmospheric Administration, 1973, with F. Beach Leighton.

"What Land-Use Planners Need from Geologists," Gelogy, Seismicily and Environmental Impact, special Publication of Association of Engineering Geologists, October 1975, with R. Henderson and F. Beach Leigh on.

"Geology Along the Whittier Fault, Santa Ana Canyon, California," M.A. Thesis, Claremont Graduate School, 1954.

"Surface Faulting along the Newport Inglewood Zone of Deformation," (in press), with P. D. Guptill.

Q. Have you presented expert opinions or testimony?

A. Yes, I presented expert opinion to the ACRS in this proceeding as well as in that for the Vidal Nuclear Generating Station. I have also made presentations as an expert at public hearings for seismic safety elements in the southern California area for the Cities of Glendora, San Dimas, Pomona and Long Beach.

Q. On which projects have you been retained as an expert consultant in seismic geology?

A. In addition to these projects listed in response 10 above, I have managed or been the principal engineering

geologist in several other seismic element studies in southern California, including the County of Los Angeles and cities of Inglewood, Culver City, and Yorba Linda. I was also retained by the County of Los Angeles in the post earthquake evaluations of the siting of a new hospital at the Olive View site. I have been retained by the Los Angeles County Flood Control District for the seismic safety re-analysis of several existing dams in southern California and by the Corps of Engineers to evaluate the active fault and earthquake hazard potential to Prado Dam on the Santa Ana River.

Q. What is the purpose of your testimony in this proceeding?

A. One of the issues in this proceeding is whether based on the geologic and seismic characteristics of the OZD, including its length, assignment of M_s 7 as the maximum magnitude earthquake for the OZD renders the seismic design basis for SONGS 2 & 3 inadequate to protect the public health and safety. My testimony will address the assignment of the maximum magnitude earthquake for the OZD.

Q. Would you please state your conclusions as to the appropriate value to be assigned for the maximum magnitude earthquake for the OZD?

A. In my opinion, M_s 6-1/2 is a reasonable maximum earthquake magnitude consistent with the geologic and seismologic features of the NIZD. Because the NIZD is

considered to conservatively represent the earthquake potential of the OZD, transferring M_s 6-1/2 to the OZD provides a degree of conservatism for the maximum magnitude estimate for the OZD opposite the site. Based on incorporation of additional conservatism through evaluation of ranges in the slip rate data and review of other elements for assessing the degree of fault activity of the OZD, the most conservative maximum magnitude is M_s 7. A larger earthquake is inconsistent with the geologic and seismologic features of the OZD.

Q. Would you please describe the methodologies considered and applied in reaching your conclusions?

A. Several methodologies were considered in evaluating the maximum earthquake applicable to the OZD. My specific approach uses both a qualitative and quantitative comparison of features, such as maximum historic earthquake, fault rupture length, total displacement, degree of deformation, and long-term slip rate on faults as a means of differentiating and ranking faults and evaluating the earthquake potential of the OZD. I also evaluated rupture-length versus magnitude, and displacement-per-event versus magnitude relationships, however, use of either of those methodologies alone is not appropriate based upon the uncertainties in the data base available for the OZD. My degree-of-fault-activity approach is neither independent of, nor is it meant to

replace other methods of estimating maximum magnitude. The approach extends existing knowledge and provides a viable supplement to other methods. The degree-of-fault-activity methodology is presented in Exhibit EGH-1; "NRC Staff Question 361.38 and Parts (a), (b), and (d) of Response".

The method for estimating earthquake magnitude is based on comparing the degree of fault activity on the OZD with that of similar faults in the southern California region and in similar tectonic environments around the world. By correlating the levels of activity with the maximum earthquakes associated with those faults an estimate can be made of the maximum earthquake that may be associated with the OZD. The degree-of-activity approach considers: relative behavior of faults, particularly in terms of strain release or long term slip rates; the size, periodicity, and energy release of seismic events; the mechanical and compositional properties of the faults; and the tectonic setting. This approach for a specific fault considers evidence of fault behavior in the following steps:

1) the tectonic setting and style of the fault is defined;
2) fault activity parameters are compiled for those faults of interest within the tectonic province. The fault activity factors most accessible and

germane to characterize the differences in degree of fault activity include: slip rate, recurrence for large slip events, slip per event and fault rupture length;

3) the degree-of-activity parameters compiled above are compared so that the fault of interest is ranked relative to other faults. The degree of activity as measured by the long term, or geologic, slip rate is then compared to the maximum historic earthquakes that have occurred on these faults. From this context, a maximum magnitude limit can be estimated for each fault.

Techniques such as using fault-length versus magnitude or amount-of-surface-displacement versus magnitude incorporate only one or two aspects of fault behavior. Such singular approaches fail to describe the complexities of fault behavior; for example, such characteristics as those reflecting the degree of activity are not considered (EGH-1). The degree-of-fault-activity methodology incorporates these characteristics and compares those of the OZD to other faults within the same or similar tectonic environments.

The NIZD has been selected as a model to represent the style of faulting for the entire OZD because the greatest amount of information regarding fault behavior along the OZD is available from the NIZD. The tectonics

of the OZD as defined by the evidence of structural style along its length is representative of the wrench-style tectonics as defined by Wilcox and others (Wilcox, R.E., Harding, T.P. and Seely, D.R., "Basic Wrench Tectonics", 57 American Association of Petroleum Geologists Bulletin, no. 1, 74-96 (1973)) and Harding (Harding, T.P., "Newport-Inglewood Trend, California, An Example of Wrenching Style of Deformation," 57 American Association of Petroleum Geologists Bulletin, No. 1, 97-116 (1973)). The magnitude of the folding and faulting and the historical seimicity on the NIZD are greater than on the other portions of the OZD suggesting that the NIZD has the greatest seismic potential of the three portions, and that it serves as a conservative model to characterize the earthquake potential of the OZD (Exhibit EGH-2, "Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generating Station, June 1979, Appendix A, Tectonic Setting of the Offshore Zone of Deformation").

Q. You have stated that the first step in your assessment of maximum magnitude is an examination of the tectonic setting and style of the fault in question. Would you describe the tectonic setting and style of the OZD?

A. Yes. The major faults of southern California are set forth in Figure EGH-A, "Map of Major Faults in Southern

California." Southern California is dominated by the San Andreas fault system, which is the major boundary between the Pacific and North American plates. This system, consisting of the large northwest-trending, right-lateral San Andreas and San Jacinto fault zones, is paralleled to the west by other smaller right-slip fault zones such as the Whittier-Elsinore fault zone, the OZD and the San Clemente fault.

Although all these fault zones show evidence of predominant right slip, the faults westward from the San Angreas fault zone show a general decrease in (1) amount of total displacement, (2) continuity of surface trace, and (3) amount of seismic activity.

A detailed discussion of this fault system is presented in EGH-2 and concludes that by far the greatest amount of post middle Miocene regional displacement has occured along the San Andreas-San Jacinto fault zone and that the faults to the west are characterized by less historical seismicity, smaller total displacements and lower geologic slip rates.

The OZD consists of three tectonic elements 1) Newport-Inglewood zone of deformation (NIZD), 2) South Coast Offshore zone of deformation (SCOZD), and 3) Rose Canyon fault zone (RCFZ); Figure EGH-B, "Location Map Hypothesized OZD". The three elements extend from the Santa Monica Mountains southward to offshore of the

Mexican-American international border, a distance of approximately 200 km. The OZD passes by the SONGS site about 8 kilometers (5 miles) to the west. Several geologic features are common to each of the segments of the OZD These features include north to northwest-trending en echelon fault segments, aligned and en echelon drag fold anticlines, and numerous smaller second-order faults intersecting the primary faults, all suggestive of predominant wrench faulting (Harding, supra). However, there appears to be a progressive change in the amount and style of faulting between the elements. Starting at the north, the NIZD is characterized by discontinuous faults and folds that have evidence of right-lateral displacement of post-middle Miocene basin sediments. The SCOZD to the south displays a pattern of similar wrench fault tectonism; however, it lacks direct evidence for the amount of lateral or vertical displacement. The RCFZ, at the south end of the OZD, displays evidence for both strike-slip and normal faulting but lacks conclusive evidence of the amount of either type of displacement. Prior investigators of the RCFZ suggest highly differing interpretations, ranging from mostly strike-slip faulting to mostly dip-slip faulting. Locally, folding in the western block of the RCFZ has produced an apparent reversal of faulting style, such as at

Mt. Soledad where the western block has been raised, and at Mission Bay where the western block has been dropped.

Of the three fault elements, the NIZD is best documented and has the most complete geologic data base because it has been extensively explored and studied by oil companies, as discussed in EGH-2. The NIZD consists of: a series of short, discontinuous, northwest-trending en echelon, right-lateral faults; a northwest-trending series of relatively shallow drag fold anticlines; and numerous short subsidiary normal and reverse faults. This tectonic style is representative of right-lateral, wrench faulting; Figure EGH-C, "Structure Along the NIZD". (cf. Harding, supra).

The most recent period of deformation along the NIZD appears to have begun contemporaneous with the deposition of uppermost Miocene marine sediments and has continued at more or less the same rate up to the present time. Several geologic observations support continued deformation since Miocene: (1) the Miocene units are displaced laterally a greater distance than are the overlying younger units, as discussed in Exhibit EGH-3, "Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979, Appendix B, Estimates of Displacement Along the Newport-Inglewood Zone of

Deformation Based on E-log Correlations" and Exhibit EGH-4, "NRC Staff Question 361.61 and Response"; (2) these Miocene units also show more structural relief on the major anticlinal structures than do the younger units, which indicates evidence of structure growth during deposition; and (3) the time-displacement plots discussed in EGH-3 and EGH-4, suggest that intermittent horizontal displacement has produced a relatively consistent average slip rate since late Miocene.

The tectonic structure of the South Coast Offshore Zone of Deformation (SCOZD) was evaluated through examination of offshore geophysical reflection profiles; Exhibit EGH-5, "Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generating Station June 1979, Appendix D, South Coast Offshore Zone of Deformation Geophysical Data". This interpretation by Western Geophysical depicts the apparent tectonic deformation of two deeply buried reflecting horizons, and shows the SCOZD to consist of a zone of branching and discontinuous faults trending south to southeast about 8 kilometers (5 miles) seaward of the SONGS site; Figure EGH-D "Horizon B Contour". Local northwest- to west-trending anticlinal folds in the shallower horizons are also associated with this zone and, together with the faults, appear to reflect a

tectonic style similar to that of the NIZD, but of a lower level of deformation.

The RCFZ consists of a zone of northwest and north-striking faults both offshore north of La Jolla and south of Coronado, and onshore in San Diego between La Jolla and Coronado. The RCFZ is believed to die out toward the south in the vicinity of the international border west of Imperial Beach (Figure EGH-E, "Southern RCFZ", from Kennedy, M.P. and Welday, E.E. "Recency and Character of Faulting Offshore Metropolitan San Diego, California", California Division of Mines and Geology Map Sheet 40 (1980)).

The onshore segment in the vicinity of Rose Canyon has been interpreted as having evidence of right-lateral displacement (Kennedy, M.P. "Geology of the San Diego Metropolitan Area, California California Division of Mines and Geology Bulletin 200 (Part A) (1975); Moore and Kennedy, M.P. "Quarternary Faults at San Diego Bay, California, 3 U.S. Geological Survey Journal of Research, 589-595 (1975)). Folding is evident along the western block, which has produced both normal and reverse fault relationships across the RCFZ (EGH-2). A strike-slip style of deformation within the RCFZ has been suggested on the basis of the postulated displaced stratigraphic units and other features such as slickensides that have been observed on individual

faults within the zone. Measurements of displacements are difficult to corroborate and those reported in the literature are at best speculative. (Exhibit EGH-6, "NRC Staff Question 361.44 and part K of Response").

Although the available data provide no unique geologic line that can be used as a piercing point for the precise determination of net slip along the RCFZ, evaluation of geologic evidence indicates tht some dip-slip displacements exist and an indeterminate but small amount of strike-slip is probable in the San Diego area. Threet (Threet, R.L., "Rose Canyon Fault: An Alternative Interpretation" in <u>Earthquakes and Other Perils, San Diego Region</u> (Abott, P.L. and Elliot, W.J., eds.). p.61-71 (1979)) discusses the published estimates of strike-slip displacement focussing on the fundamental problems of interpretations and he provides alternative interpretations to those of Kennedy and Moore (e.g. Moore and Kennedy, <u>supra</u> (1975); Kennedy, Tan, Chapman, and Chase "Character and Recency of Faulting in San Diego Metropolitan Area, California," California Division of Mines and Geology Special Report 123 (1975); and Kennedy, <u>supra</u> (1975)). The data pertaining to the published displacements are discussed in EGH-6. Recently acquired evidence of faulting in San Diego is presented in Artim and Streiff, "Trenching the Rose Canyon Fault Zone San Diego, California", Final

Technical Report U.S. Geological Survey Contract No. 14-08-0001-19118 of the Earthquake Hazards Reduction Program (1981).

The southern terminous of the RCFZ occurs as a series of sub parallel en echelon fault traces south and west of Coronado. The main traces as defined by Kennedy and Welday, <u>supra</u>, are the Spanish Bight, Coronado and Silver Strand Faults. These are north-south striking faults that become less continuous and tend to die out southward from Coronado before reaching the international border.

Q. You have stated that the NIZD conservatively represents the earthquake potential of the OZD. On what basis do you reach that conclusion?

A. The NIZD is a representative model of the OZD because of the similarities in structural style among the three elements of the OZD, and because of the extensive and high-quality data available regarding the style and amount of the deformation along the NIZD. The available surface and subsurface geologic data allow a higher degree of accuracy in assessing the amount and rate of faulting and folding for the purpose of estimating the maximum earthquake to be assigned to the OZD. Of the three elements of the OZD, the NIZD has by far the highest levels of both historical and recorded seismic activity. It has produced two damaging earthquakes, one

in Inglewood in 1920, having an estimated magnitude of 4.9, and the other in Long Beach in 1933, having a recorded magnitude of 6.3. The NIZD is considered to be a conservative model for the other segments because (1) it has a higher level of historical seismicity; (2) it has the most prominent surficial anticlines and short but prominent fault scarps; (3) it is coincident with a Mesozoic basement rock discontinuity not known to exist beneath the SCOZD or the RCFZ; and (4) it is closer to the area of high stress at the interaction between the San Andreas fault system and the Transverse Range than are the other segments of the OZD to the south.

Q. You state that the next step in your evaluation is to examine in a qualitative and quantitative manner, the geologic parameters of strike-slip faults. Would you describe the comparisons you made for the OZD?

A. Comparison of faults covers a broad range of possible systems for differentiating faults. Among systems for comparing faults are: 1) the relative importance of a fault in its structural-tectonic setting, 2) relative rates of deformation, 3) fault lengths, 4) seismicity, 5) relative geomorphic expression of the faults and 6) degree of segmentation.

One of the quantitative methods for comparing faults is by geologic slip-rate; this method is particularly useful because it describes quantitatively

the relative degree of activity of faults in their present tectonic setting, and it incorporates properties of the mechanics and behavior of faults, including stress accumulation, strain release in earthquakes, and recurrence intervals of earthquakes. Because geologic slip rates reflect average fault displacements during a relatively long time interval, the behavior of faults in the past can be evaluated and can provide a basis for projection of fault behavior into the future.

A table comparing fault parameters of the San Andreas, San Jacinto, and Whittier-Elsinore faults, and the hypothesized OZD is presented in Figure EGH-F "Southern California Strike - Slip Fault Zones Characteristics and Ranking Criteria". More detailed information on the hypothesized OZD from north to south is summarized in Figure EGH-G, "Comparison of Zone Characteristics North to South Along the Hypothesized Offshre Zone of Deformation.

The general conclusions that can be drawn from comparing degree-of-activity parameters presented in EGH-F and EGH-G are: 1) the major plate motions between the North American and Pacific Plates is occurring along the San Andreas and San Jacinto fault zones and has continued to do so for at least the past 5 million years; 2) this is particularly well demonstrated by comparing total displacement across the faults and the

long term geologic slip rates of the faults; and 3) there is a consistent decrease in essentially all of the measurable parameters westward from the major plate boundary faults to the OZD suggesting that the OZD is a less significant fault with a much lower level of earth quake potential than the more activie faults along the plate boundary.

Q. Would you describe precisely how you used the foregoing degree of activity approach to assign a maximum magnitude for the OZD?

A. As stated earlier the degree-of-fault-activity method is a broadbased multiparameter method of considering various geologic and seismologic characteristic in comparing and ranking of faults. This approach leads to a generalized categorization of faults and their earthquake potential.

In addition to this qualitative analysis several other methods were considered in making a quantitative estimate of the maximum earthquake applicable to the OZD. These methods include analysis of maximum historic earthquakes, fault rupture-length versus magnitude relationships, displacement versus magnitude relationships, and long term or geologic slip rate on a fault versus the maximum historic earthquake.

If we review the historical seismicity of the OZD and other strike-slip faults in southern California the

following conclusions can be made: 1) seismicity is lower along the OZD than for other major stike-slip fault zones in southern California; 2) the major interplate motion is occurring on the San Andreas and San Jacinto faults and to a lesser degree on the faults to the west; 3) the maximum historical earthquake on the OZD is the 1933 Long Beach event--M 6.3; 4) the estimated maximum magnitude for the zone could be expected to be somewhat greater than the historical M_s 6.3 but less than that for the more active zones such as Elsinore, San Jacinto, and San Andreas; and 5) the subsurface rupture length of the 1933 earthquake, based on aftershock data was 30 km, this approaches the maximum measured fault segment length for the NIZD and thus the M_s 6.3 event may be close to the maximum for this zone.

The rupture length and displacement-per-event methods of estimating earthquake magnitudes involves the use of empirical relationships between length of surface rupture or amount of surface displacement per event and magnitude. Commonly, the consieration of fault length is used by selecting the half-fault length as a maximum potential rupture length. This method is commonly applied in the absence of other data and sometimes even to the exclusion of other data. From empirical data (Slemmons, D.B., "State-of-the-Art for Assessing

Earthquake Hazards in the United States, Report 6: Faults and Earthquake Magnitude", U.S. Army Corps of Engineers, Miscellaneous Paper S-73-1 (1977)) we can see that style of faulting and tectonic setting directly affect the relationship between magnitude and length of rupture and the amount of surface displacement. We also know that strike-slip faults do not necessarily rupture their half lengths ("Safety Evaluation Report Related to the Operation of the San Onofre Nuclear Generating Station Units 2 and 3, Docket Nos. 50-361 and 50-362, (NUREG-0712)." Appendix E, p.1-28 (1981)). For example, the San Jacinto fault generally is not believed to rupture half of its length, but rather segment lengths that are less than 30 percent the total fault length. With this in mind, if we look at the rupture length versus magnitude method for the OZD we find that the lengths of the various segments provide limits on the maximum magnitude that could be expected from the zone. Total segment lengths for faults in the younger geologic formations (upper Miocene and Pliocene), as defined in the subsurface by drilling and geophysical exploration along the OZD, are presented in EGH-F and EGH-G. The longest segments of each of the elements of the OZD range from 27 to 48 km and if you assume full rupture length and obtain an estimate of maximum

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magnitude from Slemmon's, supra, relationships you get magnitude ranges from M_S 6.6 to M_S 6.9.

Nowhere along the OZD is there good evidence of the amount of surface displacement that has occurred from single major past earthquakes. Evidence of possible surface displacement during the 1933 Long Beach earthquake has recently been uncovered. This data showed apparent offsets in the surficial units, however, it provides no actual horizontal or vertical displacement measurements. (Guptill, P. D. and Heath, E. G., "Surface Faulting Along the Newport-Inglewood Zone of Deformation",(in press)). Therefore we cannot directly apply the displacement per event versus magnitude methodology to the OZD. However, we can estimate how much surface displacement might be expected for hypothetical earthquakes of various sized large events and then test the likelihood that such displacements could have occurred on the OZD. Based on the relationships of Slemmons, supra, a magnitude 6 1/2 earthquake could produce up to 1 meter of lateral surface rupture, EGH-1. This appears feasible for the zone. Similarly a magnitude 7 earthquake could produce up to 1.7 meters of displcement. Such displacement also appear feasible but should be readily visible in the geologic record, and geologists have not reported evidence of such observed displacements. A hypothetical

earthquake of magnitude 7 1/2 could produce up to 3.2 meters of surface displacement in a single-event, but surface displacements of this amount are not supported by geological evidence and are certainly not characteristic of the OZD.

In order to assess the degree of activity of the various faults in terms of geologic slip rate a literature search was conducted to estimate the displacements with time and thus geologic slip rates of the NIZD, other strike-slip faults in southern California, and other strike-slip faults from similar tectonic settings around the world. Available data of fault displacements and slip-rate estimates were compiled and are presented in Exhibit EGH-7, "NRC Staff Question 361.45 and part (e) of Response". However, because the literature on the NIZD provided a wide range of poorly constrained estimates, it was necessary to evaluate long-term geologic slip rates by interpreting subsurface geologic data. Hill applied a technique utilizng oil well electric logs, which record the lithologisic facies relationships of layered geologic units, to estimate the total fault displacement that has occurred since these units were deposited. (Hill, M.L., "Tectonics of Faulting in Southern California" in <u>Geology of Southern California: California Division of Mines and Geology Bulletin 170</u>, (Jahns, R.H. ed) p. 5-13

(1954); and Hill, M.L., "Newport-Inglewood Zone and Mesozoic Subduction California," 82 Geological Society of America Bulletin 2957-2962 (1971)) This process was applied in three areas along the NIZD to estimate the geologic slip rates from displacements recorded in upper Miocene and Pliocene rocks, see Figure EGH-H, "Horizontal Geologic Slip Rate, Seal Beach and Huntington Beach, Newport-Inglewood Zone of Deformation" and Figure EGH-I, Horizontal Geologic Slip Rate, Long Beach, Newport-Inglewood Zone of Deformation". All of the slip-rate data for faults considered in this analysis were compiled and presented in EGH-7.

The data for slip rates were selected specifically for strike-slip faults in southern California and for strike-slip faults in other similar tectonic environments. Selection of faults was carefully limited to California-style strike-slip faults because fundamental differences in fault behavior appear to exist between this group of faults and normal dip-slip faults, reverse faults and other strike-slip faults (e.g. Japan) of different tectonic environments. These differences are discussed in Exhibit EGH-8, "NRC Staff Question 361.47 and Response".

Because slip rate is perhaps the most quantitative measure of the degree of activity of a fault a plot of slip rate versus maximum historical magnitude was

constructed as a method to compare those measures of fault behavior. This was done by plotting the geologic slip-rate from Tables 361.45-2 and 361.45-3 of EGH-7 against the magnitudes of the largest historical earthquakes on these faults in a semi-log format of slip-rate versus maximum magnitude; see Figure EGH-J, "Empirical Plot, Geologic-Slip Rate Versus Historical Magnitude for Strike-Slip Faults" (from Figure 361.45-1 in EGH-7). The pattern of historic earthquake data presented in EGH-J indicates a trend of increasing maximum earthquakes with increasing geologic slip rates.

In order to evalutate the slip-rate relatiorship, a line can be drawn bounding these empirical observations as shown in Figure EGH-K, "Historical Earthquake Limit, Geologic Slip Rate Versus Historical Magnitude For Strike-Slip Faults", (from Figure 361.45-3 in EGH-7). This line suggests that there is a consistent limit to the size of an earthquake associated with the geologic slip rate of these strike-slip faults. This assumes that some of the strike-slip faults in the world have had maximum or close-to-maximum earthquakes and that when these maximum data points are enveloped, they form a maximum Historic Earthquake Limit (HEL) related to slip rate.

Several procedures can be used to assess the conservatism and the significance of this observational

limit. One method is to consider the ranges of slip rate and magnitude data obtained from published and unpublished sources. The data presented in Tables 361.45-2 and 361.45-3 of EGH-7 provide for this assessment of uncertainty in the data interpretation.

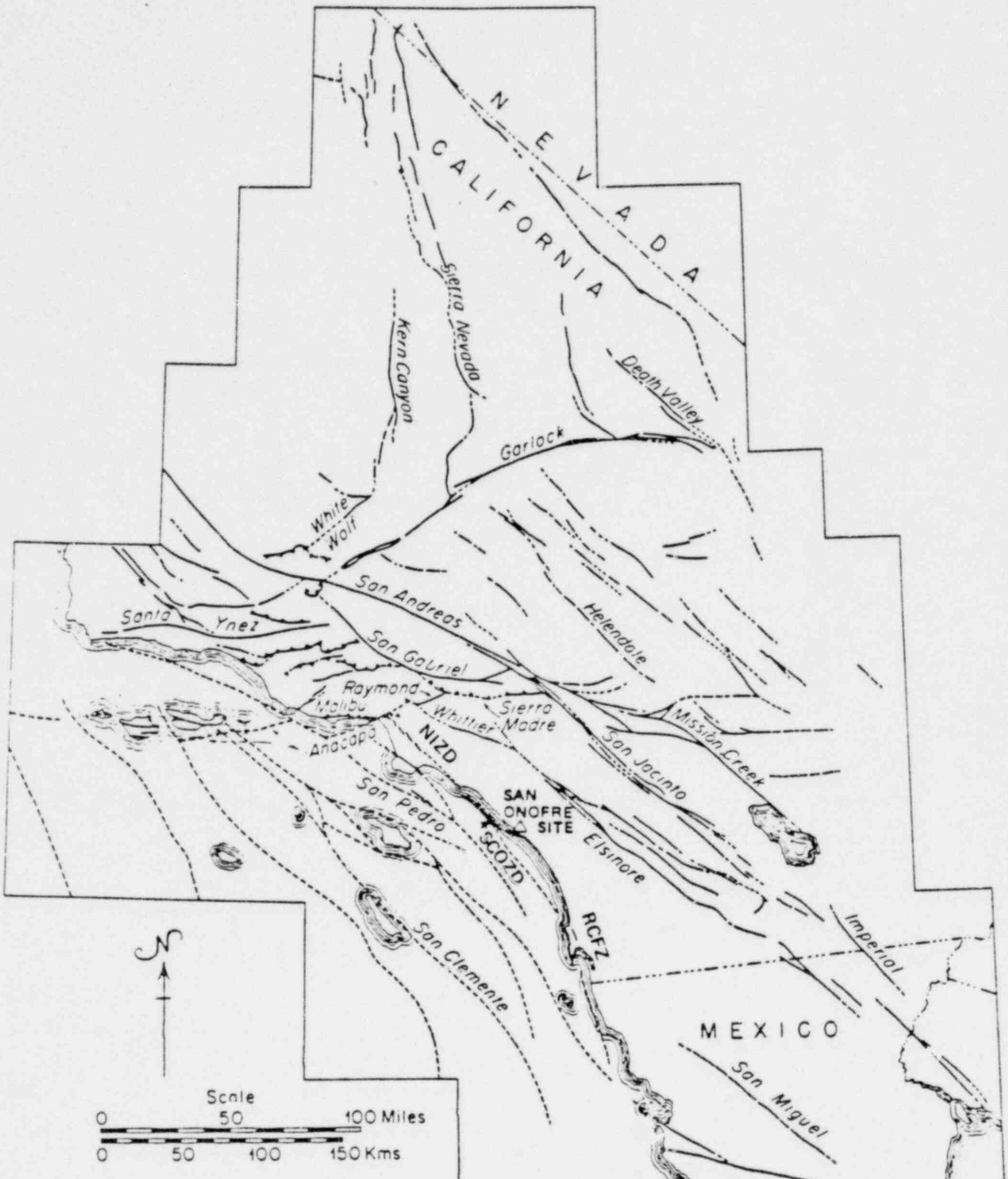
To account for possible uncertainty in earthquake magnitude values, a magnitude range is assigned to each earthquake. The earliest surface wave magnitude estimates were considered to be dependable to one quarter of a unit (Richter, C.F., Elementary Seismology, p. 347 (1958)). Modern estimates, based on a larger and better distributed set of stations, are dependable to one tenth of a unit at a confidence level of 95% (e.g., Shimazaki D. and Somerville, P, "Static and Dynamic Parameters of the Izu-Oshima, Japan Earthquake of January 14,1978", 69 Seismological Society of America Bulletin, 1343-1378 (1979)). The Applicants, therefore, conclude that a value of two tenths of a unit plus or minus is a conservative estimate of the uncertainty associated with surface wave magnitude estimates.

To account for variations in slip rate the ranges of data were evaluated and have been included in Figure EGH-L, "Data Range Analysis, Geologic Slip Rate Versus Historical Magnitude For Strike-slip Faults", (from Figure 361.45-2 in EGH-7). The variations shown represent the widest reasonable ranges of data as

discussed in available literature. These ranges of slip rates can be used in conjunction with the magnitude ranges to establish a Maximum Earthquake Limit line (MEL), see Figure EGH-M, "Maximum Earthquake Limit, Geologic Slip Rate Versus Historical Magnitude For Strike-slip Faults", (from Figure 361.45-4, in EGH-7). The MEL is drawn to envelope 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 believe that the MEL line represents an outer bound for maximum magnitude that should not be exceeded by future earthquakes on these faults. This line does not mean that each of these faults is capable of the MEL earthquake, but only that this line should not be exceeded by future earthquakes.

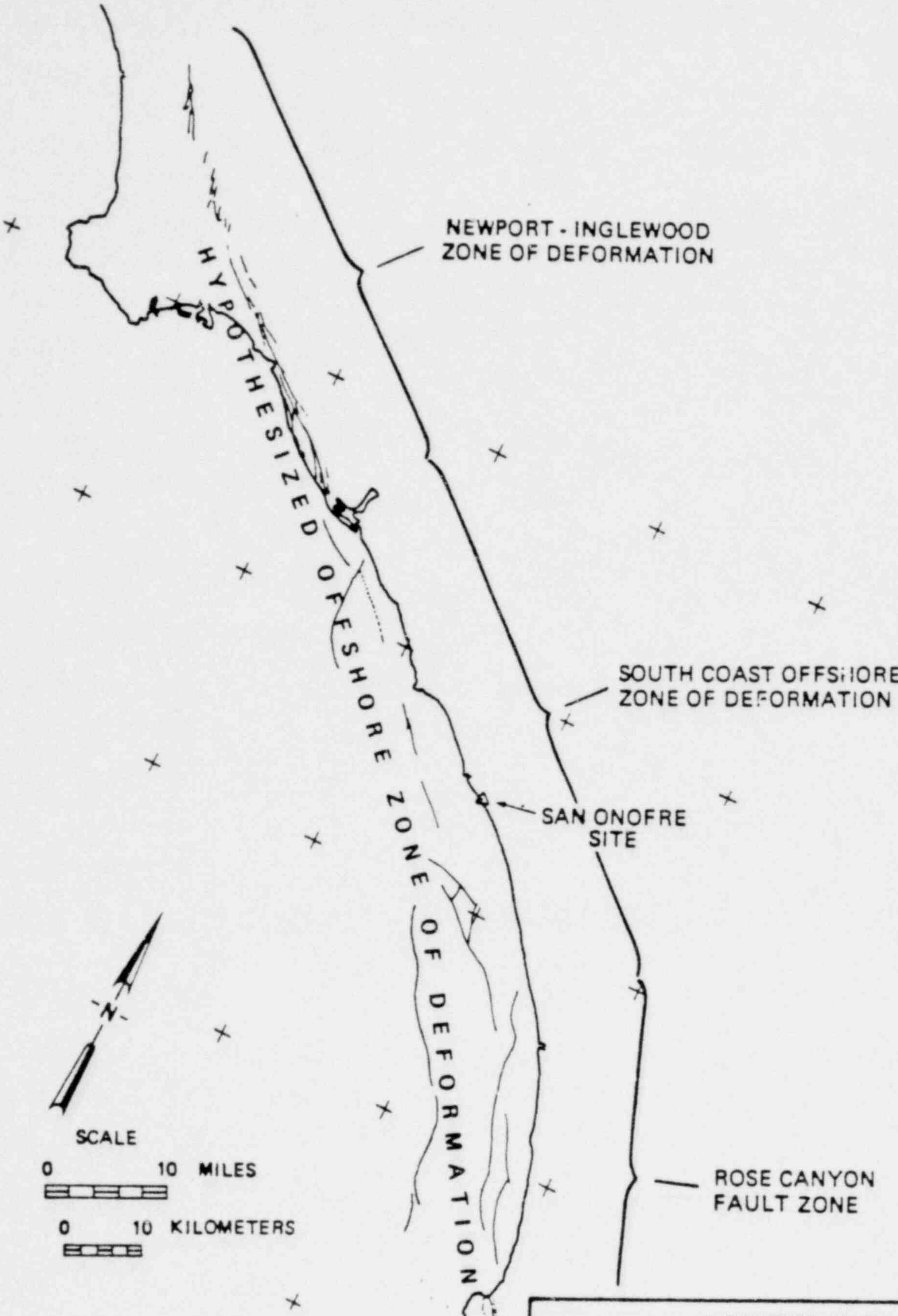
This relationship was used to estimate the maximum magnitude earthquake on the NIZD, On the basis of the most conservative interpretation of the MEL line, the maximum magnitude for the NIZD associated with the highest slip rate of 0.68 mm/year results in M_S 7.0. A comparison between magnitudes predicted for numerous strike-slip faults using the slip-rate methodology and magnitudes based on the rupture length-magnitude methodology is provided in EGH-1, Section 361.38(b).

The comparison shows that the results of the half-fault length rupture approach is consistent with the results predicted from the Historical Earthquake Limit (HEL) and the Maximum Earthquake Limit (MEL).



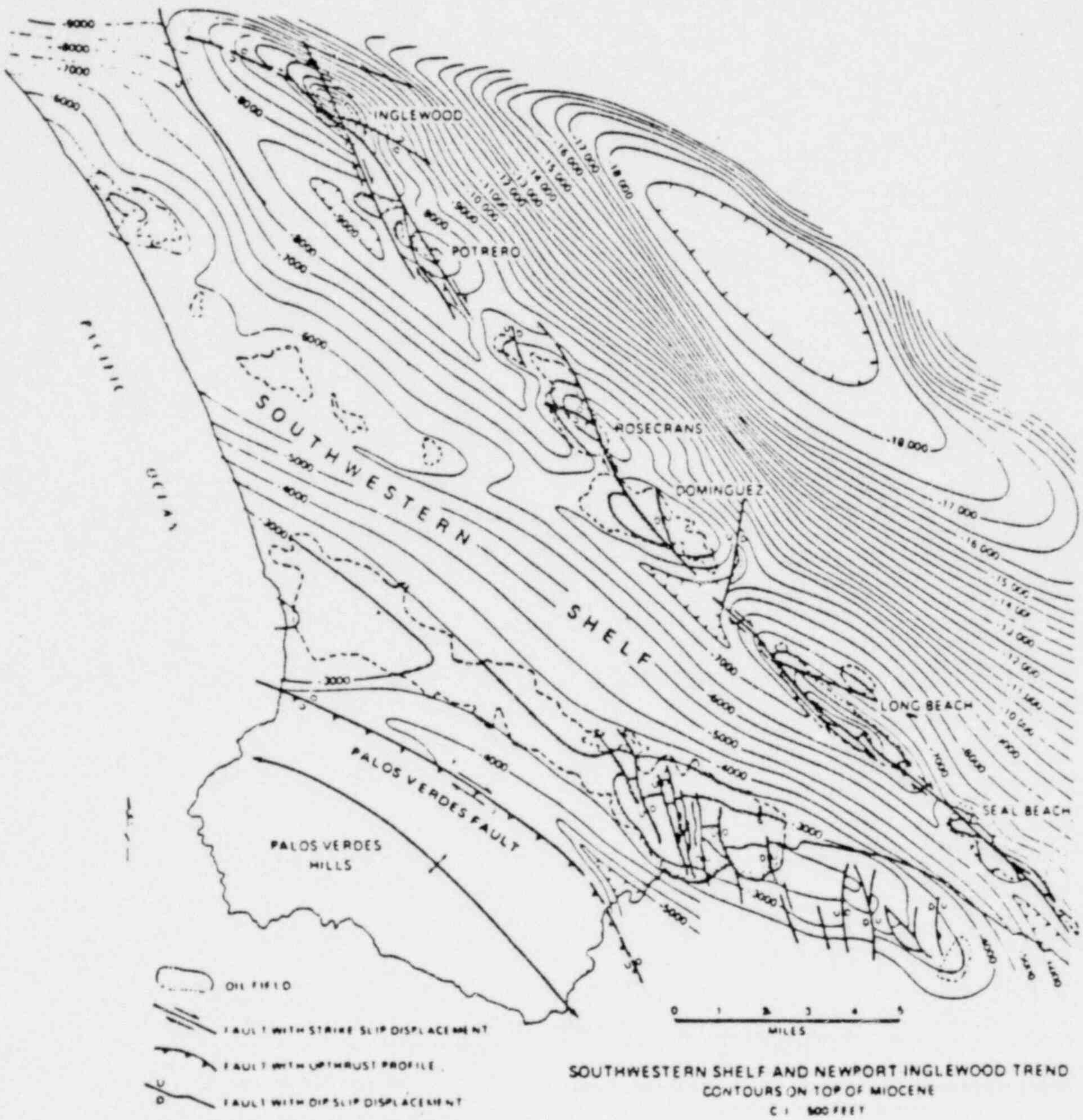
(Modified from Allen et al, 1965; California Department of Water Resources, 1964a; Emery, 1960; Hill, 1916).

MAP OF MAJOR FAULTS IN SOUTHERN CALIFORNIA SONGS 2 & 3	
	FIGURE EGH–A



LOCATION MAP
HYPOTHESIZED OZD
SONGS 2 & 3

FIGURE
EGH–B



—Structure of northwest and central part of Newport-Inglewood trend (with oil fields named) and southwestern shelf of Los Angeles basin.

(From Harding, 1973)

FIGURE EGH–C STRUCTURE ALONG THE NIZD

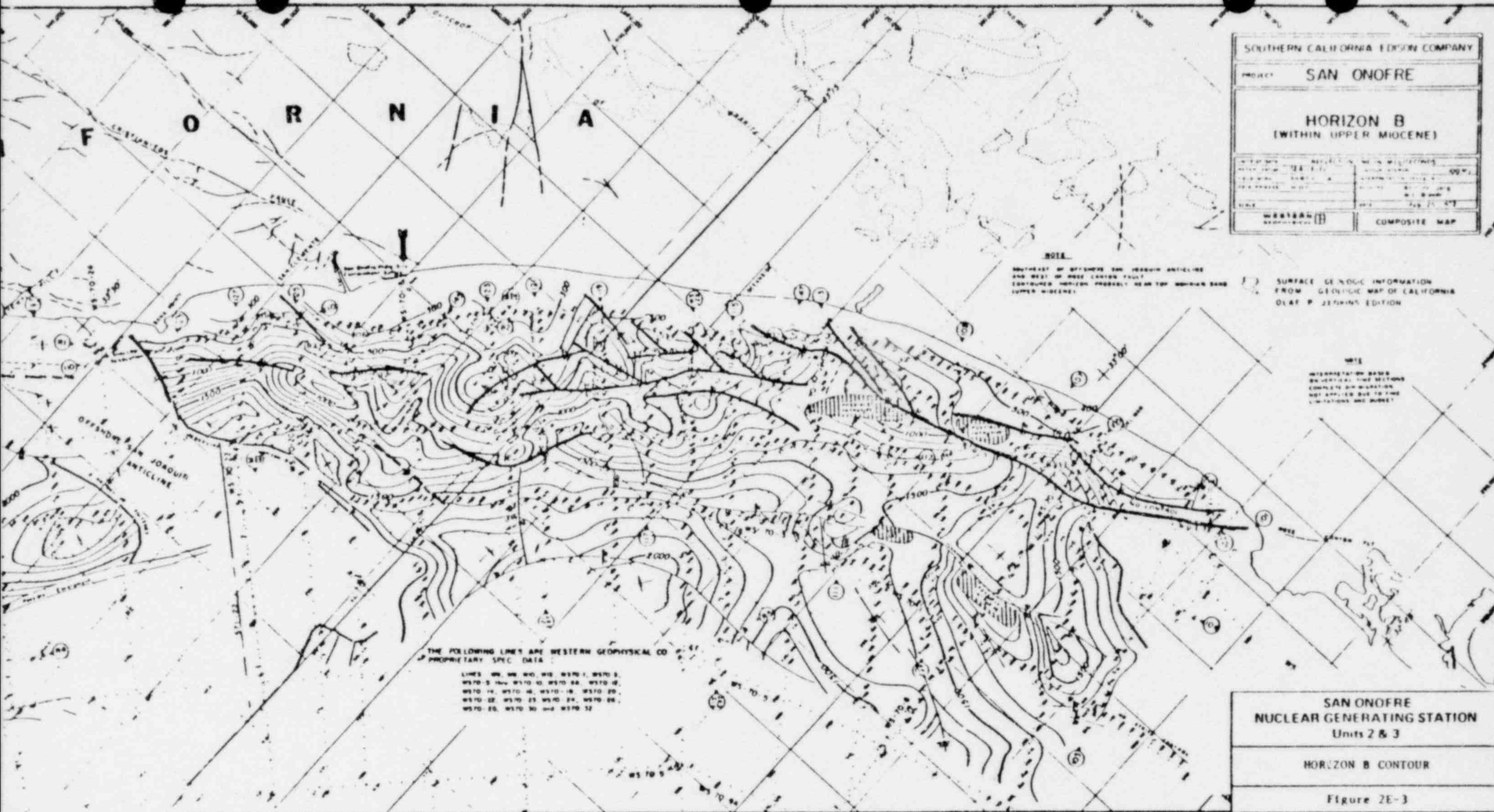


FIGURE EGH–D HORIZON B

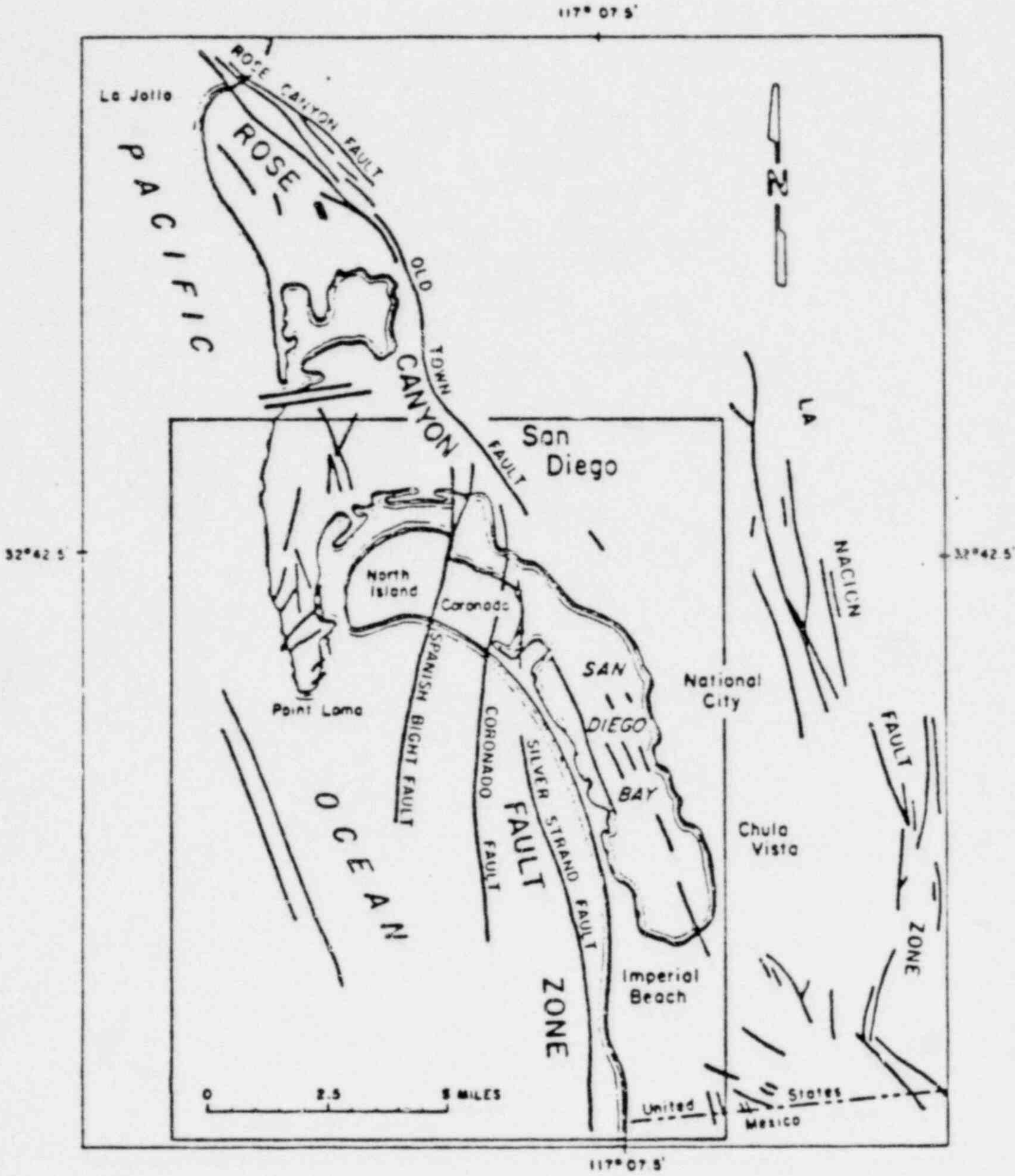


Figure 2. Generalized fault map of offshore area studied and immediately adjacent onshore area.

From Kennedy and Welday, 1980

FIGURE EGH-E SOUTHERN RCFZ

TABLE 361.38-2
SOUTHERN CALIFORNIA STRIKE-SLIP FAULT ZONES
CHARACTERISTICS AND RANKING CRITERIA

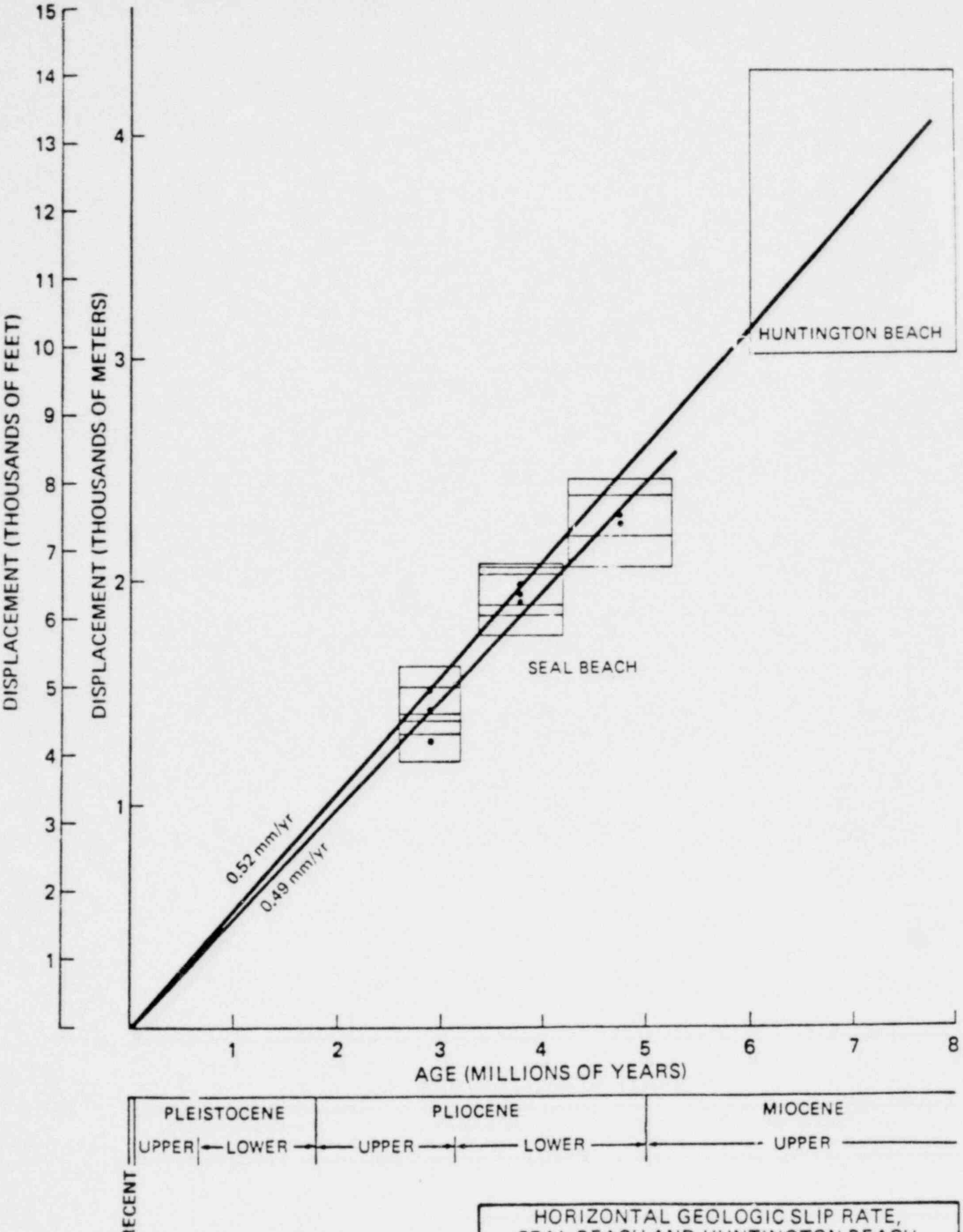
FAULT ZONE CHARACTERISTICS	SAN ANDREAS	SAN JACINTO	WHITTIER-ELSINORE-LAGUNA SALADA	HYPOTHESIZED OZD
Dimensions and Segmentation	Total length - 1300 km Imperial-Cerro Prieto segment - 180 km (Imperial Valley to Gulf of California) Southern segment - 225 km (Cajon Pass to Imperial Valley) Central segment - 330 km (Parkfield to Cajon Pass) Creep segment - 135 km (Hollister to Parkfield) Northern segment - 435 km (Cape Mendocino to Hollister)	Total length - 260 km Loma Linda-Claremont - 97 km Casa Loma-Clark - 126 km Coyote Creek - 60 km Superstition Mountain - 5[illegible] km Superstition Hills - 53 km	Total length - 339 km Whittier - 42 km Chino - 32 km Eagle-Glen Ivy - 43 km Wildomar-Elsinore - 160 km Laguna Salada 80 km	Total length - 200 km NIZD - 70 km Segment lengths - 6.5-36 km SCOZD - 75 + km Segment lengths - 8-27 km (Horizon B) RCFZ - 65 + km Segment lengths - [illegible]
Total Displacement	300 km (Miocene-Cretaceous)	24 km (Pliocene)	8-13 km (Tertiary)	3 km (Upper Miocene-NIZD)
Distance from San Andreas Fault (Plate Boundary)	0 km	0-48 km	40-80 km	62-150 km
Historic Rupture Length	435 km (Northern Segment)	33 km (Coyote Creek)	N/A	30 km (Aftershock Zone - NIZD)
Historic Displacement	6.1 m	.38 m (Coyote Creek)	N/A	31 - .46 m (Seismic Moment - NIZD)
Continuity and Geomorphic Features	Great Continuity Long linear surface scarps, numerous traces; traces suggest great continuity; sag pods, offset streams and topography	En echelon Segments Strong linear trends in young alluvium, water barriers; sag depressions, offset streams and topography, linearity and continuity not as pronounced as San Andreas	En enchelon Segments Linear scarps, offset alluvial fans and streams but fault trace vanishes frequently in younger sediments sag depressions	Discontinuous en echelon Segments En enchelon large folds at north end with smaller and more gentle folding to the south. Occasional linear fault scarps at north end with no persistant scarps to the south.
Historic Seismicity	Very High	Very High	Moderate	High in the north, low in central and southern areas
Maximum Historic Magnitude, M_S	8.2 (1857)	6.7 (1968 Coyote Creek) 7.1 (1940 Imperial)	5.5-6 (1910)	6.3 (1933 - NIZD)
Geologic Slip Rate	37 mm/yr	8 mm/yr	2.3 mm/yr (Elsinore) 1.2 mm/yr (Whittier)	0.5 mm/yr (NIZD)

FIGURE EGH-F SOUTHERN CALIFORNIA STRIKE-SLIP FAULT ZONES
CHARACTERISTICS AND RANKING CRITERIA

TABLE 361.38-3
COMPARISON OF ZONE CHARACTERISTICS NORTH TO SOUTH ALONG
THE HYPOTHESIZED OFFSHORE ZONE OF DEFORMATION

	NORTH	CENTRAL	SOUTH
FAULT RELATED CHARACTERISTICS	NEWPORT-INGLEWOOD ZONE OF DEFORMATION	SOUTH COAST OFFSHORE ZONE OF DEFORMATION	ROSE CANYON FAULT ZONE
Total Length	70 km	75 ± km	65 ± km
Maximum Segment Length	18 km (36 km combined)	27 ± km (Horizon "B")	48 ± km (offshore)
Structural Features	Large en echelon folds, En echelon faults, North trending branch faults near basement	Smaller en echelon folds, folds, En echelon faults, North trending branch faults near basement	Gentle folds on opposite sides of fault zone, En echelon faults
Continuity of Geomorphic features	Low en echelon folds, short fault scarps	Little to none Fault scarps up to 1/2 meter	Main fault segments tend to follow Rose Canyon, No persistent fault scarps
Distance from San Andreas Fault (Plate Boundary)	62 - 80 km	85 - 130 km	110 - 150 km
Historic Seismicity	High	Very Low	Low
Maximum Historic Earthquake - M_S	6.3 (1933)	4.5 (1969)	3.7 (1958)
Historic Rupture Length	30 km (Aftershock Zone)	U.K.	U.K.
Geologic Slip Rate	0.5 mm/yr	U.K.	Indeterminant, see Responses to Question 361.44 k)

FIGURE EGH-G COMPARISON OF ZONE CHARACTERISTICS NORTH TO SOUTH ALONG THE HYPOTHESIZED OFFSHORE ZONE OF DEFORMATION

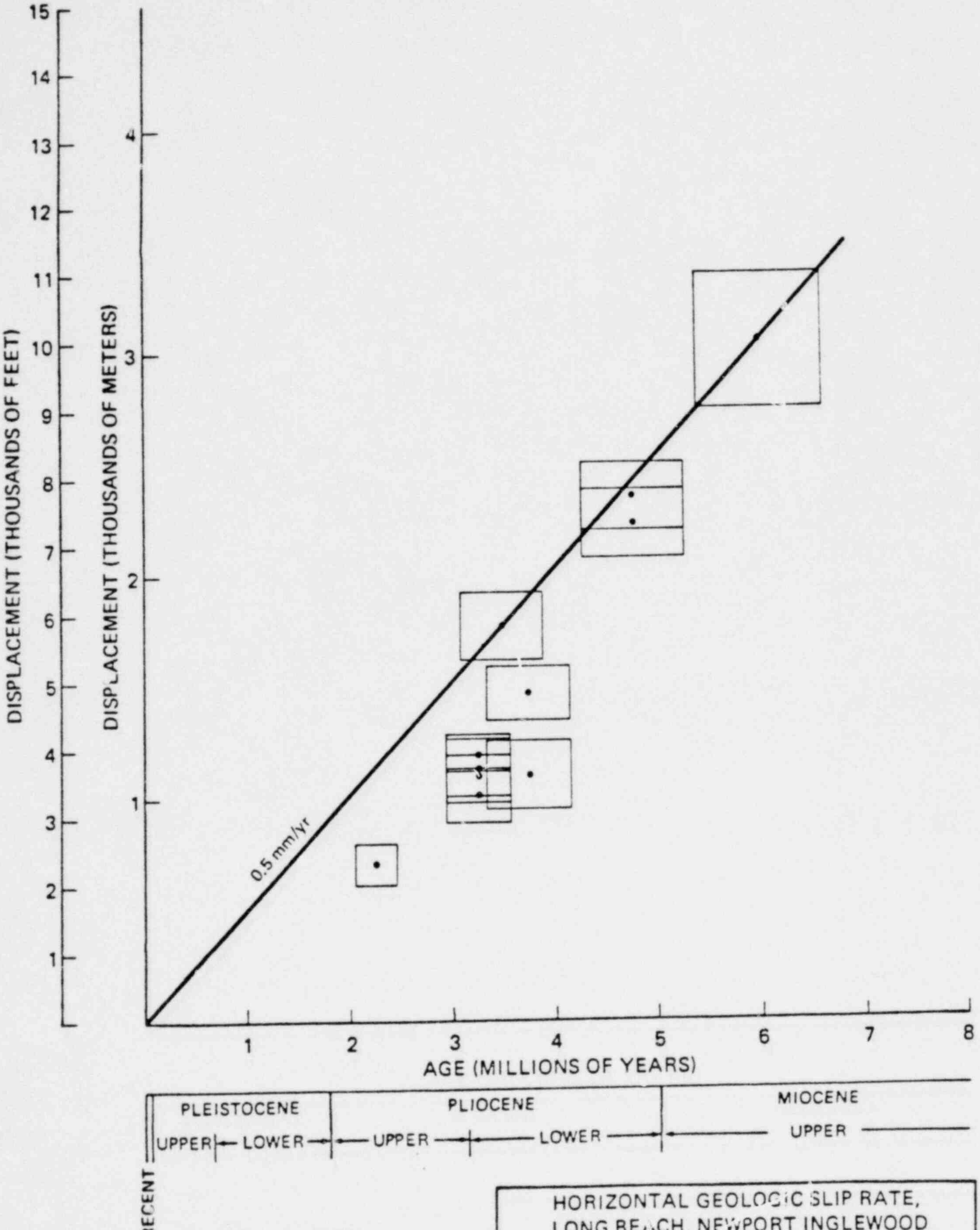


EXPLANATION

Box represents limits of accuracy

HORIZONTAL GEOLOGIC SLIP RATE,
SEAL BEACH AND HUNTINGTON BEACH,
NEWPORT INGLEWOOD ZONE
OF DEFORMATION
SONGS 2 & 3

FIGURE
EGH–H

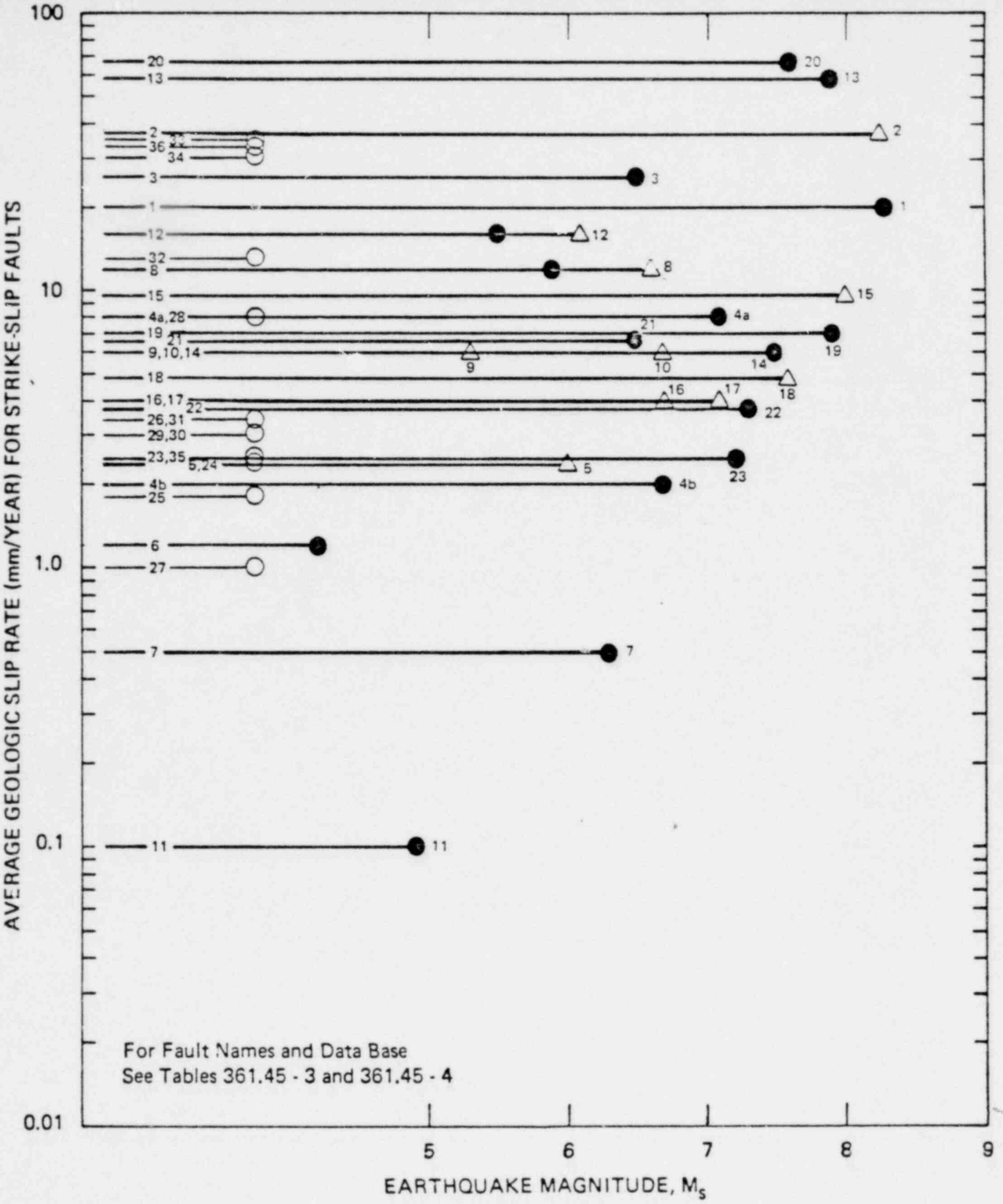


EXPLANATION

Box represents limits of accuracy

HORIZONTAL GEOLOGIC SLIP RATE,
LONG BEACH, NEWPORT INGLEWOOD
ZONE OF DEFORMATION
SONGS 2 & 3

FIGURE
EGH-1

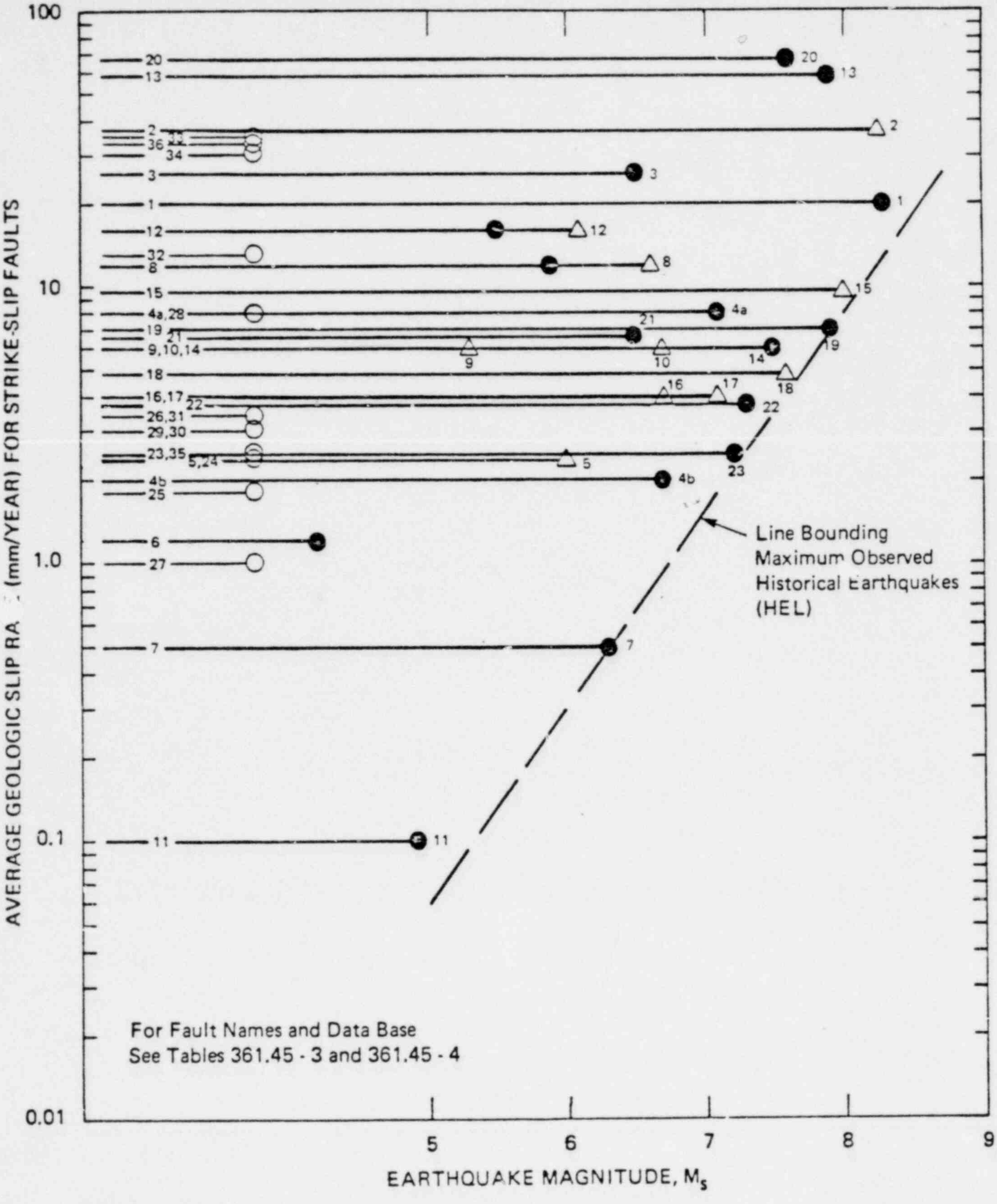


EXPLANATION

- ● 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

FIGURE EGH–J

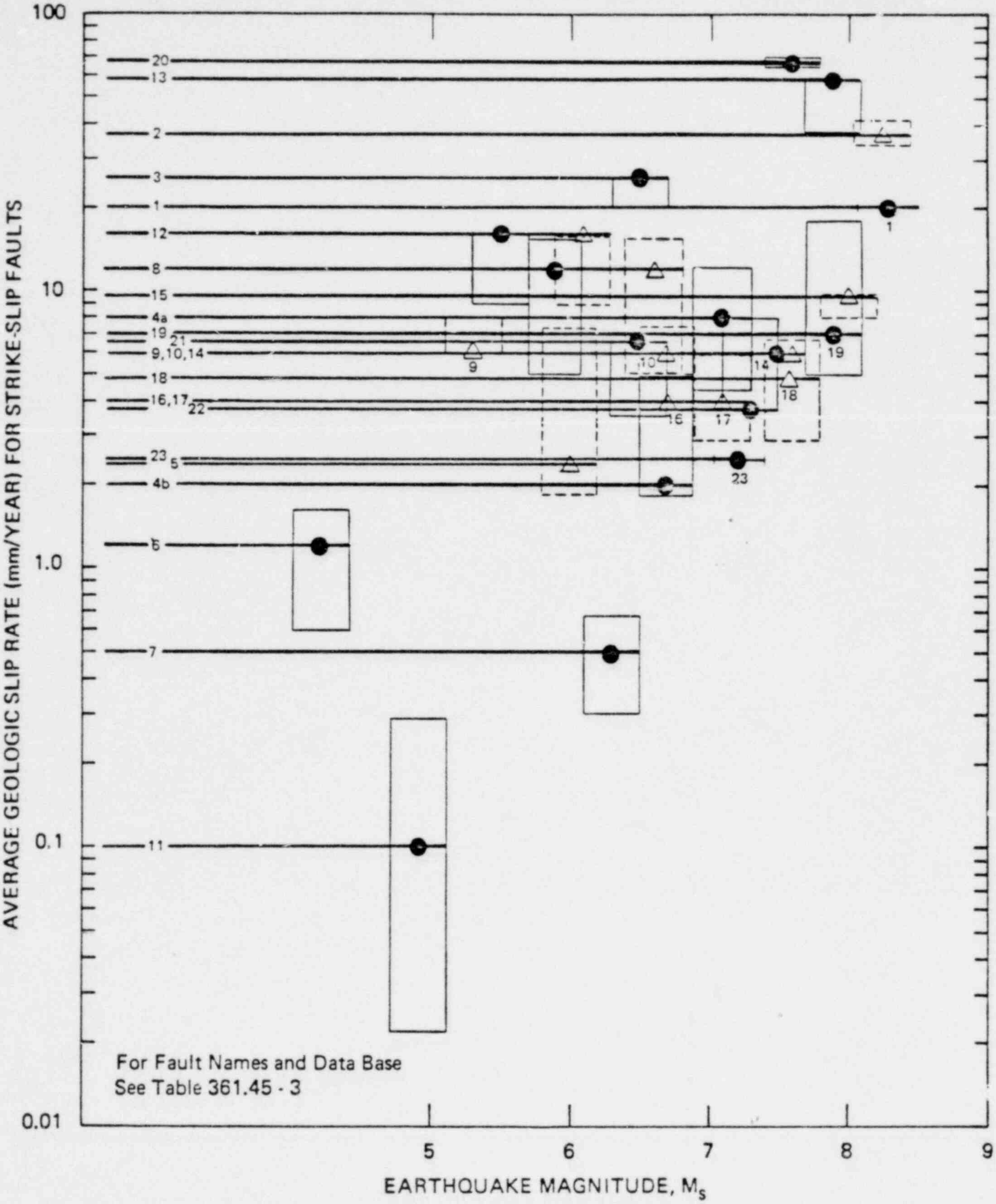


EXPLANATION

- ● 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 - 3 Historical Earthquake Limit Geologic Slip Rate VS Historical Magnitude for Strike–Slip Faults

FIGURE EGH–K

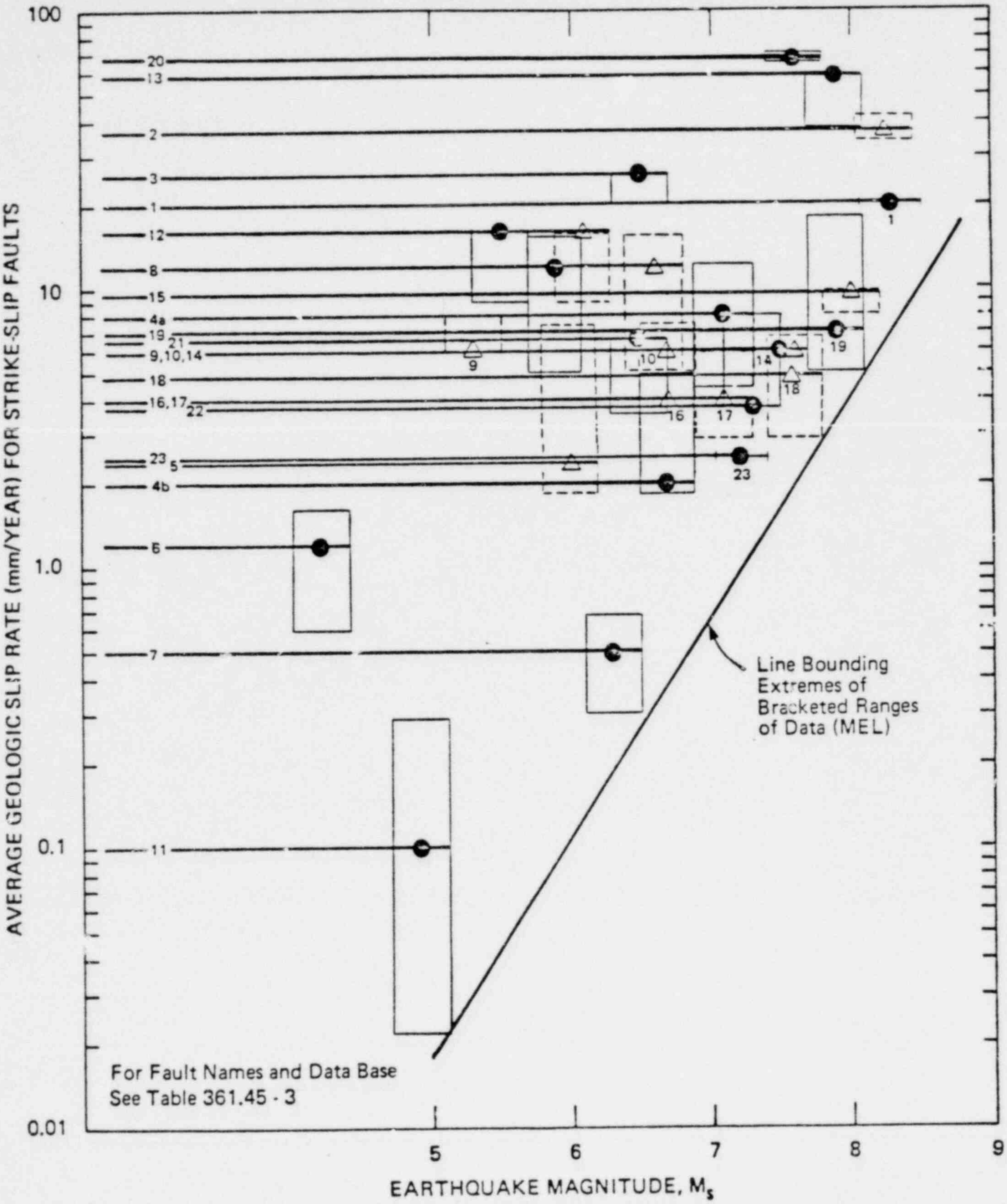


EXPLANATION

- ● Maximum instrumental recording
- △ Maximum pre-instrumental estimate
- — Range over which smaller earthquakes occur
- Box represents most likely range of geologic slip rate data and possible error range of ±0.2 in Magnitude calculation. Dashed box represents uncertainty of pre-instrumental estimates.

Figure 361.45 - 2 Data Range Analysis Geologic Slip Rate VS Historical Magnitude for Strike–Slip Faults

FIGURE EGH–L



EXPLANATION

● Maximum instrumental recording

△ Maximum pre-instrumental estimate

— Range over which smaller earthquakes occur

Box represents most likely range of geologic slip rate data and possible error range of ±0.2 in Magnitude calculation. Dashed box represents uncertainty of pre-instrumental estimates.

Figure 361.45 - 4 Maximum Earthquake Limit Geologic Slip Rate VS Historical Magnitude for Strike–Slip Faults

FIGURE EGH–M

TESTIMONY OF DR. STEWART W. SMITH

Q. Would you please state your name?

A. Stewart W. Smith

Q. By whom are you presently employed?

A. I am a Professor of Geophysics at the University of Washington, Seattle, Washington.

Q. In what manner are you associated with the Applicants in this proceeding?

A. I was retained as a member of their Board of Technical Review to review the original work for the San Onofre site in 1970 and have continued as a consultant since that time.

Q. Would you please describe your formal education?

A. I received a Bachelor of Science degree from the Department of Geology and Geophysics at the Massachusetts Institute of Technology in 1954; a Masters of Science degree by the California Institute of Technology in 1959 and a Ph.D in Geophysics by the California Institute of Technology in 1961.

Q. What professional positions have you held in the area of seismology?

A. I was a staff member of the Seismological Laboratory and an Assistant Professor (1961-64) and Associate Professor (1964-1970) of Geophysics at the California Institute of Technology. I am

currently Professor of Geophysics at the University of Washington having served as Chairman of Geophysics from 1970-1980.

Q. What other professional positions have you held in the area of seismology?

A. I was a Geophysicist for the Shell Oil Company from 1954-1957 in the area of exploration seismology. In addition I have been a Principal Scientist, earthquake seismology, for TERA Corporation since 1974.

Q. Do you hold any professional registrations in the State of California or any other state?

A. I am a Registered Professional Geophysicist in the State of California.

Q. What are your pertinent professional or organizational memberships?

A. I am a member of the following organizations:

Seismological Society of America
Earthquake Engineering Research Institute
American Geophysical Union

Q. Have you written or published articles in the field of seismology?

A. I have published about 40 articles in the field of geophysics during the period from 1961 to the present. A list of my publications is appended hereto.

Q. Have you served with formally-organized groups concerned wholly or in part with matters of seismic safety?

A. I have served on a number of committees and panels concerned with seismic safety. Recent activities include the U.S. Geological Survey, Workshop on Earthquake Hazards in Puget Sound, the National Science Foundation Workshop on Strong Motion Instrumentation and the American Nuclear Society Standards Committee on Active Faulting.

Q. On which matters have you been retained as an expert consultant in seismology?

A. I have served as a consultant to private industry on a number of important structures in the Western U.S., including Diablo Canyon Nuclear Power Plant, Humboldt Bay Nuclear Power Plant, Pebble Springs Thermal Power Plant Site, and others. I have also served as a consultant to the Nuclear Regulatory Commission on matters related to the st istical evaluation of seismic hazards and to the State of California regarding seismic considerations for several dams.

Q. Have you testified as an expert in any previous hearings or trials?

A. Over the past fifteen (15) years, I have testified at numerous regulatory proceedings including all

hearings on seismic related issues before the Atomic Safety and Licensing Appeal Board (ALAB) and the Atomic Safety and Licensing Board (ASLB) for Diablo Canyon.

I also presented expert testimony to the ASLB at the construction permit stage for SONGS 2 & 3 (1972).

Q. What is the purpose of your testimony in this proceeding?

A. One of the issues in this proceeding is whether, based on the geologic and seismic characteristics of the OZD, including its length, assignment of $M_s 7$ as the maximum magnitude earthquake for the OZD renders this seismic design basis for SONGS 2 & 3 is inadequate to protect the public health and safety. My testimony addresses whether assignment of $M_s 7$ is a reasonable maximum magnitude for the OZD and whether such assignment renders the seismic design basis for SONGS 2 & 3 established for issuance of the construction permit inadequate.

Q. In addressing the question of the maximum magnitude that could be generated from a particular structure, what factors do you consider?

A. The factors to be examined, in very general terms, are; the seismic history of the area, the geologic record of deformation, the regional stress as

inferred from focal mechanisms and the faulting characteristics of the particular structure.

Q. Would you please describe the seismic history of the area relevant to the SONGS site?

A. The south coast region has not been an area of high seismic activity either in the historic record that dates back to the early missions (1769) or in the modern era of instrumental seismic recording that dates back to about 1934. The historic record is reviewed in FSAR Section 2.5.2.1; Tables 2.5.1 and 2.5-3. The instrumental record is reviewed in FSAR Section 2.5.2.1; Tables 2.5-2 and 2.5-4. The following figures display the seismic activity of Southern California from the transverse ranges to Baja California:

Figure SWS-A	"EPICENTER PLOT M3-M6 AND ABOVE CIT CATALOG 1932 - JUNE 1980"
Figure SWS-B	"EPICENTER PLOT M4-M6 AND ABOVE CIT CATALOG 1932 - JUNE 1980"
Figure SWS-C	"EPICENTER PLOT M5-M6 AND ABOVE CIT CATALOG 1932 - JUNE 1980"
Figure SWS-D	"EPICENTER PLOT M6 AND ABOVE CIT CATALOG 1932 - JUNE 1980"

These four figures illustrate the seismic activity at different magnitude levels. They indicate in a general way that although small earthquakes (less

than magnitude 4.0 for example) are widely distributed over the Southern California area, they show a clustering along major faults on which larger earthquakes have occurred. Major fault systems that are active and may form part of the boundary between the Pacific and North American Tectonic Plates can be seen in the Imperial Valley area, the Los Angeles area, and in the Transverse Range area. The conclusion from such displays is that no significant zone of seismic activity has existed during the nearly half century during which accurate recording of earthquake locations has been possible. Further, this data supports the idea that the principal plate boundary at the latitude of SONGS occurs on the San Andreas and San Jacinto fault systems, and that activity generally decreases westward away from these faults.

Q. How is the geologic record of deformation on the OZD relevant to maximum earthquake magnitude?

A. Since one cannot use several centuries of seismic record as a sole indicator of future possible activity, the geologic record must be examined for evidence of prehistoric activity.

Earthquakes represent the disturbance that occurs during sudden fault movement, thus, the geologic record of past fault movement as preserved

in the rocks of a fault zone, allows us to look back millions of years beyond the historic record to get an idea of the level of earthquake activity that may have occurred.

The geologic information most important for assessing the seismic potential of a fault system is the rate of deformation, or slip rate, over about the last ten to twenty thousand years. The measured slip rate (testimony of Edward G. Heath) shows between 0.5 and 1.00 mm/year for the OZD over the past several million years. This is to be contrasted with other faults of greater activity and seismic potential such as the San Jacinto with 3.0 mm per year or the San Andreas with 37.0 mm/year. A specific line of reasoning has been developed by Mr. Heath to provide a quantitative estimate of maximum magnitude based on slip rate. In the context of the historic and pre-historic seismic history being discussed here, it is sufficient to note that earthquakes larger than about 6.5 - 7.0 (M_s) could not have occurred with any regularity over the past million years without producing a record of geologic deformation much more impressive than what is seen in the region of the OZD. Finally, the rate of vertical uplift and downwarping, which is often used as a measure of

the vigor of tectonism, indicates that the south coast region has been a stable area compared with the more active regions of California over the past several hundred thousand years. This is discussed in detail in the testimony of Dr. Roy J. Shlemon.

Q. Based on your investigations of the seismic history and geologic deformations in the area of San Onofre, have you drawn any conclusions?

A. My investigations reveal a consistent picture of relative stability over four different time scales involving four different types of data; the instrumental record of a half century, the historic record of several centuries, the geomorphic record of several hundred thousand years, and the geologic record of several million years. By itself, no one of these could be used as conclusive evidence that large earthquakes have not (and will not) occur in this area, but taken together they provide a very strong case for just this conclusion.

Q. Are there additional seismological considerations that have been investigated in arriving at an assignment of maximum magnitude?

A. Yes, several other seismological charactereistics of the OZD can be determined. The first concerns the nature of the stress field operative at the present time and at the time of development of the

OZD. Earthquake focal mechanisms provide the most direct way of estimating slip directions associated with the contemporary record of seismicity, that is, earthquakes for which we have modern seismographic data. From the slip direction or focal mechanism during individual earthquakes one can infer the direction of principal stresses. In order to derive such focal mechanisms, good seismographic coverage is necessary, a level which has only been obtained during the past decade. Since seismograph coverage on all sides of the earthquake source is desireable for a well constrained focal mechanism, the offshore region is especially difficult to handle as a result of the lack of stations on the seaward side. The other really important point to consider concerning the offshore zone is of course that there haven't been any significant earthquakes there with which a seismologist can work. Despite these difficulties, some information on focal mechanisms of events occurring in the southern California coastal region is available. The principal conclusion drawn from these focal mechanisms is that the pattern is irregular, with little preference for any one slip direction or system of fault planes. There is some preference for a general northerly direction for

the compressive axis. I conclude that the lack of consistent focal mechanisms is evidence that the regional stress levels are not at a high level. If the area were part of the active section of a plate margin, I would expect much more consistency in focal mechanisms and a higher level of seismicity. If stress levels are not dominated by a regional stress field, then residual stresses, which are much more influenced by local geological conditions, and thus more irregular, will be the ones revealed by current seismic activity.

Q. Given the irregular nature of focal mechanisms and the lack of seismicity on the South Coast Offshore Fault, on what basis have seismic characteristics for the OZD been assigned?

A. We have assumed that the Newport Inglewood zone is representative of the overall OZD in terms of seismological characteristics. Since the 1933 Long Beach earthquake (M 6.3) is the largest and most significant earthquake on this zone, it is the basis of the assignment of seismological charactereistics to the overall OZD. Although the modern seismic network was not in operation at the time of this earthquake, the earthquake was large enough to record long-period seismic waves on seismograph stations throughout the world. This

data made possible some special studies which have yielded a focal mechanism, an estimate of fault rupture length and depth, and a measure of fault slip associated with the earthquake. The conclusion is that the mechanism was primarily right lateral strike slip and involved an average slip of 41 cm over a rupture length of about 33 km, and that the depth of energy release was approximately 11 km. Since this is by far the largest earthquake anywhere near the OZD, it should carry the most weight in assigning characteristics to the OZD. We thus conclude that future significant earthquakes on the OZD can be best characterized as being strike slip, responding to a northerly direction of compression, and would involve rupture and energy release to depths of about 12-15 km.

Q. Have you considered any additional factors characteristic of the OZD that assist in assignment a maximum magnitude for the OZD?

A. Yes, I have reviewed the investigations presented by Mr. Heath in this proceeding. I would agree with him that assignment of a maximum magnitude for the OZD requires a multifaceted approach to bring to bear as many different lines of evidence as are available. As an example, one particular piece of

geologic information that has a direct bearing on the maximum magnitude for the OZD is the style of faulting or the degree of continuity. As discussed in Mr. Heath's testimony, the OZD consists of a complex series of short and sinuous sections of faults and folds. The seismological question is, can such systems generate large earthquakes. It is clear that large earthquakes require large rupture zones, that future earthquakes are unlikely to form on new ruptures but rather on existing ones and thus it seems unlikely that a long continuous or throughgoing rupture could develop on the OZD.

Q. Is assignment of M_S 7 on the OZD consistent with your assessment of the earthquake on which the SONGS 2 & 3 seismic design basis was predicated?

A. Ye[illegible] the early work for the SONGS site, I characterized the earthquake potential of the OZD in terms of a rupture length rather than a maximum magnitude. The reason for this was my concern that the only relevant prediction for earthquake engineering purposes is a prediction of ground shaking at the site. I believed at that time that it was possible and desireable to eliminate the uncertain step of estimating earthquake magnitude and go directly from rupture length to ground motion. Although a maximum magnitude was not

specified at the time of the Construction Permit hearing, one can ask now whether an M_s7 would have been consistent with the ground motion (.67g) used at that time. My answer in 1972 would have been yes. At that time although very little data was available close-in to large earthquakes, it already appeared that the design basis was adequate to cover virtually any "size" earthquake. My conclusion is strengthened by statistical analysis of the new data collected during the past ten years and by developments in numerical modelling of earthquake sources. My earlier objections to specification of a magnitude are now largely overcome by an improved understanding of the relationship between magnitude (M_s) and ground motion and reductions in the uncertainty of ground motion estimates that have occurred with the increased data now available.

Q. Have you an opinion as to the maximum magnitude that should be assigned to the OZD?

A. Forecasting the size of future earthquakes is a difficult task, and one in which there is considerable uncertainty. It is, however, not impossible and the uncertainties are not overpowering. It involves a large number of different types of evidence, each one of which has

uncertainties attached to it. I would also say that the process involves professional judgment, in much the same way that professional judgment enters into engineering assessments. The necessity of judgment can be seen by considering what would result if independent predictions of maximum parameters were made from each class of seismologic or geologic data, and then the maximum magnitude taken from the upper bound of these parameters. The result of "cascading" levels of conservatism yields a result which is essentially useless from an engineering viewpoint since it would make no real distinction between any different parts of western North America. In my opinion there is a real distinction between the earthquake potential of the OZD compared with other fault systems in southern California such as the San Jacinto, Imperial, and Elsinor. Its potential is less based on all the seismologic and geologic parameters we can quantify. My professional judgment of the overall geologic-seismic situation including the data presented by Mr. Heath in his degree-of-fault activity analysis leads me to conclude that M_s7 is a conservative maximum magnitude to assign to the OZD.

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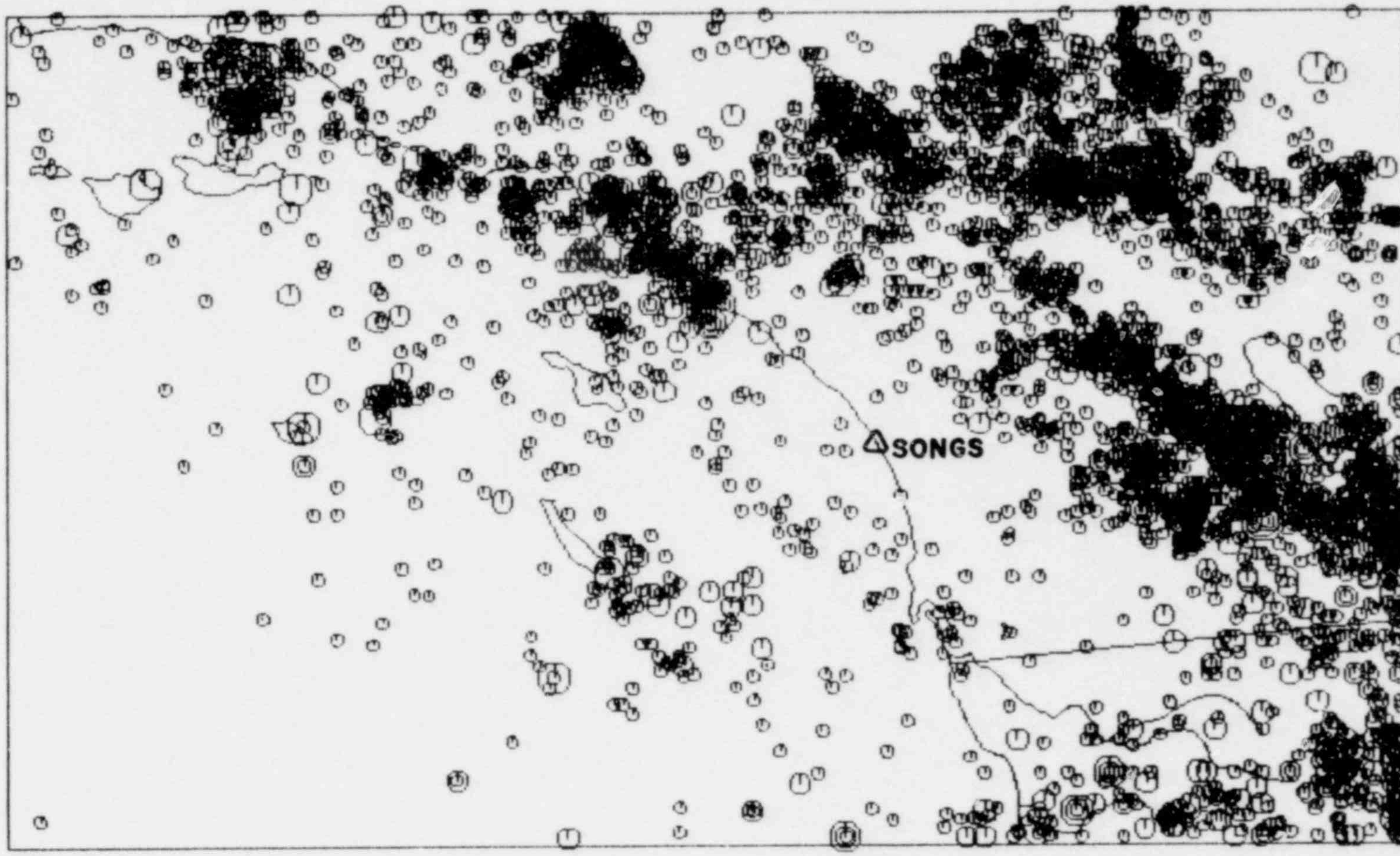
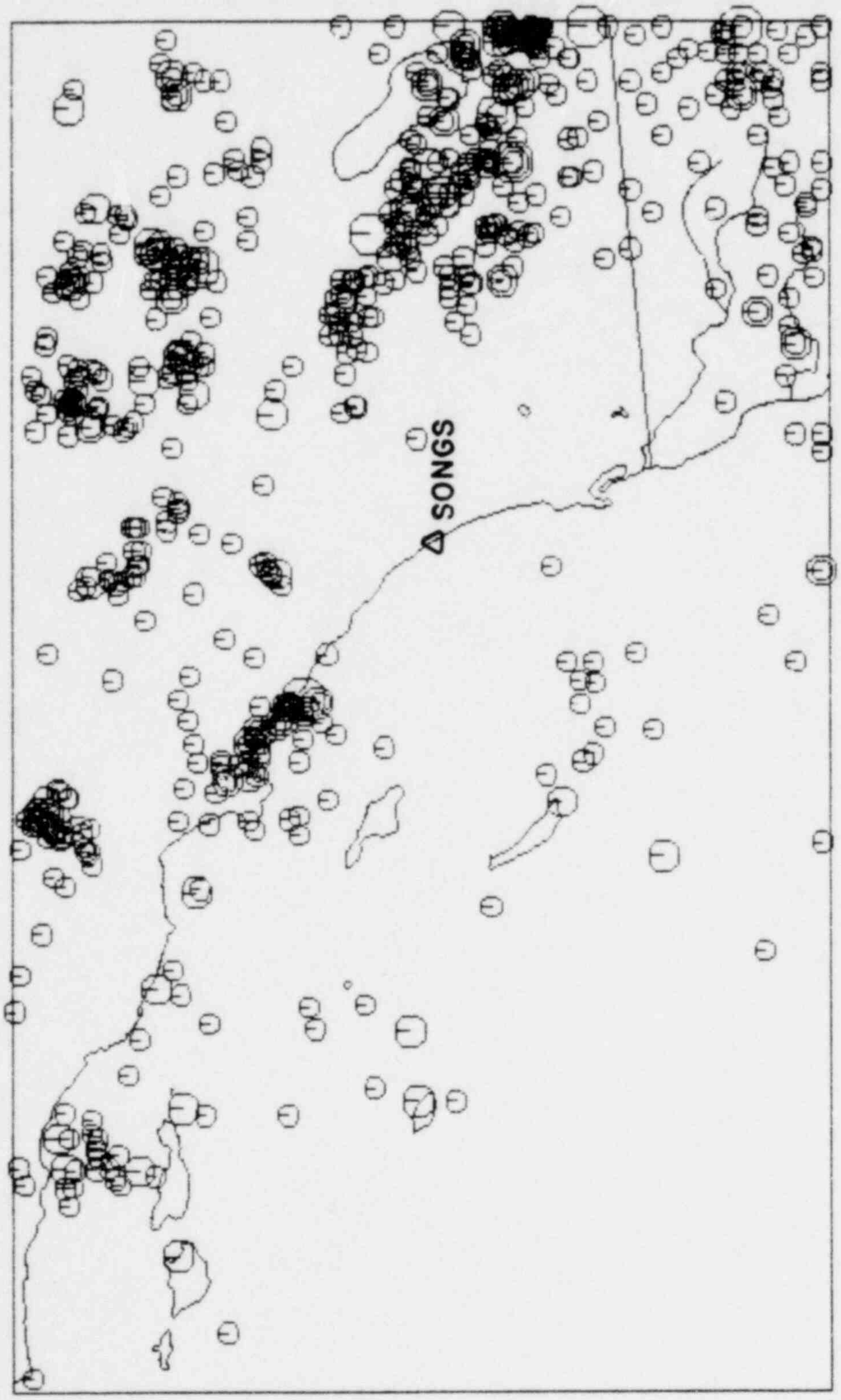


EPICENTER PLOT
M3-M6 AND ABOVE
CIT CATALOG 1932 - JUNE, 1980

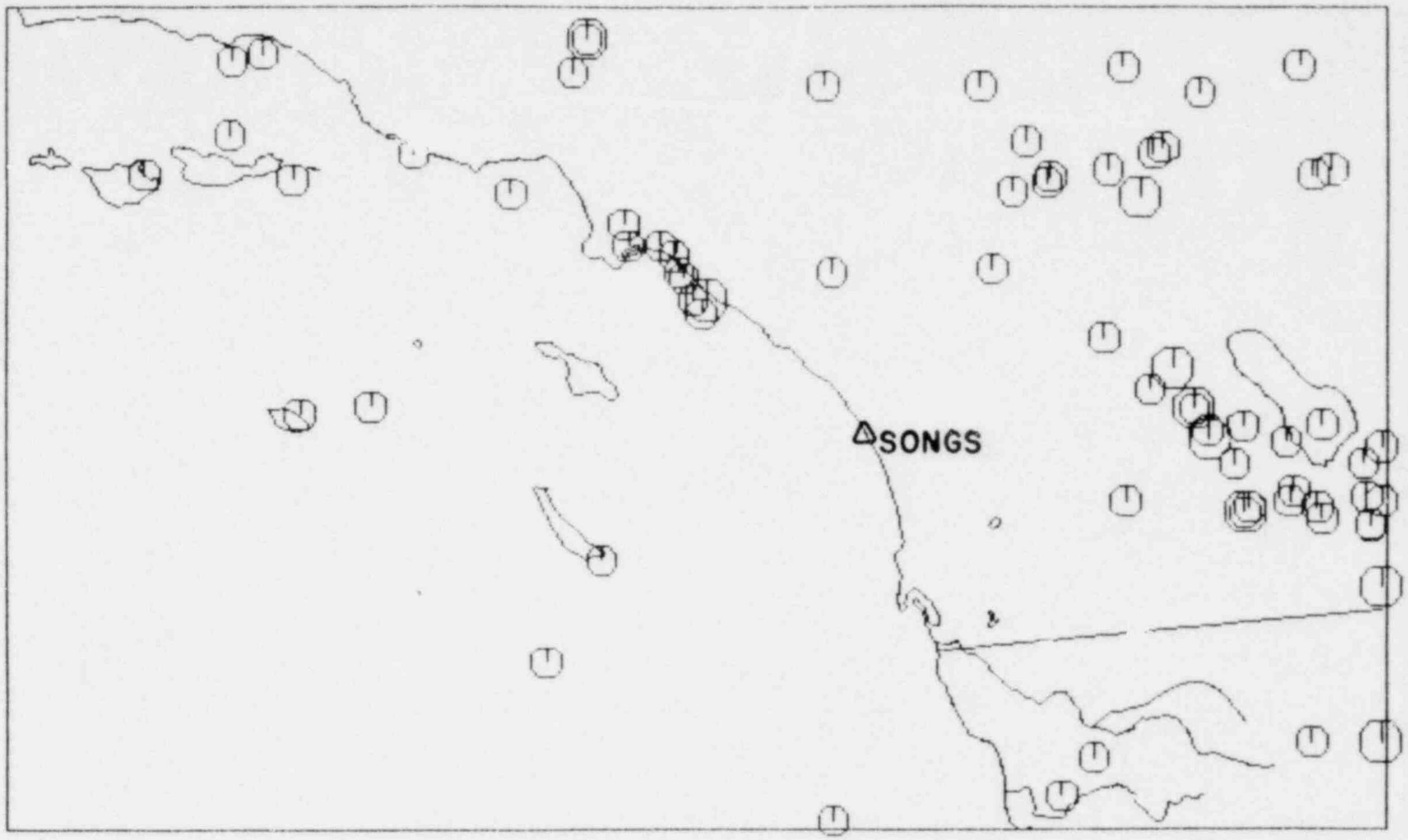
FIGURE SWS - A



EPICENTER PLOT
M4-M6 AND ABOVE
CIT CATALOG 1932 - JUNE, 1980

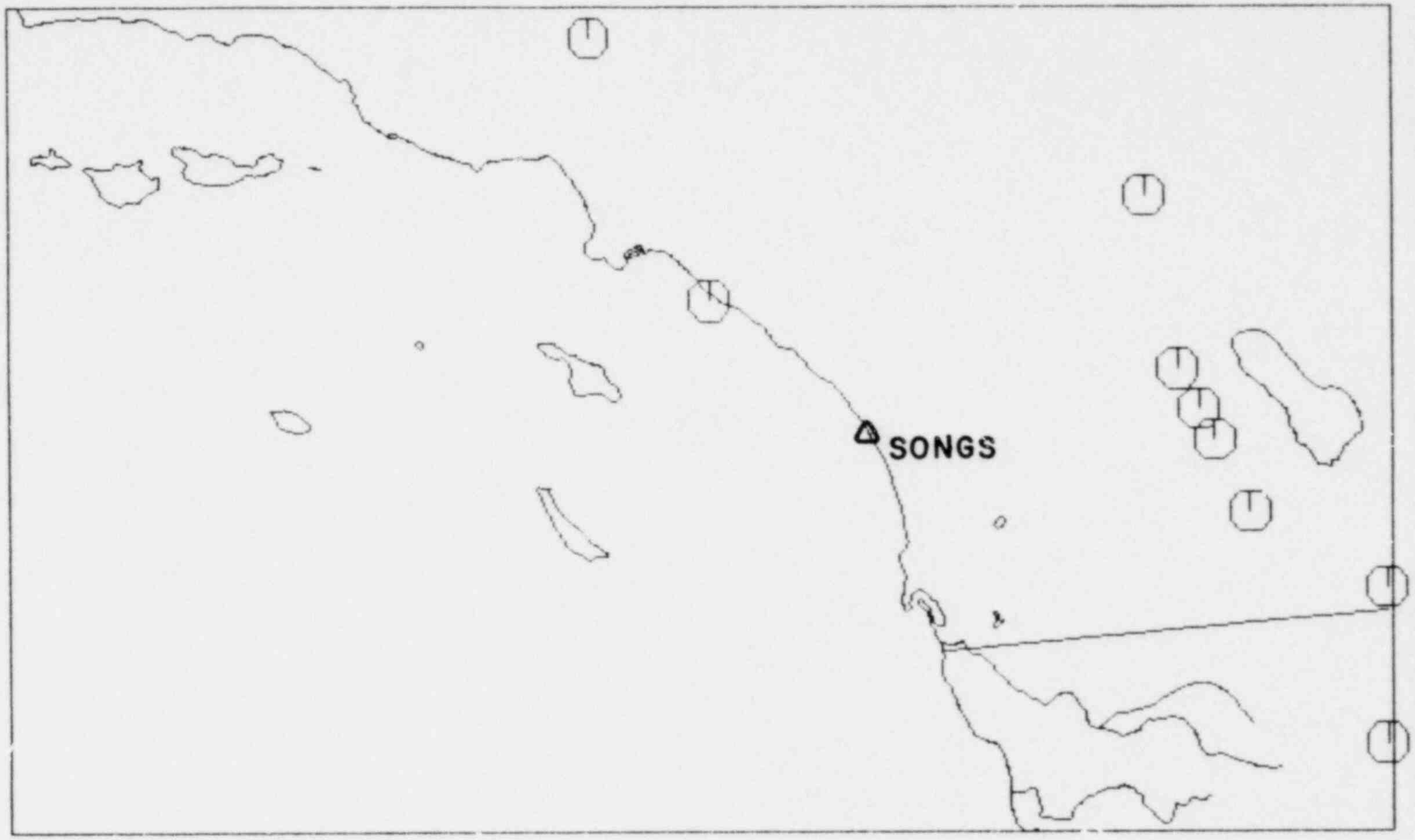
- 6.0 ≤ MAG
- 5.0 ≤ MAG < 6.0
- 4.0 ≤ MAG < 5.0

FIGURE SWS - B



EPICENTER PLOT
M5-M6 AND ABOVE
CIT CATALOG 1932 - JUNE, 1980

FIGURE SWS-C



6.0 ≤ MAG

EPICENTER PLOT
M6 AND ABOVE
CIT CATALOG 1932 - JUNE, 1980

FIGURE SWS - D

TESTIMONY OF LAWRENCE H. WIGHT

Q. Would you please state your name?

A. Lawrence Howard Wight.

Q. By whom are you presently employed?

A. TERA Corporation of Berkeley.

Q. In what manner are you associated with the Applicants in this proceeding?

A. My firm has been a consultant to the Applicants on seismic issues since approximately 1974. Since I joined the firm in 1976, I have been involved in these efforts in a variety of positions, initially in a very technical role, more recently in a position of technical management and direction.

Q. Would you please describe your formal education?

A. In 1965 I received my Bachelor's Degree in Engineering Management from Boston University. Between 1965 and 1967 I conducted research in geophysical fluid mechanics that led to a Master's Degree in Engineering Mechanics from the Pennsylvania State University in 1967. In 1971 I entered the Graduate Program in Geophysics at the University of Washington where I completed all the course requirements for a Ph.D.

Q. What professional positions have you had in the area of seismology or earthquake engineering?

A. In the years 1967 to 1969, I was employed by Lawrence Livermore Laboratory with the responsibility to

organize, implement and operate a seismic array around the Nevada Test Site. During 1969-1970, I was a lecturer at the Middle East Technical University in Turkey where I taught civil engineering courses and participated in earthquake engineering research. Between 1970-71 I was a lecturer of mathematics, physics, and geophysics at the Caribbean Meteorological Institute of the University of the West Indies. Between 1972 and 1976, I was employed again at the Lawrence Livermore Laboratory where I participated in or directed research in earthquake engineering. During this time I was also a lecturer at the University of California at Berkeley, Extension Division, in engineering and engineering mechanics and in 1976 I was an invited lecturer at Chabot College on seismology and earthquake hazards. My position at TERA Corporation is Vice President in charge of Geotechnical Engineering.

Q. What are your pertinent professional or organizational memberships?

A. I am a member of the Seismological Society of America, the American Geophysical Union, the Earthquake Engineering Research Institute, and the American Association for Advancement of Science.

Q. Have you written or presented articles or papers in the field of seismology and earthquake engineering?

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A. Yes. A list of such publications, reports, and abstracts is attached hereto.

Q. On what projects have you been retained as an expert consultant in seismology and earthquake engineering?

A. In 1977 Battelle Memorial Institute retained me to sit on a multi-disciplinary panel that was responsible for providing expert opinion on the safety of geologic waste repositories. My responsibility on this panel was for the areas of seismology and earthquake engineering. The panel meets annually to review on-going programs and make recommendations for future work.

I have also been retained by Lawrence Livermore National Laboratory/Nuclear Regulatory Commission to review and assess the seismic safety at the General Electric test reactor near Pleasanton, California.

Between 1977-78 the Pacific Northwest Laboratory retained me to examine the state of the art in establishing seismic design criteria and to postulate the design criteria that would be appropriate for a nuclear energy center on the Hanford Reservation.

In addition, I have directed many projects at my company involving seismic hazard analyses. These include studies for nine eastern nuclear power plants, all Department of Energy's facilities, all the commercial plutonium facilities in the U.S., the Diablo

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Canyon Nuclear Power Plant and the Humboldt Bay Nuclear Power Plant.

Q. Have you appeared as an expert in any previous hearings or trials?

A. Yes, I have given expert opinion to the ACRS on the seismic safety of the General Electric Test Reactor, and I have also appeared before the ACRS on the seismic safety of the following nuclear power plants:

1) Oyster Creek
2) Yankee Rowe
3) Ginna
4) Dresden 1 & 2
5) Palisades
6) Big Rock Point
7) Connecticut Yankee
8) LaCrosse
9) Millstone

Q. What is the purpose of your testimony on this proceeding?

A. One of the issues in this proceeding is whether based on the geologic and seismic characteristics of the OZD, assignment of M_s 7 as the maximum magnitude earthquake for the OZD renders the seismic design basis for SONGS 2 and 3 inadequate to protect the public health and safety. My testimony demonstrates and it is my conclusion that given occurrence of a M_s 7 event on the

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OZD, .67g as the anchor for the design response spectrum is conservative.

Q. On what do you base these opinions?

A. I base them largely on the result of studies my office has performed for Applicants, on my review of the relevant work performed by others, and my experience.

Q. What role did you play in the work your firm performed?

A. My firm has been responsible for a variety of seismological/earthquake engineering studies. Dr. Gerald A. Frazier, technical director of our Del Mar office, is giving testimony in this proceeding on the earthquake source modeling studies performed in that office.

I was responsible for the technical and project management of empirical ground motion studies performed in our Berkeley office and which are discussed in this testimony.

Q. Would you briefly describe the nature of the work your firm has performed for Applicants?

A. We have performed an extensive study of the available relevant earthquake acceleration data. The results of our data analysis and interpretation are presented in Exhibit LHW-1, "Evaluation of Peak Horizontal Ground Acceleration Associated with the Offshore Zone of Deformation at San Onofre Nuclear Generating Station," dated August, 1980. With regard to the effects that

structures have in reducing ground motion, we have used the available earthquake data to quantify the effect of structural filtering on soil structure interaction. The results of this study were presented in Exhibit LHW-2, "Reduction in Free Field Ground Motion Due to the Presence of Structures," dated August, 1980.

Q. Is there anything in your data set that makes it well suited for predicting ground motion at the SONGS site?

A. We selected the 192 peak ground acceleration ("PGA") recordings from 22 earthquakes based on a selection criteria that statistically tested and eliminated data irrelevant to the SONGS site. For example, we restricted the data set to accelerations recorded within 50 kilometers of the earthquake fault. We also restricted the data set to stations which recorded ground motion statistically consistent with the SONGS site geology. As another example we excluded recordings from the basements of large buildings and restricted the data set to recordings from instruments located either in the free field or at the ground level or basement of small buildings.

We further subjected this selected data set to quality screening. The recordings from earthquakes whose magnitude was uncertain were eliminated. Similarly, we eliminated recordings whose distance to the rupture surface could not be adequately defined.

Our data set can be used confidently to predict near-source ground motion. One measure of this confidence is the average distance compared to the prediction point. Our data base has an average distance of about 11 km. This compares with the Cal Tech data base having an average distance of about 50 km. This distance reduction was achieved through the introduction of data from several large non-north American earthquakes and some smaller magnitude near-source recordings. Our average distance of 11 km can be compared to the 8 km distance for SONGS.

Q. What conclusions were reached in your analysis of earthquake acceleration data?

A. As more specifically stated in LHW-1, the accelerations predicted from our statistical analysis of the data base correspond to a median prediction of .33g and an 84th-percentile prediction of .52g. My principal conclusion is that given a M_s 7.0 earthquake occurring at 8 km from the site, the design peak ground acceleration of .67g is conservative.

Several other conclusions were reached. The analysis confirmed that peak ground accelerations tend to saturate both with decreasing distance from the fault rupture surface, and with increasing magnitude at small distances. Also, the effects of site geology on peak ground accelerations in the near-source region is

negligible compared to the influence of other parameters, such as magnitude and distance. Finally, the calculations confirmed that earthquake accelerations can be considered lognormally distributed.

Q. Would you describe the assumptions you have made in your analyses and describe for us how you have tested the sensitivity of these assumptions?

A. There were three important assumptions or elements to our calculations:

(1) The functional form used in the regression analysis,

(2) The far field acceleration decay rate, and

(3) The inclusion of two very well-recorded earthquakes in the data base (San Fernando, 1971 and Imperial Valley, 1979).

We have examined the sensitivity of our results to these assumptions by repeating the analysis using different functional forms, different far field acceleration decay rates, and deleting from the data base the well-recorded eqartnquakes. These sensitivity studies, which were set forth in Section 3.0 of Exhibit LHW-1, showed that the SONGS predictions are insensitive to each of the above assumptions.

Q. Since submittal of LHW-1, have you refined or improved that analysis?

A. Subsequent to the SONGS report, LHW-1, we continued to investigate PGA in the near field. This involved

augmenting and refining the data base, implementing improvements to the magnitude definition, and performing additional sensitivity studies. Results of these additional analyses were presented to several scientific conferences (e.g., Campbell, K. W. and Davis, B. J. "The Effect of Fault Type on Recorded Peak Ground Accelerations", presentation to Eastern Section of Seismological Society of America ("SSA"), Pennsylvania State University (Oct. 28, 1980); Campbell, K. W. and Davis, B. J., "Statistical Analysis of Earthquake Ground Motion Characteristics, presentation to SSA, University of California, Berkeley (March 28, 1981); Campbell, K. W., and Polit, M. W., "An Empirical Analysis of the Source of Energy Release During the Imperial Valley Earthquake", presentation to SSA, University of California, Berkeley (March 25, 1981)), were submitted for journal publication (Campbell, K.W., "Near-Source Attenuation of Peak Horizontal Acceleration", submitted to Bulletin of the Seismological Society of America (May 4, 1981)) and were published as a TERA Technical Report (1980). Results of the extensions and improvements have further strengthened our previous conclusions. Specifically, our current and previous predictions for M_S 7.0 at 8 km are presented in Figure LHW-A "Effect of Improvements on SONGS Predictions," for both the Statistical and Physical models. The difference between

the previous and current results for both models are essentially negligible. The results of these subsequent investigations have thus increased the level of confidence in our earlier predictions.

I would like to elaborate on these improvements, and in particular, the results of some of the additional sensitivity studies:

- o After LHW-1, the magnitude scale was improved. The improvement amounted to the use of M_S for magnitudes greater than 6 and M_L for magnitudes less than 6. We have examined the sensitivity of this criterion and find the results to be exeeedingly insensitive to the division point between M_L and M_S.
- o The data base for LHW-1 was frozen in January 1980. In August, 1980, we increased the data base by adding 37 acceleration components from 5 earthquakes. The improved data base consists of 229 acceleration components recorded from 27 separate earthquakes.
- o Refinements were made to certain magnitude and distance values based on further investigation.
- o Whereas in LHW-1, our calculational approach employed two physically-derived constraints in the regression analysis, (the "Physical Model"), we subsequently tested the sensitivity of our results

to these constraints by repeating our calculations without the constraints. This is termed the "Statistical Model".

This expanded data base allowed for more elaborate sensitivity studies. This allowed us to isolate the influence of fault type and building effects.

We have carefully examined our results for any influence of fault type (e.g., reverse vs. strike-slip). As Figure LHW-B, "List of Earthquakes in Data Base by Fault Type" indicates, the 27 earthquakes in the augmented data set represent a diversity of fault types, but principally strike-slip and reverse. When the effect of fault type is incorporated in the regression analysis, we find that there is a systematic upward bias in the ground motion associated with reverse faults. Reverse fault ground motion is approximately 23 percent higher than the corresponding ground motion for strike-slip faults. This confirms the conservatism of our analysis since our SONGS ground motion predictions include reverse fault ground motion.

Our augmented data base enabled us to precisely address the effect of structure size on in-structure recordings relative to free-field. The location of the instruments that recorded the majority of the data in our data base can be divided as follows: free-field, ground level of small (one to two story) buildings,

basement level of larger (three to twenty stories) buildings. The effects of both structural embedment and building size were studied by regression analysis on these instrument locations. Comparisons were made between small buildings/free-field recordings at ground level (115 components) and recordings obtained in the lowest basement level of larger buildings (40 components). The results indicated that the peak ground acceleration recorded in the basement of larger buildings was on the average 24 percent lower than the corresponding accelerations recorded at ground level in small buildings or the free field. This result is significant at the 90 percent confidence level.

Q Do you have additional evidence to support your statistically derived results that the ground motion in the basement of larger building in the near-source region from large earthquakes is roughly 25 percent less than the corresponding free-field ground motion?

A. Yes. We have compiled additional evidence that specifically addresses the reduced ground motion associated with in-structure recordings. These results were first tabulated in our report LHW-2 "Reduction in Free Field Ground Motion Due to the Presence of Structures" d[illegible]d August 1980. This work also has been extended and elaborated upon. Improved comparisons have been presented to a scientific conference (Darragh, R. B.

and Campbell, K. W. "Empirical Assessment of the Reduction in Free Field Ground Motion Due to the Presence of Structures", presentation to SSA, University of California, Berkeley (March 23, 1981), SSA). This report and abstract tabulate and analyze data from nearby instruments and compare recordings obtained in the free-field, in small structures and in very large structures. On the average, the peak ground acceleration in very large buildings is approximately 30 percent less than the corresponding free-field acceleration. This reduction is a function of frequency with the reduction factor being roughly constant between 25 Hz and 2 Hz.

Q. As a result of your studies, can you conclude that .67g is a conservative anchor point for the design response spectrum given a M_s 7 event on the OZD?

A. Yes. The San Onofre design criteria of .67g has been compared above to predictions based on instrumental values. The instrumental one standard deviation free-field acceleration for the San Onofre site is .52g for an M_s 7.0 at 8 km. This should be further reduced for the strike-slip environment and by consideration of structure effects. The corresponding one standard deviation design acceleration is then even less, perhaps one-half of the acceleration to which structures at the

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San Onofre site have been designed. The seismic design criteria for SONGS 2 and 3 are extremely conservative.

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Lawrence H. Wight

PUBLICATIONS, REPORTS AND ABSTRACTS

"Acoustic Waves in the Ionosphere," AFOSR-67-1904, August 20, 1967.

"Analysis of the Cooling System for the Plowshare Nuclear Explosive," UCRL-51527, 45 pages, February 1, 1974.

"Empirical Tuff Equation-of-State Models," UCID-16764, 23 pages, April 24, 1975.

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"Site Response Calculations for Nuclear Power Plants," UCRL-77371, 9 pages, October 14, 1975.

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"Seismic Risk Analysis for the General Electric Plutonium Facility, Pleasanton California, Part I," TERA Corporation Report, July 31, 1978.

"Response Spectrum Attenuation Relation for the Eastern United States," Abstract to the Eastern Section of the SSA, October 1979.

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"The Feasibility of Computer Interrogation of Experts for WISAP," PNL-2862, May, 1980.

"Evaluation of Peak Horizontal Ground Acceleration Associated With the Offshore Zone of Deformation at San Onofre Nuclear Generating Station," TERA Corporation Report, July 1980.

"Evaluation of Peak Horizontal Ground Acceleration Associated With the Hosgri Fault at Diablo Canyon Nuclear Power Plant," TERA Corporation Report, August, 1980.

FIGURE LHW-A

EFFECT OF IMPROVEMENTS ON
SONGS PREDICTIONS

M_s	PGA(g)	
	m	m + σ
Previous Physical Model		
6.5	0.29	0.46
7.0	0.33	0.52
Current Physical Model		
6.5	0.27	0.41
7.0	0.32	0.49
Current Statistical Model		
6.5	0.26	0.39
7.0	0.33	0.50

FIGURE LHW-B

LIST OF EARTHQUAKES IN DATA BASE
BY FAULT TYPE

Earthquake Name	Date Yr-Mo-Day	Magnitude	Fault Type
Long Beach	33-03-11	6.2	Strike-Slip
Helena, Montana	35-10-31	5.5	Normal
Imperial Valley	40-05-19	7.1	Strike-Slip
Santa Barbara	41-07-01	5.9	Reverse
Kern County	52-07-21	7.7	Oblique
Daly City	57-03-22	5.3	Strike-Slip
Parkfield	66-06-28	6.0	Strike-Slip
Fairbanks, Alaska	67-06-21	5.7	Strike-Slip
Koyna, India	67-12-10	6.5	Strike-Slip
Borrego Mtn.	68-04-09	6.7	Strike-Slip
Lytle Creek	70-09-12	5.4	Strike-Slip
San Fernando	71-02-09	6.6	Reverse
Bear Valley	72-02-24	5.1	Strike-Slip
Sitka, Alaska	72-07-30	7.6	Oblique
Managua, Nicaragua	72-12-23	6.2	Strike-Slip
Point Mugu	73-02-21	5.9	Reverse
Lima, Peru	74-10-03	7.6	Reverse
Hollister	74-11-28	5.1	Strike-Slip
Oroville	75-08-01	5.7	Normal
Gazli, USSR	76-05-17	7.0	Reverse
Santa Barbara	78-08-13	5.7	Reverse
Tabas, Iran	78-09-16	7.7	Reverse
Bishop	78-10-04	5.8	Strike-Slip
Malibu	79-01-01	5.0	Reverse
St. Elias, Alaska	79-02-28	7.2	Reverse
Coyote Lake	79-08-06	5.9	Strike-Slip
Imperial Valley	79-10-15	6.9	Strike-Slip

TESTIMONY OF DR. I. M. IDRISS

Q. Would you please state your name?

A. Dr. I. M. Idriss.

Q. By whom are you presently employed?

A. I am presently employed by Woodward-Clyde Consultants in San Francisco. I am a Principal and a vice-president of this firm.

Q. In what manner are you associated with the Applicants in this proceeding?

A. I am a consultant to the Applicants in areas of geotechnical earthquake engineering. I am also the responsible principal for all consulting work done by Woodward-Clyde Consultants for this project.

Q. Would you please describe your formal training?

A. My formal training has been in civil engineering with emphasis on geotechnical engineering. I received a Bachelor of Civil Engineering degree in 1958 from Rensselaer Polytechnic Institute in Troy, New York, and a Master of Science in Civil Engineering in 1959 from the California Institute of Technology in Pasadena, California. I received a Ph.D. in 1966 from the University of California in Berkeley; my major was in geotechnical engineering and the minors were in applied mathematics and in engineering mechanics.

Q. What professional positions have you held in the areas of geotechnical earthquake engineering?

A. I am currently director of geotechnical earthquake engineering at Woodward-Clyde Consultants; I have had this responsibility since 1974. From 1969 through 1973, I was working in the area of geotechnical earthquake engineering at Woodward-Clyde Consultants. From 1967 through 1969, I was a consultant to various architect-engineering firms, structural engineers, and others in geotechnical earthquake engineering.

Q. Have you been associated with any educational institutions?

A. From 1966 to 1969, I was Lecturer in soil mechanics and a research engineer in geotechnical earthquake engineering in the Department of Civil Engineering at the University of California in Berkeley. I continued my research activity, on a part-time basis, until 1974. Since 1977, I have been consulting professor at Stanford University, where I teach a course on geotechnical earthquake engineering.

Q. Do you hold any professional registrations in the State of California?

A. Yes, I am a registered Professional Engineer, Civil, in the State of California.

Q. What are your pertinent professional or organizational memberships?

A. I am a member of the following professional organizations:

American Society of Civil Engineers

Structural Division:
- Nuclear Structures and Materials Committee, (Chairman, Ad Hoc Group on Soil-Structure Interaction, 1974-1979);
- Seismic Analysis Committee (Chairman, Subcommittee on Sliding and Overturning);
- Nuclear Standards Committee

Geotechnical Division:
- Publications Committee

Earthquake Engineering Research Institute

Seismological Society of America

Structural Engineers Association of Northern California

Seismology Committee: (Soil-Structure Interaction Subcommittee; Chairman 1971-1972; 1977-1979; Chairman, Subcommittee on Sliding and Overturning 1979-date)

U.S. Committee of the International Commission on Large Dams

American Petroleum Institute

Q. Have you written or published articles in the field of geotechnical earthquake engineering?

A. Yes, I have authored or co-authored over 60 technical papers and research reports on subjects relating to geotechnical aspects of earthquake engineering (seismic response of soil deposits; earth structures including slopes and earth and rockfill dams; dynamic soil material properties; liquefaction; soil-structure interaction; and probabilistic and deterministic

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assessment of characteristics of ground motions.) A list of my publications is attached.

Q. Have your served with formally-organized groups concerned wholly or in part with matters of seismic safety?

A. Yes. Since 1970, I have been a member of the Seismology Committee of the Structural Engineers Association of Northern California and a member (and Chairman) of its subcommitteee that developed recommendations which became part of the seismic design provisions of the Uniform Building Code. From 1974 to 1977, I was a member of the subcommittee on Ground Motions and Site Effects of the Applied Technology Council; this subcommittee developed recommendations which became part of ATC-3 design provisions. From 1970 to 1976, I was a consultant to the Government of Italy on reactor safety related to earthquake effects and assisted the Italian nuclear regulatory commission in developing safety guidelines. From 1975 to 1977, I was a consultant to the International Atomic Energy Agency in Vienna and co-authored IAEA's Safety Guide on "Seismic Analysis and Testing of Nuclear Power Plants." I am a member of the Nuclear Standards Committee of ASCE, which is writing standards for "Seismic Analysis of Safety Class Structures." I am currently serving as a panel member of the Seismic Review Panel for the State of California

Public Utilities Commission reviewing seismic aspects of the Point Conception LNG Terminal.

Q. On which projects have you been retained as an expert consultant in geotechnical earthquake engineering?

A. Since 1967, I have been retained in such capacity on several projects. I have directed and participated in the following projects:

Nuclear Power Plants: Bolsa Island, Cooper Station, Ft. St. Vrain, Ranch Seco, Farley, Trojan, Mendicino, Summer, Shearon Harris, Bugey (France), Satsop, Bandar Abbas (Iran), Torrente Saccione (Italy), Marzola (Italy), South Texas Project, Stanislaus, Fast Flux Testing Facility, Davis Besse, Pilgrim, Braidwood, Clinton, Humboldt, Indian Point, Oyster Creek, Hanford, SONGS 1, and SONGS 2 & 3.

Earth and Rockfill Dams: Approximately 30 earth and rockfill dams in California, Alabama, Alaska, North Carolina, Tennessee, Utah, and in Latin America.

Industrial Facilities: Offshore platforms in California, Alaska, and New Zealand; waterfront facilities, fossil plants, office buildings and other industrial facilities in California, Idaho, Alaska, New Jersey, Texas, Arizona, Washington,

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France, Puerto Rico, Europe, Middle East and Latin American.

Applied Research and Non-Site Specific Studies: Seismic soil structure interaction for GESSAR and General Electric's Standard Plant (1973-date); behavior of marine clay sediments under earthquakes and wave loading conditions (1973-date); behavior of soil-pile-structure systems during earthquakes (1976-79); probabilistic and deterministic assessment of earthquake ground motions (1976-date); offshore Alaska seismic exposure studies (1977-81); engineering characterization of earthquake ground motions, which is a generic study initiated in late 1980 for USNRC to develop guidelines for seismic input for nuclear plants.

Q. Have you presented expert opinion or testimony?

A. Yes, since 1967 I have presented expert opinion and testimony, orally and in writing, to municipal, state and federal regulatory bodies such as the Advisory Committee on Reactor Safeguards and to foreign and international regulatory bodies.

Q. What is the purpose of your testimony in this proceeding?

A. One of the issues in this proceeding is whether assignment of M_s 7 as the maximum magnitude earthquake for the OZD renders the seismic design basis for SONGS

2 & 3 inadequate to protect the public health and safety. My testimony presents the results of earthquake ground motion studies based on recorded data conducted subsequent to issuance of the construction permit for SONGS 2 & 3 to examine the adequacy of the seismic design basis for SONGS 2 & 3, as represented by the .67g DBE and the spectral shape proposed in Section 2.5.2.6 of the FSAR. My testimony demonstrates and it is my conclusion that the DBE spectrum for SONGS 2 & 3 is conservative relative to the resulting ground motion from such an event.

Q. Would you please describe the approach you have developed to estimate the characteristics of ground motion at the San Onofre site resulting from an M_s 7 earthquake on the OZD?

A. My approach involves three steps: First, I used recorded data to develop site-specific empirical attenuation relationships for a magnitude M_s 6.5 earthquake. This provided estimates of mean and 84th percentile instrumental peak acceleration and response spectra at SONGS. Second, I scaled the instrumental peak acceleration and response spectra to a magnitude M_s 7 and compared the resulting 84th percentile instrumental response spectrum with the SONGS 2 & 3 DBE spectrum. Third, I verified my results with ground

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motion data recorded in the 1979 Imperial Valley earthquake ("IV-79").

Q. Why did your approach to this problem commence with a M_s 6.5 earthquake on the OZD?

A. M_s 6.5 is a reasonable maximum magnitude earthquake consistent with the geologic and seismological features of the NIZD which was conservatively taken as representative of the seismic potential of the OZD for purposes of designing SONGS 2 & 3. (See testimony of Edward G. Heath). Based on that determination, the first analysis of ground motion at the site was based on a M_s 6.5 earthquake. Subsequently, as a result of the additional conservatism incorporated in estimation of the maximum magnitude event, the results of my initial analysis were scaled to M_s 7.

Q. Would you describe step one in your analysis, the development of site-specific empirical attenuation relationships and the development of estimated mean and 84th percentile instrumental peak acceleration and response spectra for SONGS 2 & 3 for a M_s 6.5 earthquake?

A. The development of site-specific empirical attentuation relationships was accomplished by the selection of earthquake recordings screened according to source factors, travel path and local site conditions appropriate to the San Onofre site. A regression analysis of peak acceleration and response spectral

values for the selected accelerograms was then performed to derive these relationships.

The screening of available accelerograms was accomplished considering the following criteria:

Source Factors:

Earthquakes of approximate magnitude 6.5 were considered.

Travel Path Effects:

Accelerograms recorded in the Western United States were considered (i.e., same geographic locale).

Local Site Conditions:

The accelerograms were recorded at sites having subsurface conditions generally similar to those at the site of San Onofre Nuclear Generating Station.

The results of the above screening process led to the selection of 56 accelerograms obtained during seven earthquakes in the M_L range 6.3 to 6.5 and M_S range 6.3 to 6.7. Submitted herewith are Exhibit IMI-1, "Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generating Station, June 1979, Section 5, Maximum Site Ground-Motion Parameters, Figures 8, 9, 10 and 11" and Exhibit IMI-2, "Report of the Evaluation of Maximum Earthquake and Site Ground

Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generating Station, June 1979, Appendix J, Development of Attentuation Relationships for SONGS." Both exhibits describe in more detail the manner in which the data were selected and treated.

Exhibits IMI-1 and IMI-2 discuss the data in terms of M_L rather than M_S. Exhibit IMI-3, "NRC Staff Question 361.52 and Response" is submitted herewith. Exhibit IMI-3 provides the M_S values for the earthquakes used in these studies.

In arriving at the final form of the attenuation relationships, a much larger number of recordings obtained on soil sites from Western United States earthquakes with magnitudes approximately equal to 6.5 was examined. Submitted herewith is Exhibit IMI-4, "Report of the Evaluation of Maximum Earthquakes and Site Ground Motion Parameters Associated with the Offshore Zone of Deformation San Onofre Nuclear Generation Station, June 1979, Appendix I, Development of Peak Acceleration Attenuation Relationships for Soil Site and Combined Soil and Rock Site Data Sets." Exhibit IMI-4 examines the suitability of attenuation form $a = \alpha(R + C)^{\beta}$, and provides a basis for selecting an appropriate value for parameter C for magnitude 6.5 earthquakes. Visual examination of the data indicates

the flattening of attentuation at close distances. It was noted that this trend would require a non-zero value of C. Further support for the selected form of the attenuation relationship and quantification of parameter C was provided by simulation studies. Such studies are described in Exhibit IMI-5, "NRC Staff Question 361.53 and Response."

It was concluded that: (1) the functional form $a = \alpha(R + C)^{\beta}$ adequately describes the attentuation of acceleration with distance for a given magnitude, and (2) the selected value of C = 20 for M_s 6.5 is consistent with the constraints and guidelines indicated by the simulation studies and by statistical analysis of recorded ground motion data.

The site-specific attenuation relationships for peak instrumental acceleration are summarized in Figure 8 of Exhibit IMI-1, which shows the data points and the mean and 84th percentile attenuation curves. Similar relationships were developed for the attenuation of instrumental spectral velocity for 25 individual periods in the period range of .04 to 2 seconds. As an example, the attenuation curves and associated data points for a period of .1 seconds are presented on Figure 9 of Exhibit IMI-1.

From the site-specific attenuation relationships developed from the regression analyses the mean and 84th

percentile peak accelerations and response spectra at SONGS site resulting from a M_s 6.5 earthquake on the OZD were obtained. The mean and 84th percentile instrumental peak accelerations are .42g and .57g, respectively. The mean and 84th percentile instrumental response spectra are shown in Figure 10 of Exhibit IMI-1.

Figure 11 of Exhibit IMI-1 presents a comparison of the 84th percentile spectrum derived using recorded data (that is, the instrumental spectrum) with the design basis (DBE) spectrum for SONGS. As was noted in Exhibit IMI-1, the DBE spectrum exceeds the instrumental spectrum at all periods.

Q. Would you please describe step two of your analysis: your scaling of the 84th percentile instrumental peak acceleration and response spectrum for M_s 6.5 to a magnitude M_s 7 and your comparison of the resulting spectrum with the SONGS 2 & 3 DBE spectrum?

A. The procedure involved and the relationships used for scaling the 84th percentile instrumental peak acceleration and response spectrum at SONGS 2 & 3 from M_s 6.5 to M_s 7 is described in Exhibit IMI-6, "NRC Staff Question 361.54 and Response." The relationships given in IMI-6 and the results of simulation studies indicate that: (1) the dependence of peak acceleration on magnitude decreases with decreasing source distance; (2) the dependence of peak acceleration on magnitude at

close distances decreases as the magnitude increases; and (3) the dependence on magnitude of spectral ordinates at different periods increases with increasing period.

As given in IMI-6, the scaling factor (from M_s 6.5 to M_s 7) is 1.11 for periods up to .2 seconds increasing to 1.4 for periods in the range 1 to 2 seconds. Using the relationships in IMI-6 and the 84th percentile instrumental response spectral ordinates for magnitude 6.5 (given in Figure 11 of Exhibit IMI-1), the 84th-percentile instrumental response spectrum for M_s 7 earthquake on the OZD was obtained as shown in attached Figure IMI-A, "Instrumental 84th Percentile Response Spectra Estimated for SONGS from Magnitudes 6.5 and 7 Earthquakes on the OZD." The 84th percentile instrumental peak acceleration for a M_s 7 is estimated to be .63g compared to .57g for a[illegible] 6.5.

Attached Figure IMI-B "Comp[illegible] of the 84th Percentile Instrumental Spectra with [illegible]e DBE Spectrum" presents a comparison of the 84th percentile instrumental spectra for M_s 6.5 and M_s 7 with the DBE spectrum for SONGS 2 & 3. The DBE spectrum exceeds the 84th percentile instrumental spectra for M_s 6.5 and M_s 7 at all periods.

The DBE spectrum is a design spectrum; the equivalent instrumental spectrum would be significantly

higher than the design spectrum, as noted by Dr. Robert McNeill. Therefore, the instrumental spectrum equivalent to the design DBE spectrum is significantly higher than the 84th percentile instrumental spectra for M_s 6.5 and M_s 7 at all periods.

Q. Would you please describe the verification of your results with ground motion data recorded in the 1979 Imperial Valley earthquake?

A. Additional strong motion recordings were obtained from the October 15, 1979 Imperial Valley earthquake. Accelerograms recorded during this earthquake provided significant data, particularly at near source distances. The examination of the 1979 Imperial Valley earthquake data confirmed the conclusions reached with regard to the selected form of the attentuation relationship and quantification of parameter C. These observations are set forth in Section 3-b of Exhibit IMI-7, "NRC Staff Question 361.55 and Response" and Section 3 of IMI-5.

Peak accelerations and response spectra for horizontal components of the IV-79 earthquake are presented in Exhibits IMI-7 and IMI-8, "NRC Staff Question 361.57 and Response." As shown in Exhibit IMI-7, the mean and 84th percentile peak acceleration values for IV-79 at 8 km are .32g and .44g, respectively. The mean and 84th percentile instrumental

response spectra for IV-79 corresponding to a distance of 8 km are illustrated in Figure 361.55-3 of Exhibit IMI-7.

The mean and 84th percentile peak horizontal accelerations for IV-79 earthquake at 8 km are significantly below the .63g instrumental peak acceleration derived for M_s 7. They are also significantly below the .67g acceleration used as the horizontal design basis for SONGS 2 & 3. As indicated in Figure IMI-C "Comparison of the Imperial Valley 1979 Spectra with the 84th Percentile Instrumental Spectrum and the DBE Spectrum," the 2% damping horizontal DBE spectrum and the 84th percentile instrumental response spectrum for M_s 7 envelop the mean and 84th percentile instrumental spectra associated with horizontal ground motions at 8 km from the 1979 Imperial Valley earthquake.

Q. Have you made an estimate of the probability of exceedance of SONGS 2 & 3 DBE spectrum?

A. Yes. Equal-probability-of-exceedance instrumental response spectra were developed from the results of probabilistic seismic exposure analyses. The results of these analyses are shown in attached Figure IMI-D "Comparison of SONGS 2 & 3 DBE Spectrum with Equal Probability of Exceedance Instrumental Spectra." As shown in Figure IMI-D, the SONGS 2 & 3 DBE spectrum coincides with the instrumental spectrum with an equal

probability of exceedance of 1 x 10^{-4} at zero period and exceeds this spectrum at all other periods. At periods greater than approximately .5 sec the probability of exceedance is less than 10^{-5}.

However, the SONGS 2 & 3 DBE spectrum is a design spectrum; the equivalent instrumental spectrum would be significantly higher than the design spectrum, as noted by Dr. Robert McNeill. Therefore, the annual probability of exceedance of the SONGS 2 & 3 DBE spectrum is estimated to be at least one order of magnitude, and more likely two orders of magnitude lower than shown in Figure IMI-D.

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[Attachment]

DR. I. M. IDRISS

Publications

Technical Articles

1. "Analysis of Soil Liquefaction: Niigata Earthquake," by H. B. Seed and I. M. Idriss, Journal of the Soil Mechanics and Foundations Div., ASCE, Vol. 93, No. SM3, May 1967.

2. "Response of Earth Banks During Earthquakes," by I. M. Idriss and H. B. Seed, Journal of the Soil Mechanics and Foundations Div., ASCE, Vol. 93, No. SM3, May 1967.

3. "Finite Element Analysis for the Seismic Response of Earth Banks," by I. M. Idriss, Journal of Soil Mechanics and Foundations Div., ASCE, Vol. 94, No. SM3, May 1968.

4. "Seismic Response of Horizontal Soil Layers," by I. M. Idriss and H. B. Seed, Journal of Soil Mechanics and Foundations Div., ASCE, Vol. 94, No. SM4, July 1968.

5. "An Analysis of Ground Motions During the 1957 San Francisco Earthquake," by I. M. Idriss and H. B. Seed, Bulletin of the Seismological Society of America, Vol. 58, No. 6, December 1968.

6. "Influence of Soil Conditions on Ground Motions During Earthquakes," by H. B. Seed and I. M. Idriss,

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Journal of the Soil Mechanics and Foundations Div., ASCE, Vol. 95, No. SM1, January 1969.

7. "Influence of Geometry and Material Properties on Seismic Response of Soil Deposits," by I. M. Idriss, H. B. Seed and H. Dezfulian, Proceedings, 4th World Conference on Earthquake Engineering Santiago, Chile, January 1969.

8. "Influence of Modulus Variation with Effective Pressure on the Seismic Response of Cohesionless Deposits," by I. M. Idriss, Proceedings, Specialty Session on Soil Dynamics, 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, August 1969.

9. "Characteristics of Rock Motions During Earthquakes," by H. B. Seed, I. M. Idriss and F. W. Kiefer, Journal of the Soil Mechanics and Foundations Div., ASCE, Vol. 95, No. SM5, September 1969.

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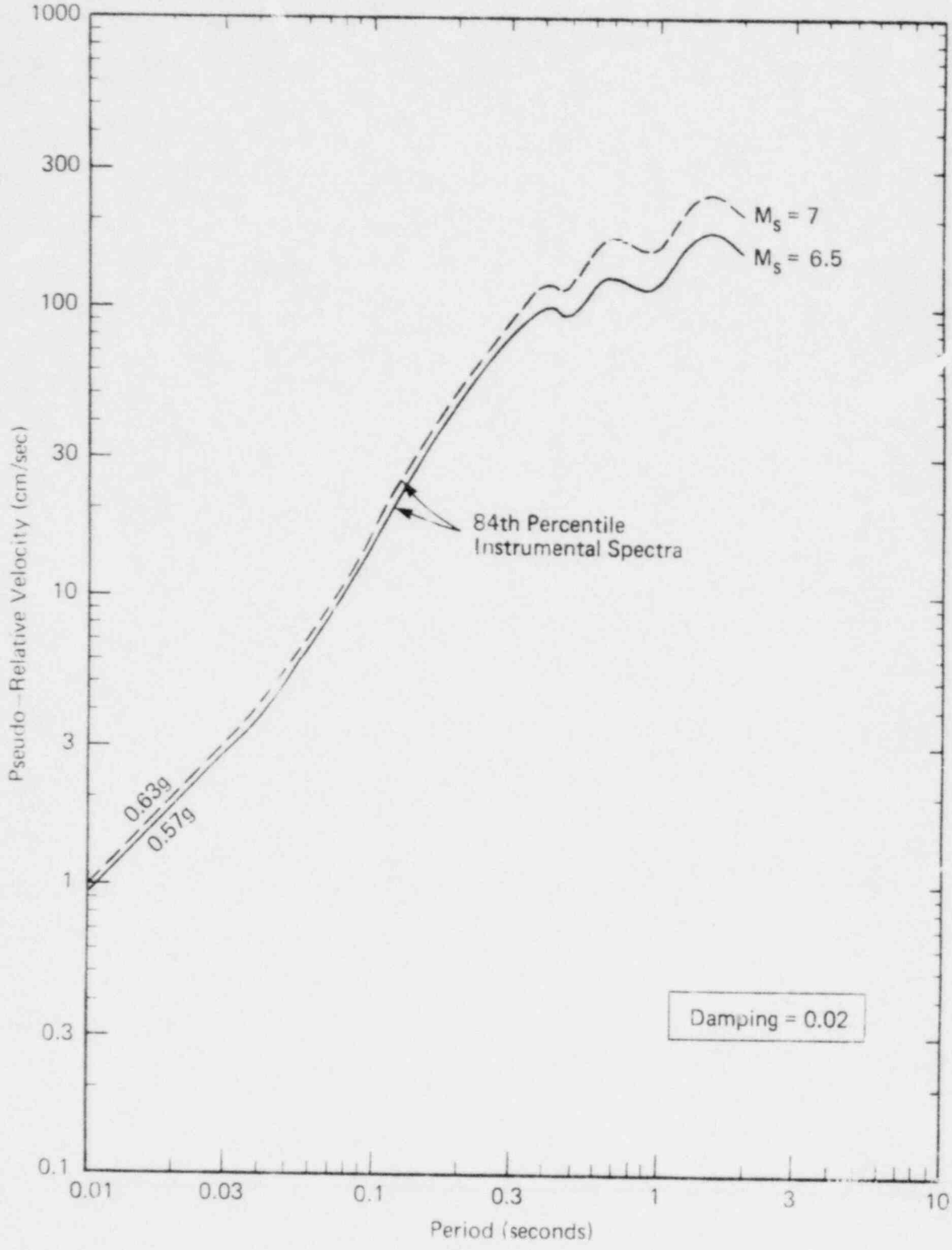

Figure IMI-A — Instrumental 84th Percentile Response Spectra Estimated for SONGS from Magnitudes 6.5 and 7 Earthquakes on the OZD

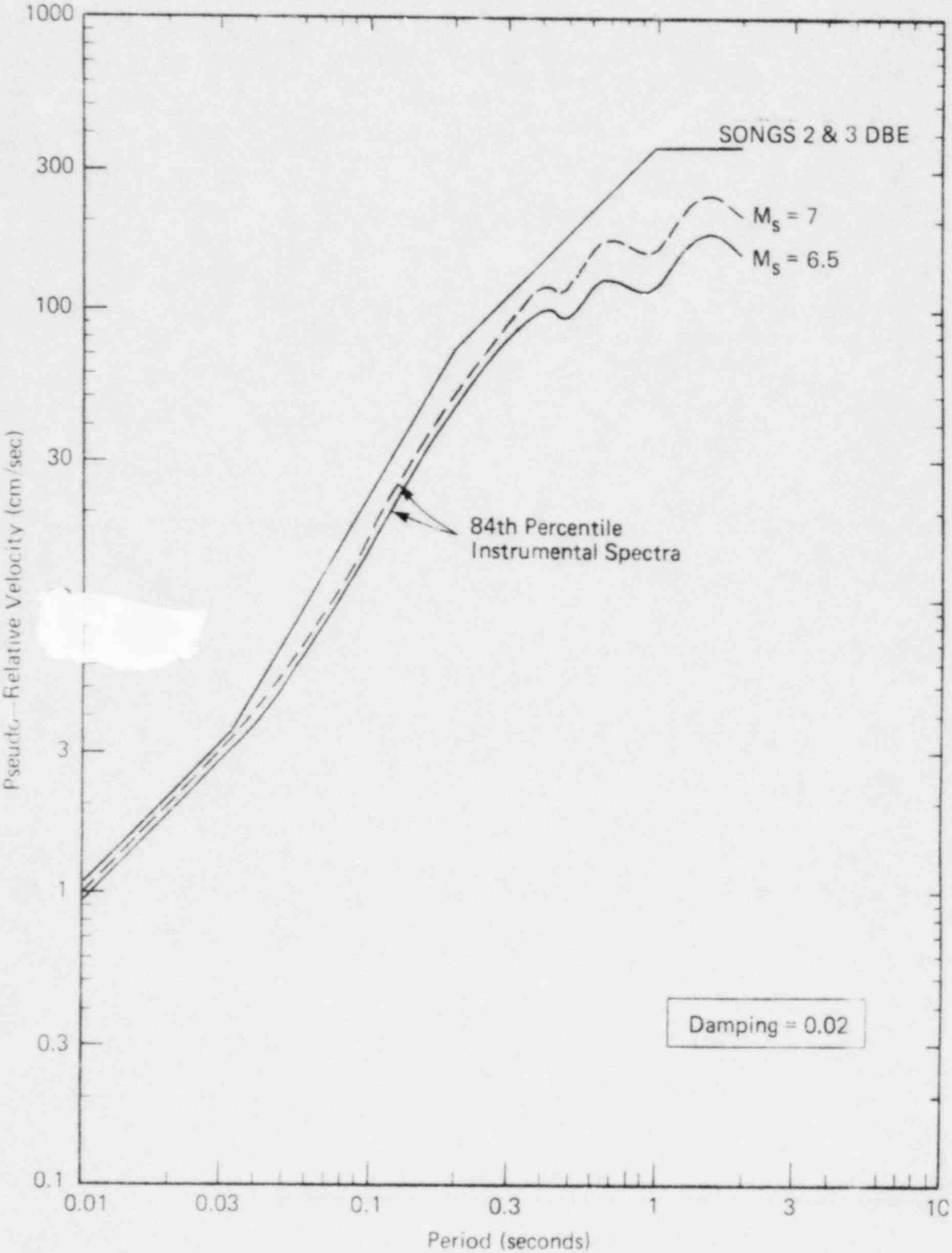

Figure IMI-B – Comparison of the 84th Percentile Instrumental Spectra with the DBE Spectrum

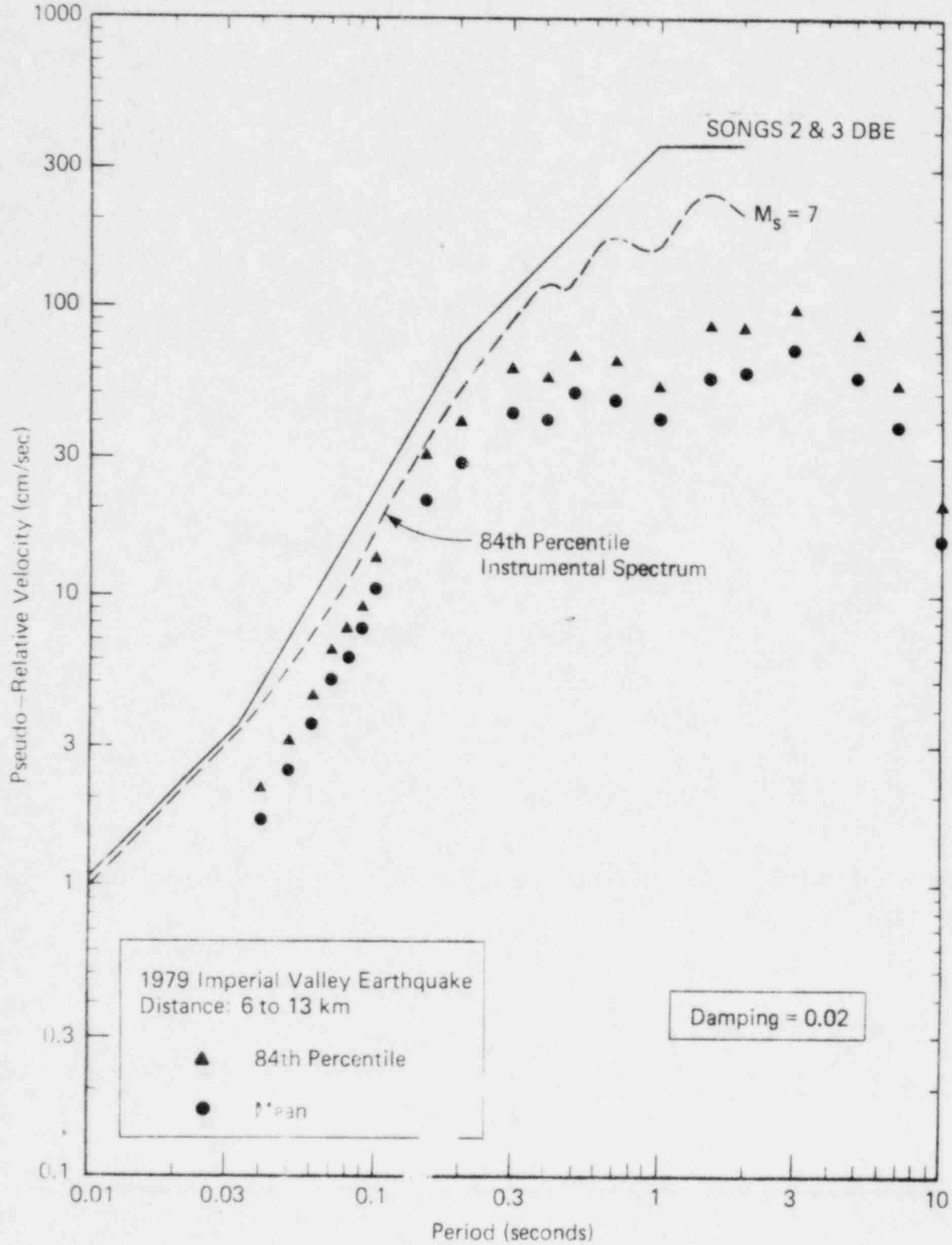

Figure IMI-C - Comparison of the Imperial Valley 1979 Spectra with the 84th Percentile Instrumental Spectrum and the DBE Spectrum

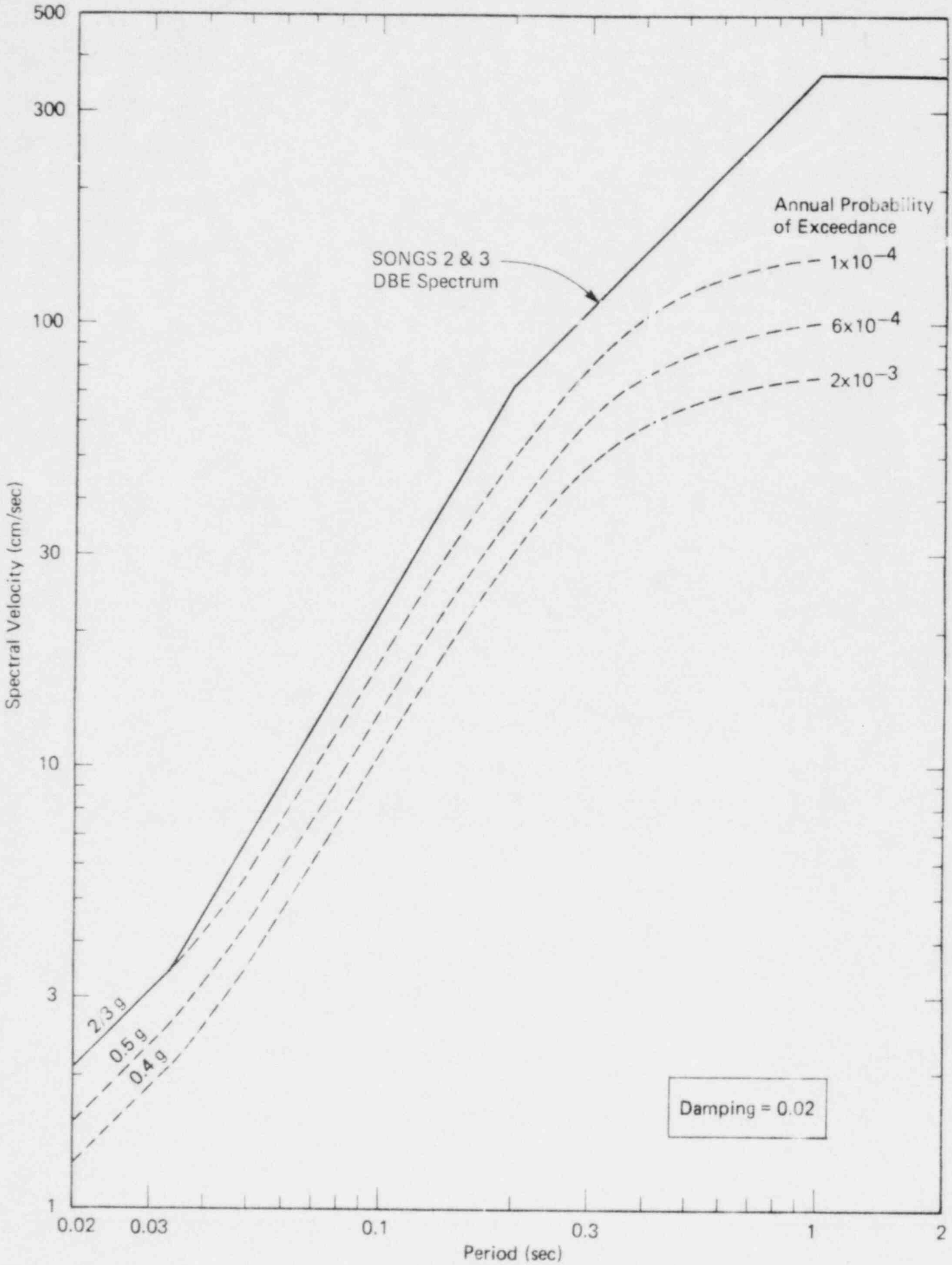

Figure IMI-D – Comparison of SONGS 2 & 3 DBE Spectrum with Equal Probability of Exceedance Instrumental Spectra

TESTIMONY OF DR. GERALD A. FRAZIER

Q. Would you please state your name?

A. Dr. Gerald A. Frazier

Q. By whom are you presently employed?

A. Del Mar Technical Associates - a division of TERA Corporation ("TERA/DELTA"). I am also self- employed as geophysical consultant on the exploration of hydrocarbons, minerals and other earth resources.

Q. In what manner are you associated with Applicants in this proceding?

A. I have been retained as a consultant for the purpose of conducting ground motion studies related to the San Onofre site.

Q. Please describe your formal education.

A. I received a Bachelor of Science in 1964, a Masters of Science in 1966 and a Ph D in 1969, all from Montana State University and all in Civil Engineering. My specialization was earthquake engineering; my minor was mathematics.

Q. Have you been associated with any educational institutions?

A. Yes. 1969-1971, post-doctorate research fellow in Earthquake Engineering at California Institute of Technology; 1971-1974 Visiting Research Associate in Seismology at California Institute of Technology; 1974-1976 Assistant Professor, Institute of Geophysics

and Planetary Physics at Scripps Institute of Oceanography at the University of California at San Diego; 1976-1981, Visiting Research Associate, Institute of Geophysics and Planetary Physics at Scripps Institute of Oceanography at the University of California at San Diego.

Q. What are your pertinent professional or organizational memberships?

A. Yes. I am a member of the Seismological Society of America, American Geophysical Union, and Society of Exploration Geophysicists.

Q. Have you written or published articles in the field of geophysics?

A. Yes. I have authored or co-authored several articles. The list of the more pertinent ones is attached hereto.

Q. Have you testified as an expert in any previous hearings or trials?

A. Yes. I have testified before the Advisory Committee on Reactor Safeguards (ACRS), the Atomic Safety and Licensing Board (ASLB), and the Atomic Licensing Appeal Board (ALAB) on the Diablo Canyon Nuclear Power Plant. In these proceedings I was qualified as an expert in seismology and earthquake engineering.

Q. What is the purpose of your testimony in the proceeding?

A. One of the issues in this proceeding is whether, assuming a M_S 7 earthquake on the OZD, the seismic

design basis is adequate to protect the public health and safety. My testimony demonstrates and it is my conclusion that the DBE spectrum for SONGS 2 & 3 is conservative relative to the ground motion that would result from such an earthquake.

Q. Have you performed earthquake modeling studies to predict ground motions at SONGS from hypothesized earthquakes along the OZD?

A. Yes. The results of these studies are provided in four reports which I am presenting as exhibits in this proceeding:

(1) GAF-1, "Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1, Final Report" 1978

(2) GAF-2, "Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1," Supplement I, 1979

(3) GAF-3, "Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1," Supplement II, 1980

(4) GAF-4, "Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1," Supplement III, 1980

Q. Would you describe the objective or premise for the earthquake modeling studies?

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A. The basic objective has been to predict ground motions at the SONGS site that would result from a large earthquake hypothesized to occur along the OZD. The premise being that by modelling the physical processes of previous earthquakes, a rational basis could be developed for simulating hypothesized earthquake conditions in the vicinity of SONGS. This effort has been conducted in four stages:

(1) Model Development: Computer methods were developed for simulating earthquake rupture and wave propagation through the earth to synthetically produce ground shaking over the frequency range 0 to 20 Hz.

(2) Model Calibration: Strong motion recordings of past earthquakes (1966 Parkfield and 1940 Imperial Valley) were used in conjunction with earthquake physics to calibrate rupture parameters in the computer model.

(3) Model Validation: The calibrated model was then tested for simulating ground motions for additional earthquakes, namely 1933 Long Beach, 1971 San Fernando and 1979 Imperial Valley.

(4) SONGS Predictions: The resulting model was used to predict motions at the SONGS site due to several hypothesized earthquake ruptures along the OZD. Conservative predictions were provided by

considering worst-case rupture configurations, i.e., ruptures that maximally focused seismic waves at the SONGS site.

Q. Could you briefly elaborate on the computer methods that were employed?

A. The computer methods have been developed to simulate the physical processes that occur during an earthquake, namely, fracture along the earthquake fault and transmission of seismic waves from the fracture zone to the recording site. The technical details on how this is accomplished are presented in GAF-1, 2, 3 and 4.

Earthquake motions have been modeled in three mathematical steps:

(1) Earthquake Fracture. The earthquake fracture is characterized as a shear crack that initiates from a point in the earth which is referred to as the "hypocenter" or the "focus" of the earthquake. The idealized fracture spreads at a subsonic speed indicated by crack theory. The fault slip that results from fracture is prescribed on the basis of crack theory and laboratory measurements of shear cracks. Additionally, random processes are included to mimic observed earthquake behavior. Because of the introduction of random fluctuations in the characterization of earthquake fracture, a simulation of ground motion for one hypothesized

earthquake is repeated several times to determine the range of effects that could result.

(2) Wave Transmission. Voluminous calculations are performed to determine the ground motions that result from fracture at each of several hundred points along the fracture surface. These results, denoted "Green's functions", provide transmission characteristics for the composite of earth materials traversed by the seismic waves. The methods used for this step simulate the complete myriad of seismic waves that arise in our layered representation of the earth. The several model layers are assigned viscoelastic properties to simulate the hysteretic behavior of earth materials.

(3) Earthquake Simulation. The fracture model (Step 1) is used as input to the wave transmission model (Step 2) to produce synthetic ground motions at the desired recording site. Mathematically, this is achieved through the convolution of fault slip with the Green's functions for the earth. The orientation and distance of the site with respect to the fracture is specified at this stage of the analysis.

Q. What are the parameters used by your model?

A. Although the modeling procedure is sophisticated, the parameterization of the model is straight- forward.

Conceptually, the model parameters allow me to characterize a specific fault slippage along a specific rupture surface in a specific earth structure. This involves characterization of (1) the geologic structure, (2) the rupture geometry, and (3) the rupture kinematics.

(1) The geologic structure for a given site is represented by a stack of horizontal, viscoelastic layers; the bottom layer extends to infinity. The layer thicknesses and seismic wave velocities are extracted from field data (e.g., well logs and seismic profiles) at the site. The layer densities are estimated from the wave velocities and geologic data on rock type. The material quality factors in each layer are empirically related to the seismic velocities for that layer as discussed in Section 2.5 of GAF-1.

(2) The rupture surface is represented by a fault with a specified dip, rake, and strike relative to the site's azimuthal location; a specified hypocentral location; and a specified rupture extent.

(3) The fault slippage over the rupture surface is characterized by a spatially invariant slip function that spreads at a specified velocity which is then perturbed randomly. The shape of the slip function is defined by three parameters: initial slip velocity, duration of slip, and final offset.

The gross rupture velocity, the duration of slip at a point and the random irregularities are assigned values generically. The gross rupture velocity is se to ninety percent of the local shear-wave velocity for each layer undergoing rupture, while the duration of slip at each point is taken as the travel time of shear waves across the narrowest dimension of fault rupture. The final offset is assigned a value so as to give a desired seismic moment to the earthquake rupture and is related to the static stress drop for the earthquake. The initial slip velocity is the principal parameter in the earthquake model that has been calibrated from near-field recordings of earthquakes.

Q. Would you elaborate on the calibration of the model parameter termed "initial slip velocity?"

A. Because the initial slip velocity governs the amplitude of ground motions for frequences above about 2 Hz, considerable effort has gone into the assignment of values for this parameter. As described in Supplement I (Exhibit GAF-2), the initial slip velocity at the lead edge of the subsurface fracture was assigned a value of 800 cm/sec to yield high-frequency accelerations equal to or slightly greater than near-field accelerations recorded for the 1966 Parkfield earthquake (M_S 6.4). Similar calibration studies were then performed for 1940

Imperial Valley earthquake (M_S 7.1). The same value of 800 cm/sec was found to be appropriate for this much larger earthquake.

Subsequently, in Supplements II and III (GAF-3 and GAF-4), the value of 800 cm/sec was found to be suited for producing the high-frequency accelerations recorded for the 1933 Long Beach earthquake (M_S 6.3), the Pacoima Station of the 1971 San Fernando earthquake (M_S 6.5) and the 1979 Imperial Valley earthquake (M_S 6.9). These five earthquakes represent a major portion of the near field data available for Southern California. Because all five earthquakes required the same value for initial slip velocity, I conclude that the production of high frequency seismic waves per square kilometer of rupture surface is independent of earthquake magnitude and static stress drop.

This earthquake property is physically reasonable, because the initial slip velocity directly relates to dynamic stress drop (the rapid change in stress at the crack tip as gouge materials undergo initial brittle fracture). The fracture strength of the earth constituents is not a function of either magnitude or fault offset, consequently neither is the empirically derived parameter - initial slip velocity.

Q. Does your modeling study include focusing effects?

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A. Yes. In fact, the model tends to overestimate the effects of directivity or rupture focusing at high frequencies. Actual earthquakes exhibit smaller focusing effects due to the apparent abundance of localized irregularities.

Q. What is the effect of focusing on earthquake ground motions?

A. Recorded ground motions tend to be higher in the direction of spreading rupture than in other directions due to focusing of seismic waves. Conversely, for the case of unidirectional rupture, recorded ground motions tend to be lower in the direction opposite to rupture growth due to defocusing of seismic energy. The bias of large amplitudes of motion in the direction of spreading rupture (i.e., the phenomenon of focusing) has been theorized, and indeed observed, for intermediate to low frequencies (less than about 3 Hz) for more than a decade. One would expect to see the primary effects of focusing in the lower-frequency parameters of peak ground velocity and displacement as opposed to the higher-frequency parameter of peak ground acceleration due to irregularities in the earth.

Earthquake focusing results from time compression of signals. Recall the familiar Doppler effect heard as a train passes: high-pitched and loud noise as the train approaches with both the loudness and pitch

diminishing as the train passes. Focusing for earthquakes can be understood by considering a unidirectional fracture that ruptures due north and emits seismic waves for a duration of 10 seconds. Because of the approaching rupture, an observer in the near field and north of the source experiences strong shaking for a duration less than 10 seconds, say 6 seconds. The fact that 10-seconds-worth of seismic energy arrives within 6 seconds tends to increase the amplitudes of ground motion in the direction of rupture focusing. Conversely, an observer in the near field, south of the source, experiences strong ground shaking for a duration longer than 10 seconds which tends to decrease the amplitudes of motion in the direction of rupture defocusing.

Actual earthquake rupture spreads in a somewhat irregular manner, lurching and altering directions in response to stress aberrations and material asperities. The consequence is that the bias toward large amplitude motions in the path of focusing is subdued for frequencies greater than about 3 Hz with significant biases confined to peak velocity and lower frequencies. The effects of rupture focusing and defocusing on lower frequencies are widely observed at distances ranging from near field to teleseismic (more than 1000 km).

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Q. How does focusing affect strong motion recordings of earthquakes?

A. Data recorded for several earthquakes illustrate the subdued nature of focusing at high frequencies. Relevant data were recorded for the 1966 Parkfield earthquake. An accelerometer (Parkfield Station 2) was positioned directly in the line of about 30 km of approaching rupture. The instrument recorded 0.5 g in the horizontal direction. About 5 km away, perpendicular to the surface break, Parkfield Station 5 recorded 0.45 g, a value only 10% smaller than that directly in the beam of maximum focusing. In contrast, the lower-frequency velocity peaks were nearly three times larger in the direct path of focusing (Station 2) as compared to recorded velocities at Station 5. Similarly, in the Pacoima Dam recording of the 1971 San Fernando earthquake, the effects of rupture focusing are more apparent in the velocity peaks than in the acceleration peaks.

The 1979 Coyote Lake earthquake was an example of focusing affecting all three parameters but with the primary effect on the low frequency parameter of displacement. The peak acceleration was 0.42 g directly in the path of focusing (Station 6) and 0.25 g within one kilometer of the fault, but in the path of defocusing (Coyote Creek). The corresponding values for

peak ground velocity are 44 and 20 cm/sec at the two stations. While effects of focusing are only slightly more apparent for velocity than acceleration, the recorded peak displacements of 9.3 cm and 2.4 cm, respectively, represent a substantially larger effect due to focusing than that for the higher frequency acceleration peaks.

Recordings of the 1979 Imperial Valley earthquake provide further evidence on the limited effects that rupture focusing has on increasing peak accelerations. At least five strong motion recordings were obtained essentially on the fault (within 1 km) at various points along the path of rupture. The horizontal accelerations of these stations range between about .25 and .75 g with a mean value well under .5 g. These values fit well within the range of peak horizontal accelerations cited above for the Parkfield and the Coyote Lake earthquakes. These values are also consistent with the values recorded out to 6 or 7 km from the fault. Furthermore, there is no significant difference between peak accelerations recorded south of the epicenter, in the defocused zone, and those recorded north of the epicenter, in the focused zone. There is apparently no significant increase in peak accelerations as a result of focusing in the IV-79 earthquake data.

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Q. Would you describe your ground motion predictions for SONGS?

A. Referring back to the three mathematical steps for modeling earthquakes, the wave transmission properties (Step 2) were calculated for the earth structure underlying the SONGS site. The viscoelastic parameters derived for the subsurface geology at SONGS are presented in GAF-2 (Table 6-1, page 6-2). The relevant parameters include compressional- and shear-wave velocities, density, compressional- and shear-wave quality factors, and layer thicknesses. The response of this earth representation has been calculated from 0 to 20 Hz for 60 epicentral distances from 1 to 60 km and for 21 source depths from 0.26 to 15.0 km. The calculated earth response at each epicentral distance/source depth pair has ten independent components, giving a total of 60 x 21 x 10 or 12,600 individual time histories of the earth's response to points of rupture distributed over the hypothesized zone of major rupture.

The earth response functions are convolved in time and space (at each point of rupture) with the standard characterization of fault slip to give the site-specific results at SONGS. Variations that result from stochastic properties of the earthquake model are

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included by repeating each earthquake simulation several times to determine the full range of effects.

A range of plausible fractures along the OZD were examined (described in GAF-2). The worst-case fracture is pictured in the attached Figure GAF-A, "Schematic representation of the SONGS site relative to the hypothesized offshore zone of deformation. The 40-km fracture corresponds to hypothesized earthquake 'D' from Exhibit GAF-2 and GAF-4." The worst-case fracture, denoted earthquake "D", represents an M_S 7, maximally oriented with respect to the SONGS site.

The predictions at SONGS, computed with both the Supplement I Model (GAF-2) and the Supplement III Model (GAF-4), are shown in Figures GAF-B, "Site specific...predictions computed with [the refined model (GAF-4)]... compared with Units 2 and 3 DBE for the vertical component with 2% damping", GAF-C, "Site specific...predictions computed with [the refined model (GAF-4)]...compared with Units 2 and 3 DBE for the horizontal SE component with 2% damping", and GAF-D, "Site specific...predictions computed with [the refined model (GAF-4)]...compared with Units 2 and 3 DBE for the horizontal component NE 2% damping". In each figure, the computed mean and mean plus one standard deviation response spectra is compared with Units 2 and 3 DBE spectrum at two percent critical damping. Also shown

are the calculated mean values for peak acceleration, velocity and displacement and local magnitude. The results indicate that the design spectrum for SONGS 2 & 3 conservative in that it exceeds the predicted instrumental spectrum at all periods of interest. Damping values of five, seven and ten percent also reveal a comparable degree of conservatism for the design spectrum.

Q. Would you describe the degree of conservatism and reliability provided in your modeling studies?

A. As illustrated in GAF-A, the SONGS site is 8 kilometers from the OZD. A conservative prediction of site specific response spectra has been determined for hypothesized earthquakes along the OZD. The site specific prediction is conservative with respect to the assigned earthquake magnitude (M_S 7) and the critical rupture sequence which maximally focusses seismic waves at the site. Also, the instrumental predictions have not been reduced to account for either the presence of SONGS structures or the conservative methods by which base motions are input into the structures.

One of the useful features of the earthquake modeling approach is the capability for examining a suite of postulated earthquakes so as to isolate particular rupture configurations that produce the strongest ground shaking. Such a study has been

conducted for SONGS (cf. Chapter 6 of GAF-2) where the ground shaking from the following suites of earthquakes were compared: (1) seven different fault locations and rupture directions; (2) three different fault lengths; (3) three different hypocentral depths; (4) three different depths to the fault bottom; and (5) three different depths to the fault top.

These site-specific calculations for SONGS are based on as complete and rigorous simulation of earthquakes as is currently available. The SONGS predictions, based on these studies, offer a high degree of reliability for the following reasons.

(1) The results have been validated against near-field recordings of five important southern California earthquakes in the same distance range that is relevant for SONGS;

(2) The capability provides a rational basis for extrapolating from past earthquakes to hypothesized conditions at SONGS, including site-specific conditions: hypothesized earthquake magnitude, distance to the OZD, and earth structure.

(3) The results provide a basis for appraising the likelihood of unusual combinations of fault rupture and wave guide effects that would cause large amplitude shaking at SONGS.

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(4) Instrumental predictions at SONGS are being compared with design spectra in GAF-B, C, and D with no reduction in the predicted spectra at short period (high frequency) to account for the presence of the SONGS structures.

Q. How does the assignment of M_s 7 impact your predictions of ground motions at the SONGS site?

A. The sensitivity of peak ground acceleration (PGA) on earthquake magnitude diminishes with increasing magnitude and with decreasing distance. The earthquake conditions hypothesized for SONGS are sufficiently severe as to be insensitive to small changes in the assigned magnitude. I will explain. The "size" of an earthquake is quantified using one of several different magnitude scales. Local magnitude (M_L) and body wave magnitude (m_b) are determined from the amplitude of waves with a period of about 1.0 sec. Both M_L and m_b saturate at values near M_s 7. Earthquakes larger than M_s 7 register about M_L and m_b 7. This is because the amplitude of 1.0-second waves does not increase with increasing size of rupture.

Surface wave magnitude (M_s) is determined from the amplitude of 20-second waves, thereby largely circumventing the problem of magnitude saturation. Eventually, the amplitude of these long-period waves saturates at about M_s 8.3. An M_s 8.3 would result from

an earthquake rupture of several hundred kilometers. Because M_s and m_b are measured teleseismically ($r > 2000$ km), considerable worldwide data are available for empirically establishing saturation levels in these measures of earthquake "size."

Similarly, the amplitude of 5 Hz waves (about the frequency of PGA in the near field) would be expected to saturate, becoming insensitive to differences in earthquake "size" for magnitudes greater than about 6.5. The saturation of high-frequency waves is not as historically documented in the seismological literature as that of the lower frequency waves used in the various measures of earthquake magnitude, because the amplitude of these high frequency waves is not easily measured at teleseismic distances. The necessity of relying on strong motion data for relating the amplitude of high frequency waves to earthquake size significantly limits the availablity of data for large magnitude earthquakes as compared to teleseismic recordings. Considering that 20-second waves saturate at a about, M_s 8.3, and 1-second waves saturate at about M_s 7.0, I conclude that 5 Hz waves (PGA) should saturate at a somewhat lower magnitude (M_s 6.5). Consequently, the ground motion criteria for SONGS is dependent on the postulated nearby earthquake; the precise magnitude assignment for this event is not critical.

Q. How does the proximity of the OZD to the SONGS site influence saturation of ground motions with magnitude?

A. As I just explained, the widely accepted phenomenon of saturation of the various magnitude scales with increasing earthquake size indicates that higher frequency motions ($f > 1.0$ Hz) will also saturate. Additionally, based on earthquake physics and recorded data, saturation of PGA with increasing magnitude is even more pronounced close to the causative rupture. For distances less than 10 km from the zone of rupture, PGA is controlled by the nearest 10- to 20-km zone of rupture. High-frequency waves produced by more distant rupture are substantially attenuated so as to negate their influence on near-field PGA. Additional rupture length would be inconsequential for influencing the high-frequency waves and consequently PGA recorded in the near field.

The earthquake modeling studies that I described above have tested this mechanistic basis for the saturation of near-field accelerations. These studies indicate that the source of high frequency waves along the rupture surface is both independent of earthquake magnitude and fault offset (static stress drop). Ground accelerations increase with increasing magnitude to a point where additional extension of the earthquake rupture serves only to increase the du[illegible]tion of

shaking. Both theory and data indicate that this point of saturation occurs at about magnitude 6.5 for high frequency ground motions within 10 km of the causative rupture.

Based on my studies of earthquakes, I conclude that the DBE used for SONGS 2 & 3 is conservative with respect to the postulated M_S7 earthquake on the OZD.

GERALD A. FRAZIER

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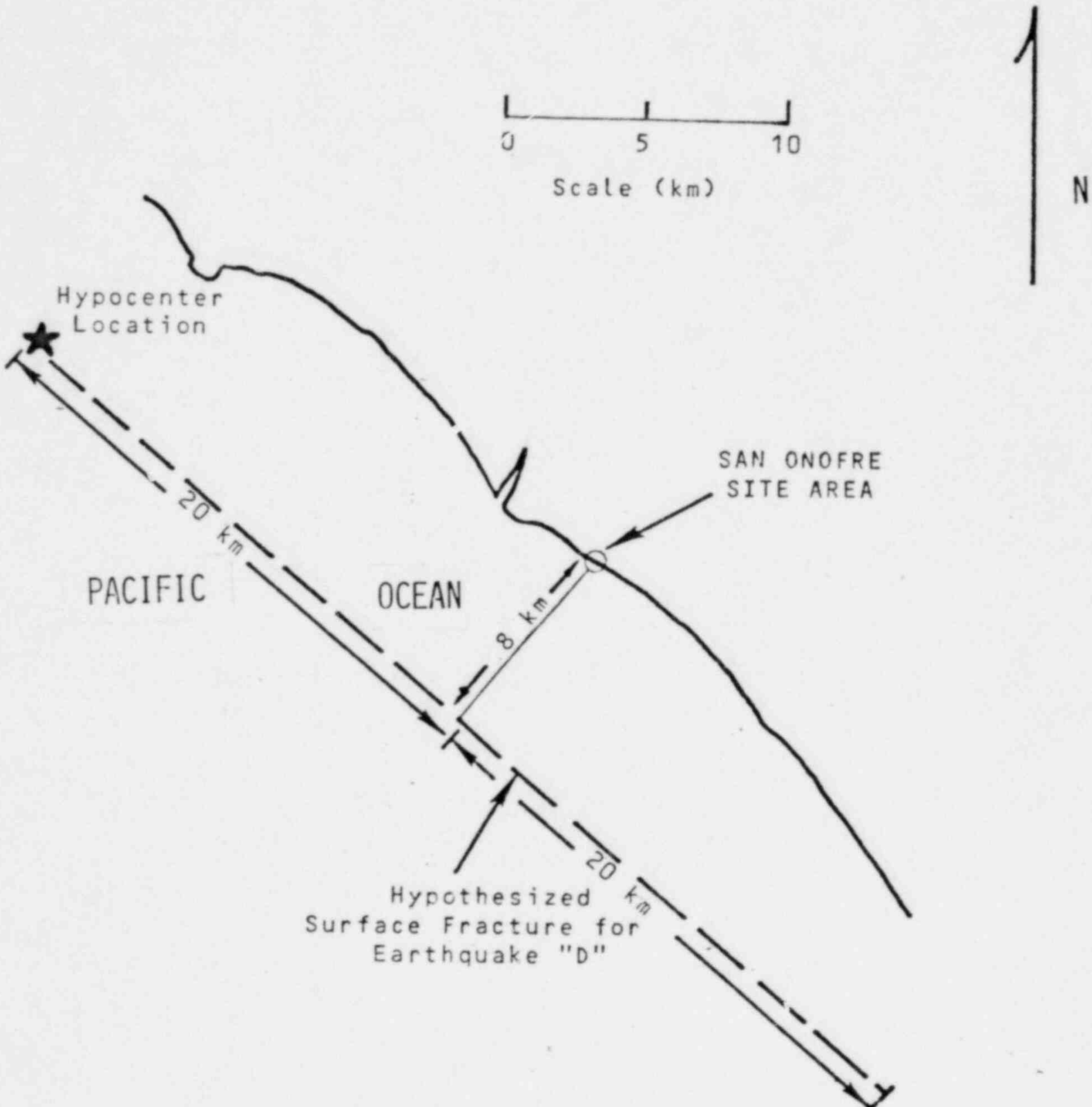

Figure GAF-A. Schematic representation of the SONGS site relative to the hypothesized offshore zone of deformation. The 40-km fracture corresponds to hypothesized earthquake "D" from Exhibits GAF-2 and GAF-4.

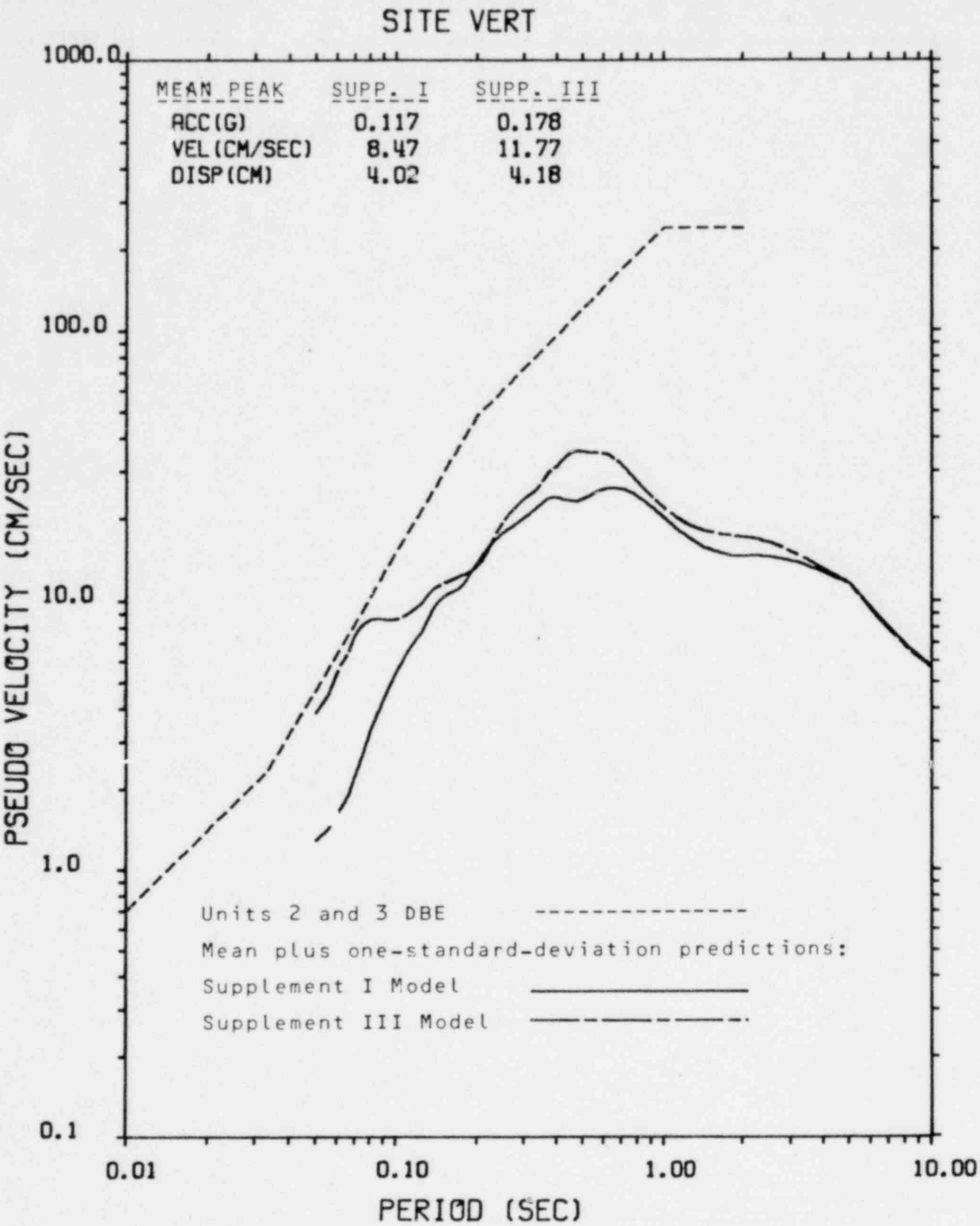

Figure GAF-B. Site specific mean plus one standard-deviation predictions computed with Supplement I Model from Exhibit GAF-2 (solid line) and with Supplement III Model from Exhibit GAF-4 (dashed line) compared with Units 2 and 3 DBE for the vertical component with 2% damping.

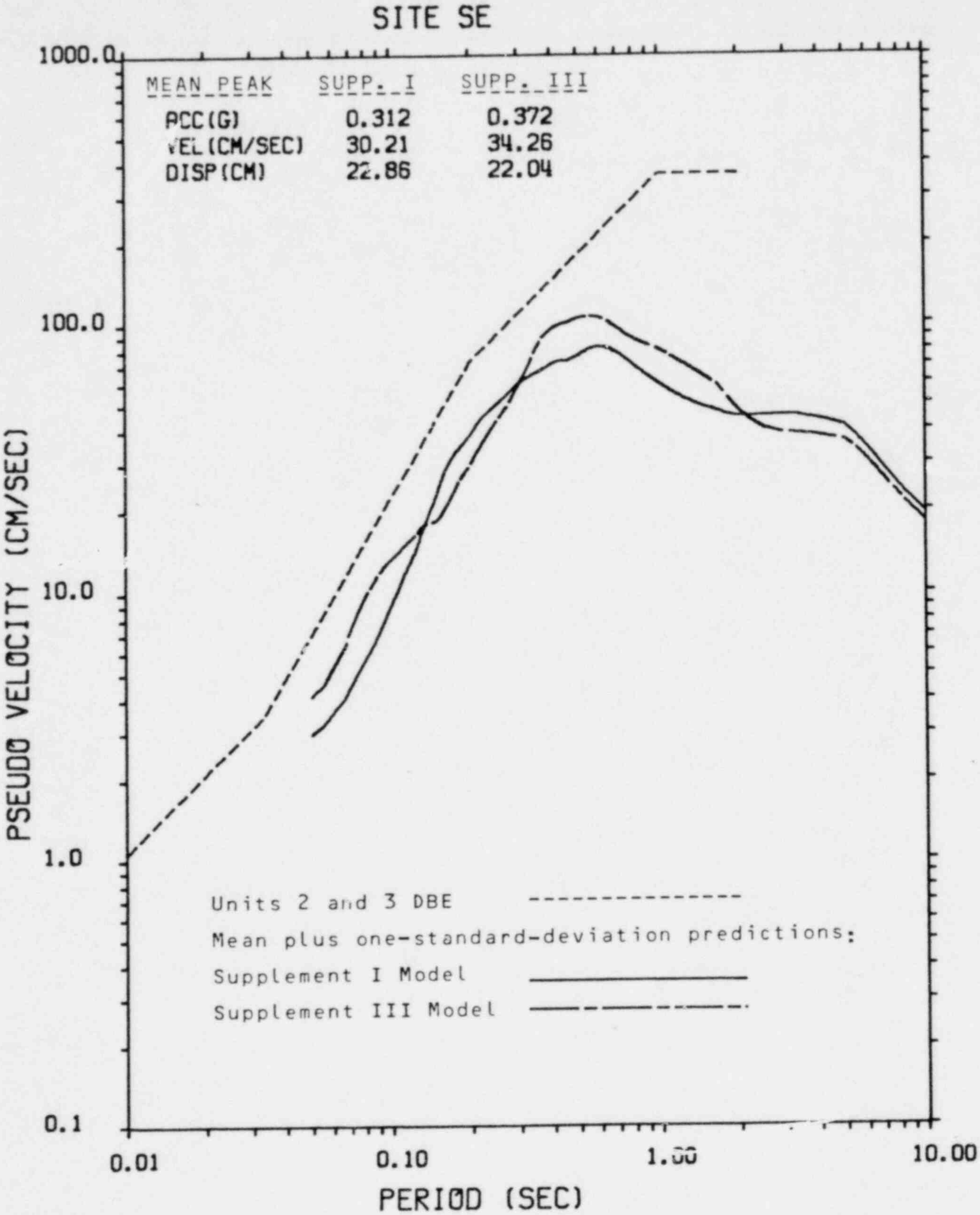

Figure GAF-C. Site specific mean plus one-standard-deviation predictions computed with Supplement I Model from Exhibit GAF-2 (solid line) and with Supplement III Model from Exhibit GAF-4 (dashed line) compared with Units 2 and 3 DBE for the horizontal SE component with 2% damping.

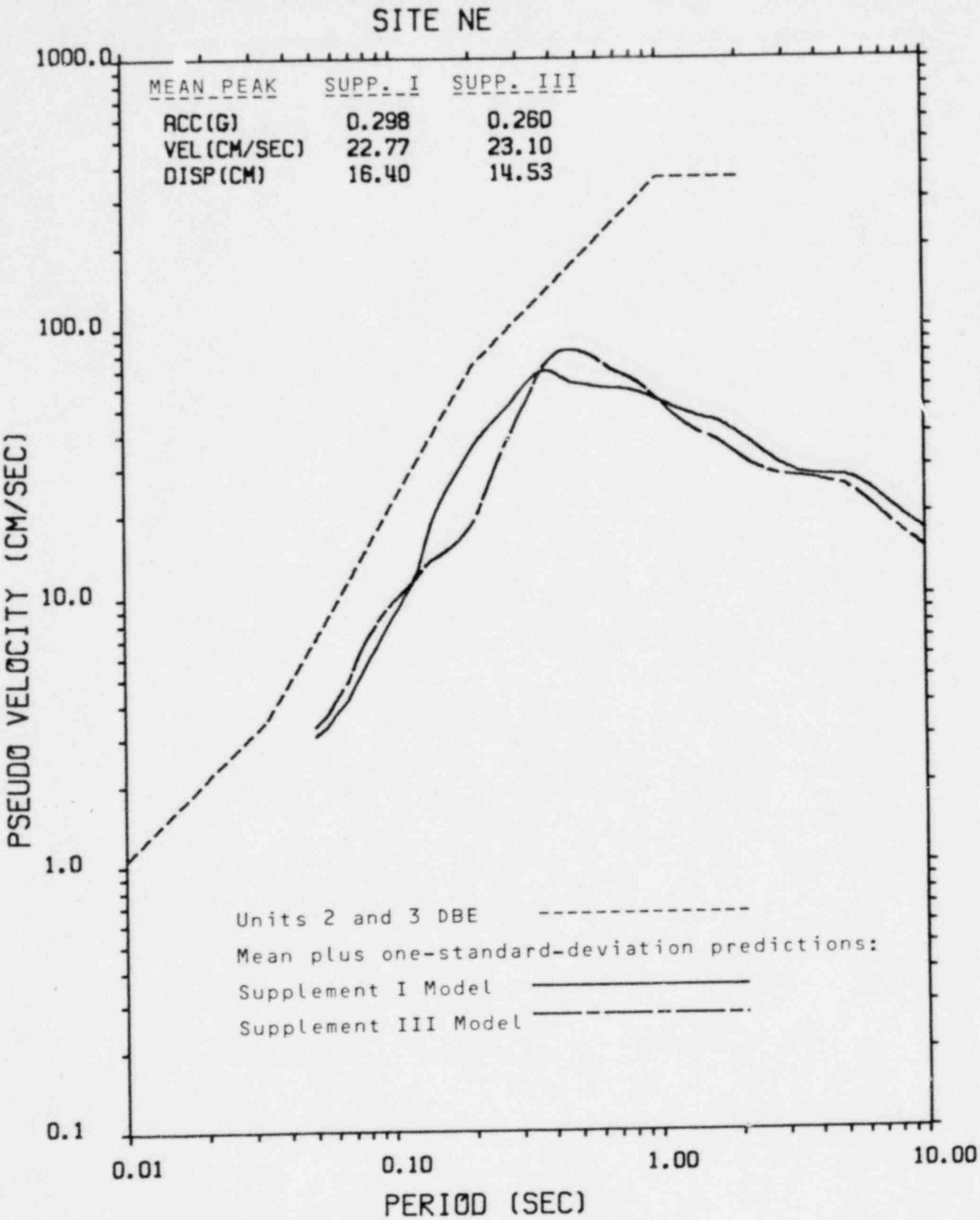

Figure GAF-D. Site specific mean plus one-standard-deviation predictions computed with Supplement 1 Model from Exhibit GAF-2 (solid line) and with Supplement III Model from Exhibit GAF-4 (dashed line) compared with Units 2 and 3 DBE for the horizontal NE component with 2% damping.

TESTIMONY OF DR. ROBERT L. McNEILL

Q. Would you please state your name?

A. Robert L. McNeill.

Q. By whom are you presently employed?

A. I am presently employed as a Member of the Technical Staff at Sandia National Laboratory, located in Albuquerque, New Mexico. In that capacity, I am doing research on earthquake ground motion offshore, and the difference between instrumental and structural response to earthquakes. I am also self-employed as a geotechnical engineering consultant to Southern California Edison Company ("SCE") for matters related to San Onofre Nuclear Generating Station, Units 2 and 3 ("SONGS 2 & 3"). The opinion expressed herein is solely my own, and does not represent the views or the position of Sandia National Laboratory, or the United States Department of Energy.

Q. In what manner are you associated with the Applicants in this proceeding?

A. From 1970 until 1975, I was President of Woodward-McNeill & Associates ("WMA"). WMA was retained by SCE for geotechnical engineering work associated with the analysis, design, and construction of SONGS 2 & 3. In that capacity I was the Principal in charge of said work, and personally accomplished a substantial amount of the geotechnical work on the project, in addition to

my management duties. Since 1975, I have been an independent consultant to Woodward-Clyde Consultants ("WCC") and to SCE, providing advice and consultation to WCC as they continued the work of WMA at SONGS 2 & 3, and providing technical advice and review to SCE on many other aspects of that project.

Q. Would you please describe your formal education?

A. I hold a Doctor of Science Degree in engineering mechanics (minors: mathematics and physics) from the University of New Mexico, and a Master of Science Degree in geotechnical engineering and a Bachelor of Science Degree in structural engineering from the University of California (Berkeley).

Q. What professional positions have you had in the area of geotechnical engineering, soil dynamics, and earthquake engineering?

A. I have 28 years experience in geotechnical engineering; two years as a field and laboratory technician, three years as an engineer-in-training in California, and 23 years as a registered professional engineer. My experience encompasses the geotechnical, dynamic, and seismic design aspects of almost every kind of heavy construction: dams, buildings, bridges, roads, power facilities, mining facilities, tunnels, subways, pipelines, offshore structures, and hardened defense structures.

Q. Have you been associated with any educational institutions?

A. I was an Adjunct Professor and lecturer from 1961-1965 and 1978-present at the University of New Mexico in geotechnical engineering. I was a lecturer at the University of California at Los Angeles in 1968, 1969 and 1971 in geotechnical engineering and soil dynamics. I was a lecturer at the California State University at Long Beach in 1971 and 1974 in a graduate course in soil dynamics and earthquake engineering. I was an Assistant Professor at California State University at San Jose in 1957 to 1961 in geotechnical engineering and soil dynamics. I have also given guest lectures on geotechnical engineering, wave propagation and soil dynamics at the University of California at Berkeley and at Los Angeles, the University of New Mexico, the Texas A & M University, and the University of Colorado at Boulder.

Q. Do you hold any professional registrations in the State of California or any other state?

A. Yes, I am a Registered Professional Engineer in California, New York, New Mexico, Nevada, and Arizona.

Q. What are your pertinent professional or organizational memberships?

A. American Association for the Advancement of Science
American Institute of Aeronautics and Astronautics

American Society of Civil Engineers
American Society of Mechanical Engineers
American Society for Testing Materials
Earthquake Engineering Research Institute
Highway Research Board
Marine Technology Society
Navy League
Oceanic Society
Seismological Society of America
Society of Experimental Stress Analysis
U. S. National Council on Soil Mechanics and Foundation Engineering

Q. Have you written or published articles in the field of geotechnical engineering, soil dynamics, and earthquake engineering?

A. I have authored or co-authored several articles dealing with geotechnical engineering, soil dynamics, and earthquake engineering. A list of these publications is appended hereto.

Q. Have you served with formally organized groups concerned wholly or in part with matters of seismic safety?

A. I was nominated for the Governor's Seismic Safety Commission for the State of California in 1978. I was Chairman of the National Soil Dynamics Committee of the American Society of Civil Engineers from 1968 to 1973.

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Q. On which projects have you been retained as an expert consultant in geotechnical engineering, soil dynamics, and earthquake engineering?

A. I have been retained by a number of governmental agencies and private companies over the past eighteen years as an expert consultant in the area of geotechnical engineering, soil dynamics, and earthquake engineering. I have participated in the following nuclear projects: Bolsa Island, Cooper Station, Ft. St. Vrain, South Texas Project, SONGS 1 and SONGS 2 and 3.

Q. Have you testified as an expert in any previous hearings or trials?

A. Yes. I presented expert opinion to the Advisory Committee on Reactor Safeguards ("ACRS") in this proceeding as well as that for the Cooper Station Nuclear Power Project. In addition, I have qualified as an expert witness in geotechnical engineering in various Superior Court cases in Los Angeles and Orange Counties. I have been an arbitrator and have presented expert opinion before arbitration boards concerning geotechnical engineering in California and New Mexico.

Q. What is the purpose of your testimony in this proceeding?

A. One of the issues in this proceeding is whether, assuming a M_S 7 earthquake on the OZD, the seismic design basis of SONGS 2 & 3 is adequate to protect the public health and safety. My testimony demonstrates and

it is my conclusion that the design basis earthquake ("DBE") spectrum as used for design of SONGS 2 & 3 is a conservative representation of the motion of structures at the site due to a very large, nearby earthquake.

Q. Would you please define and explain the technical terms which you will use in your testimony?

A. I will be speaking about earthquake vibrations, but let me first define some terms which are used when discussing virtually all vibrations. Figure RLM-A, "Definitions (Time)", shows some vibrations as they would appear as a function of time, such as would be recorded by a seismograph. The maximum motion for any one cycle is the <u>amplitude</u>, and the time it takes to complete one full cycle is the <u>period</u>. In RLM-A amplitude $Z_1 = Z_2$, but period T_1 is more than (longer than) T_2. Period is usually expressed in seconds, understanding that it really is "seconds per cycle." The reciprocal of period is <u>frequency</u>, f=(1/T), usually expressed in cycles per second or Hertz (1 cps = 1 Hz).

The foregoing terms describe the behavior of a wave in time. Figure RLM-B, "Definitions (Space)", shows the similar system in space, as if the travelling wave had been photographed. In this case, the distance travelled while completing one full cycle of vibration is the <u>wavelength</u>, L. If the wave at that location is

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travelling at a wave velocity, c, and recalling that it takes the time-period T to complete the cycle

$$L = cT$$

or, because $f=(1/T)$, $L = (c/f)$

Thus for a given ground (with a wave velocity c): the wavelengths are long for long periods or low frequencies; and the wavelengths are short for short periods or high frequencies.

A structure has a certain natural period (or frequency) at which it will vibrate when plucked. A complex structure has many natural periods, all being shorter than the fundamental period (or higher than the fundamental frequency). If a structure is shaken or vibrated at or near one of its natural periods (or frequencies), it will respond by amplifying the input motions with which it is being vibrated. The ratio between the structure's response motion and the input motion is the amplification ratio.

When a real structure is plucked and vibrates, the vibrations tend to decay or damp with time. This tendency is expressed quantitatively as the damping (or damping ratio), usually as a percentage. Generally, at the short periods (high frequencies) of interest to reactor design, response motions tend to be lower for structures with higher dampings.

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Amplitudes of motion are expressed as one of three quantities, the choice of which is purely a matter of convenience for the situation at hand. These quantities are: displacement, d; velocity, v; and acceleration, a. Velocity in this case is the velocity of a vibrating particle at a point in the earth or in a structure; and it is not the wave velocity mentioned above.

Any one of the quantities d, v, or a provide a complete description of the motions; and d, v, and a are explicitly related, so that one may easily convert from one to the others. If the wave is smooth and orderly (harmonic, sinusoidal), the absolute maxima of the three quantities are related quite simply, as follows:

Let the maximum displacement = D . . . . (1)

Then maximum velocity = $V = (2\pi D)/T$ . . . (2)

and, maximum acceleration = $A = (2\pi V)/T$ . . . (3)

Thus, for such an harmonic wave, if any two of the quantities T, D, V, or A are known, the other two are easily calculated. This is seldom done, however: the expressions above are power functions, which map as straight lines on a log-log plot. Thus there has been developed a four-axis logarithmic paper which is the solution to the harmonic expressions above. Figure RLM-C, "Examples of Use of Harmonic Paper" is an example of such an harmonic plot (also called tripartite plot), and shows two examples for reference.

The foregoing use of harmonic plot in principle applies only to smooth harmonic functions, which an earthquake usually is not. The harmonic plot is so revealing of the properties of the motions, however, that it is nevertheless widely used fro displaying earthquake motions, with the adjective pseudo appended to the quantities (either explicitly or implicitly) as a reminder. It is generally agreed that the approximations of this very powerful procedure are small, and of no practical significance for the short-period ranges of engineering applications.

Q. Would you please explain what spectra are, and how they are calculated and used?

A. The spectrum is one of the most useful tools available to the seismologist and the earthquake engineer. A spectrum clearly and concisely displays certain relevant information about an earthquake's characteristics better for some purposes than does the instrumental recording alone and, in proper form, a spectrum provides information vital to the design of earthquake- resistant structures. There are, however, important differences between the instrumental form of a spectrum (used by seismologists and engineers to study free-field ground motions), and the design form of that spectrum (used by engineers to design and evaluate structures). To avoid possible confusion, I point out that there are several

types of spectra (e.g., response spectrum, Fourier spectrum). My testimony is limited to the response spectrum, because tha* is the one of interest to these proceedings. Other types of spectra, if used or presented, should be so identified. I will now explain the terms used when dealing with spectra, develop the properties of spectra, explain the differences between the instrumental and design forms of spectra, and explain how to use spectra to compare various earthquakes.

A <u>spectrum</u> is a graphical representation of vibratory motions in an orderly array according to the frequency (or period) of each part of the motion. For example, the spectrum in Figure RLM-D, "Simplified Example of a Spectrum" represents a certain vibration and indicates that the amplitude of the vibration is 5 in. at a frequency of 10 cycles per second, but only 1 in. at 20 cps.

An instrument or a small, light structure does not alter the earthquake ground motions: that is, an instrument or small structure appears as an infinitesimal massless point to an earthquake wave, which may have a wavelength of many tens to a few hundred feet, or more. For this reason, the <u>instrumental spectrum</u> for a given instrumental recording can be calculated quite simply, by allowing the

instrumentally recorded motions mathematically to vibrate small oscillators, as shown in Figure RLM-E, "Calculation of Instrumental Spectrum". Each oscillator is composed mathematically of a mass, spring, and weightless base. The masses and springs are selected so that the oscillators have different natural periods, ranging in an orderly way over the range of the periods of interest. The recorded motion is mathematically input to the base of each oscillator, and the resulting response motions of the mass are calculated as a function of time. The maximax (maximum of all maxima) for that oscillator is then plotted at the fundamental period of that oscillator as one point of the instrumental response spectrum. The usefulness of this procedure is that any simple (single-degree-of- freedom, SDOF) structure with the same fundamental period as one of the oscillators will respond to that instrumentally recorded motion exactly as did the little oscillator. Thus the instrumental spectrum portrays the response of any small structure, regardless of the structure's characteristics, if the structure's period is known; and the portrayal on harmonic paper allows expression of that response in terms of any or all of the three maximum quantities (D, V, or A, Equations 1-3) as is convenient.

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As an example of the utility of a spectrum and the method of displaying it on harmonic paper, Figure RLM-F, "Example Accelerogram" shows an accelerogram (time history) of an earthquake. Inspection of that recording offers little quantitative information other than that the peak ground acceleration (PGA) was about one-quarter of gravity (g). The important engineering information on frequencies and responses are in that record, but they are hidden by its complexity. That information appears when the instrumental spectrum is calculated and plotted, Figure RLM-G, "Instrumental Spectrum", as will now be discussed.

The oscillator-response calculations are done for many periods, so that the resulting plot of maximax response as a function of oscillator period, the spectrum of RLM-G, is usually a nonsmooth, jagged curve. It does, however, clearly display how a small structure would respond to the same earthquake. For example, if a small structure had a natural period of 0.1 sec (a stiff, rigid structure), it would respond with about (point X, RLM-G) D = 0.09 in., V = 5.8ips, and A =0.95 g. The maximum displacement response is at point D, the maximum velocity response is at point V, and the maximum acceleration response is at point A, in RLM-G. Small, light, and rigid structures (and oscillators) have very short fundamental periods, and

there is not much motion at those periods. For this reason, the maximax response of a very short-period structure is the same as the maximax of the input recorded motion. In other words, the response of very short-period structures, the zero-period acceleration (ZPA), is the same as the peak ground acceleration (PGA). This is shown in RLM-G, where on the left side the spectrum is shown converging (dashed line) to the PGA of one-quarter g. The ZPA is also referred to as the anchor point of the spectrum.

Earthquake spectra have certain properties, which will now be discussed. To simplify the discussion, the calculated spectrum of RLM-G has been smoothed to the straight-line segments shown, and as reproduced in Figure RLM-H, "Smoothed Instrumental Spectrum". Earthquake spectra can be fairly described by plateaus where either D, V, or A are essentially constant. Those three plateaus are labelled in RLM-H. The acceleration ramp is the transition from the ZPA to the acceleration plateau. The ratio between the acceleration plateau and the ZPA is the dynamic amplification ratio (DAR). For the example shown, the DAR is (0.9/0.25) = 3.6. The turning points of the spectrum are the corners where the straight-line segments join.

The virtues of the logarithmic harmonic plot become apparent when the spectrum of RLM-G is plotted to

arithmetic scale, as is shown in Figure RLM-I, "Instrumental Spectrum". In order to display the long-period part, the short-period part is a mass of points, masking important engineering information. To make such a plot, the quantity to be plotted (D, V, or A) must be selected; and information on the other two is unavailable without further calculation. The characteristic plateaued shape is also masked.

The instrumental spectrum of RLM-G is not, in general, the spectrum which would be used to design a large or embedded structure. Large structures are not points, but rather have dimensions which are larger than the wavelengths of the short-period waves. For this reason, large structures do not respond fully to the short-period waves, much as a large ship does not respond fully to small water waves. If a structure is embedded, it responds less than a surface instrument because the motions at depth may be less than those at the reflecting surface, and because the structure is subjected to an average of the various incoming and reflecting waves. The incoming waves are likely not plane and coherent, but rather probably have some components lagging and some leading the wavefront. These effects (wavelength, embedment, and noncoherence) tend to lower the short-period end of the <u>design</u>

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spectrum relative to the instrumental spectrum. These effects collectively are soil-structure interaction.

The above discussion of the shape of a design spectrum applies to structures which behave perfectly elastically. This assumption is made for mathematical simplicity, but real structures respond in a somewhat ductile fashion, rather than perfectly elastically. Key structures at nuclear facilities are designed to minimize their ductility, but nevertheless some exists, which has the effect of lowering the entire instrumental spectrum to some degree.

As an example, Figure RLM-J, "Example of Instrumental and Design Spectra", compares an instrumental to a design spectrum. Some facilities, such as SONGS 2 & 3, are conservatively designed directly from the instrumental spectrum, with no credit taken for the above effects.

Q. How are spectra used to compare the strenths of earthquakes?

A. Spectra are often used to compare the strengths of earthquakes. This is basically a good process, provided all of the following seven conditions are met:

1. The spectra being compared must be of the same type (e.g., response, Fourier).
2. The spectra being compared must be in the instrumental form, not in the design form.

3. The spectra being compared must be for the same damping.

4. The spectra being compared should be from earthquakes of the same magnitude, or they should be scaled to represent the same magnitude.

5. The spectra being compared should be from recordings taken at the same distance from the causative fault, or they should be scaled to represent the same distance. Distance should be mesured in a consistent manner.

6. The spectra being compared should be from earthquakes with the same style of faulting, or they should be scaled to represent the same style of faulting.

7. The spectra being compared should be from earthquakes in the same or similar tectonic setting. There is probably no way to scale for this point.

Spectra which do not meet all of these seven conditions should not be compared, for the comparison will at best be misleading.

When comparing spectra, it is important to include a number of spectra. Because the world is a probabilistic place, some spectra must be anticipated to exceed, and some to lie under, a given instrumental spectrum assigned to a given site. This is precisely

the reason engineers include material <u>safety factors</u> in their design, and why they use minimum specified material strengths in their calculations. Safety factors are not, however, a panacea against distress to a structure. If an appreciable number of spectra meeting the seven conditions listed above exceed the site instrumental spectrum, then that site instrumental spectrum may be too low; and, more importantly, the design spectrum derived from it may also be too low; and, if the amount by which the design spectrum is too low exceeds the margins provided by the safety factors, distress to the structure would impend. Thus conservatism is appropriate at each stage of this process: selecting the instrumental spectrum; developing from it the design spectrum; and the selection and application of the safety factors. If these are done in a careful and prudent manner, even though the values at each step may not be exactly accurate in a scientific sense, engineering experience shows that the overall process yields structures which have a very high probability of surviving their design assumptions, and a reasonable probability of surviving loads which substantially exceed their design assumptions.

Q. Would you please describe the procedures you employed in constructing the SONGS 2 & 3 DBE spectrum?

A. During the period 1971-1972, I was directly responsible for and actively involved in calculation of the DBE spectrum for SONGS 2 & 3. The shape of the DBE spectrum was derived by mathematically propagating virtually all of the strong motion recordings then available through the profile of the San Mateo Formation. I calculated the resulting instrumental spectra at the site ground surface, and enveloped those intrumental spectra. For this purpose, the dynamic properties of the San Mateo Formation were determined by both field and laboratory tests.

The instrumental spectrum shape was anchored to a ZPA of 0.5g, which I still believe to be a realistic upper limit of the maximum ground motion governing structures response at this site. The resulting instrumental spectrum is shown in Figure RLM-K "Original Instrumental Form of DBE Spectrum". For that case, at two percent damping, the technique of enveloping the spectra of real earthquakes indicated that the acceleration amplification ratio at this site would be about 3.2, with a short-period turning point at about 0.05 seconds or higher. At that time (1972), the maximum magnitude on the OZD had not been determined, but it was recognized that design for a very large, nearby earthquake would be conservatively appropriate. For that reason, and in consideration of the state of

the art of predicting ground motions and structural response at that time, the following modifications were made to the 0.5g site instrumental spectrum to add extra conservatism: (i) the ZPA was increased to 0.67g, and the entire instrumental spectrum was scaled up to that value; (ii) the acceleration amplification ratio was increased by about ten percent; (iii) the short-period turning point was decreased from 0.05 second to 0.033 second. The resulting modified spectrum is shown in Figure RLM-L, "Design Form of DBE Spectrum".

Q. Were these the only conservatisms applied to the calculation of the DBE spectrum?

A. While these modifications added considerable conservatism to the calculated instrumental spectrum, probably the greatest conservatism lies in the way that spectrum was used: that DBE spectrum was used directly for design. No allowances were made for wave-passage, incoherence, mass, depth-of-embedment or other effects which cause the motion governing structural response to be less than those recorded by free-field instruments. Furthermore, no allowance was made for the extra strengths which are provided for in the structural design. That is, the 0.67g modified instrumental spectrum was used directly as the design spectrum, shown in RLM-L.

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Q. Would you please quantify the conservatisms you believe are contained in the design spectr~ for SONGS 2 & 3?

A. I will quantify the conservatism of the design spectrum for SONGS 2 & 3 by comparing its instrumental form to some instrumental records calculated for or taken from the free-field at the ground surface. Before making such comparisons, however, I must convert the DBE spectrum, as used directly for design, to its instrumental form. I have done that by examining data from the literature, as I will now explain.

The majority of the existing free-field instrumental data have been acquired only in the last two decades. Some of these instrumental recordings contain PGAs much larger than had previously been deduced based on observed structural behavior during earthquakes.

For example, Forrell and Nicolletti ("EERI Reconnaissance Report" (1980)) gives the maximum accelerations from recordings made in the free-field adjacent to, and on the ground floor of a steel mill building in the Guerrero, Mexico earthquake of 14 Mar 79 (M_s 7.6). In that case, the ratio of the maximum free-field instrumental acceleration to the ground-floor maximum acceleration was 1.7 to 1.9.

The foregoing is an example of the reducing effect of a structure on short-period ground motions, when that

structure has large plan dimen..ions, but no basement. The following table shows the effects of embedment of the structure for magnitudes greater than M_s 6.

Location*	Instr.+	Distance between buildings, m	Distance from earthquake km	Ratio**
14724 Ventura	G	-	15	
15250 Ventura	B	914		1.2
1260 N. Orchid	G	-	19	
7080 Hollywood	B	450		1.9
6430 Sunset	G	-	20	
6464 Sunset	B	100		1.6
6200 Wilshire	G	-	24	
5900 Wilshire	B	500		1.6
3407 W. Sixth	G	-	39	
616 S. Normandie	B	536		1.5
3470 Wilshire	B	396		1.4
3411 Wilshire	B	416		1.4
3550 Wilshire	B	666		1.2
			Average =	1.5

* In Los Angeles
\+ G = Ground Floor; B = Basement
** Ratio: $\frac{\text{Peak Acceleration at Ground Floor, no basement}}{\text{Peak Acceleration at Basement}}$

The earthquake was the 09 Feb 71 San Fernando event. The ground-fl)or recordings were in buildings with no basement. The table above shows that, although the no-basement buildings had reduced the motion, the basements under the adjacent buildings further reduced the motions, so that the ratio of the peak accelerations in buildings with no basements to those with basements averaged about 1.5.

I do not know if these two effects (plan area and embedment) are additive or multiplicative; but if they are additive their combined effect is 2.3, and if they are multiplicative their combined effect is 2.6. Thus it would seem reasonable and conservative to take an upper limit for these combined effects as about 2, for purposes only of comparing the DBE maximum acceleration to another instrumental maximum acceleration.

The foregoing is for peak accelerations. The situation with respect to spectral values is shown in Figure RLM-M, "Examples of How Structures Without Basements Have Higher Spectral Accelerations Than Structures With Basements". These are the same buildings as in the table above. RLM-M shows that buildings without basements experienced spectral accelerations from 1.15 to about 3 times those of buildings with basements.

The case histories mentioned above and in RLM-M clearly demonstrate that the PGA and spectral accelerations from instrumental free-field recordings are higher, and in many cases substantially higher, than those of structures with large plan area and/or embedment. The combined effects of area and embedment are shown in Figure RLM-N, "Examples of How Structures Reduce Ground Motion". Shown there is the ratio of instrumental free-field response to the response

measured at or near the bottom of the structures. That ratio is from 1-1/2 to about 4-1/2, at short periods. Thus, to derive the range of the instrumental form of the DBE spectrum, I have multiplied the design spectrum by 1.5 and 2 at very short periods (less than about 0.025 sec), and by 1.25 and 1.5 at periods about 0.2 sec., and by 1.0 at periods above 1 sec. The resu'ting multiplier ratio is shown in Figure RLM-O, "Values of Ratio Used to Construct Instrumental Form of DBE", along with the examples of RLM-N. I view this operation as being cautious and conservative for purposes of comparison, because the correct ratios for structures at this site are probably higher based on the data in the literature.

The results are shown in Figure RLM-P, "Design and Instrumental Forms of the DBE" where the lower bound of the Instrumental Form applies to the smaller and shallower structures at the site, and the upper bound applies to the heavier and deeper structures.

To evaluate the conservatism of the DBE spectrum, that spectrum is shown, along with the 84th-percentile corresponding values calculated from the Imperial Valley earthquake of 1979 ("IV-79") data, and the instrumental values calculated by Woodward-Clyde (regression study, cf., Testimony of Dr. I. M. Idriss) and DELTA (source modelling study, cf., Testimony of Dr. Gerald A.

Frazier), in Figure RLM-Q, "Instrumental Form of DBE Spectrum, Compared to Other Instrumental Spectra". For additional comparison, the instrumental value of ZPA (84th percentile) calculated by TERA (regression study cf. testimony of Lawrence H. Wight) is 0.49g, whereas the corresponding value for the DBE is 1 to 1.3g. Using the TERA ZPA, RLM-Q also shows the instrumental spectrum calculated by the methods of NRC Publication NUREG/CR-0098. All of the calculated values (IV-79, Woodward-Clyde, DELTA, TERA, NUREG/ CR-0098) lie below both the instrumental and the design forms of the DBE. Based on those comparisons, it is my opinion that the DBE spectrum as used for design of SONGS 2 & 3 is a conservative representation of the motions of structures at the site due to a very large, nearby earthquake.

Q. Is it your opinion that the DBE spectrum for SONGS 2 & 3 is also conservative for the vertical motions?

A. The situation for vertical motions is shown in Figure RLM-R, "Instrumental Form of Vertical DBE Spectrum Compared to Other Instrumental Spectra" where the instrumental form of the DBE vertical spectrum is shown, compared to the 84th-percentile corresponding values calculated from the IV-79 data, and to the instrumental values calculated by DELTA (source-modelling study). The IV-79 verticals are somewhat high because of the velocity profile of the Imperial Valley (which is

different from that at SONGS). Nevertheless, the values from IV-79 and the U.C. study all lie below the instrumental form of the DBE. Based on this comparison, it is my opinion that the vertical DBE spectrum, as used for the design of SONGS 2 & 3, is a conservative representation of the motions of structures at this site due to a very large, nearby earthquake.

Q. Has the recent publication USGS 81-365 caused you to modify your opinion concerning the conservatism of the DBE spectrum for SONGS 2 & 3?

A. No. First of all, I would like to state that I have disagreement with applying the results of USGS 81-365 to SONGS because the calculated accelerations and velocities appear to be inappropriate for SONGS based on engineering experience, and on the site-specific studies which have been done for SONGS (Woodward-Clyde regression study, Tera regression study, Delta source-modelling study). I agree with the testimony of Dr. Smith on this matter. Nevertheless, if one were to use USGS 81-365, for the faulting conditions assumed for purposes of licensing Units 2 and 3, the result would be an instrumental 84th percentile of 0.87g. That is less than the instrumental DBE value of 1 to 1.3 g.

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DR. ROBERT L. McNEIL

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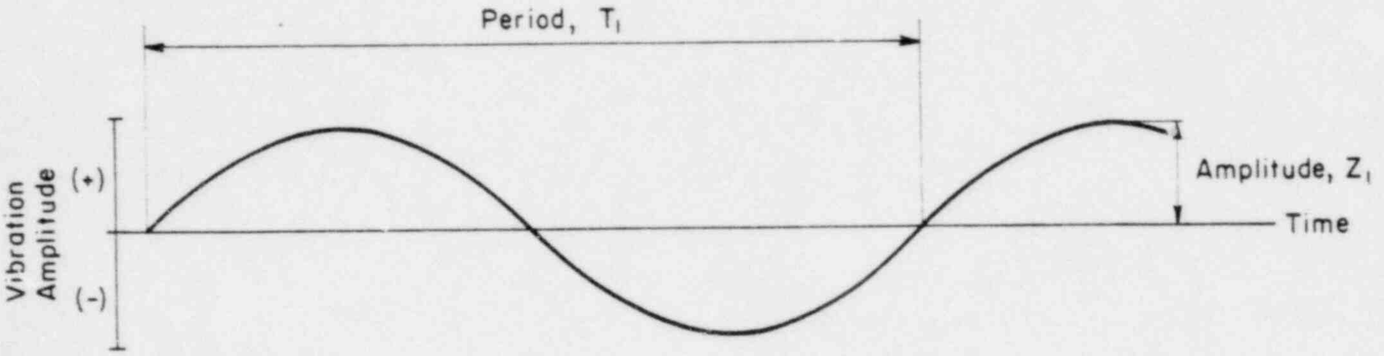
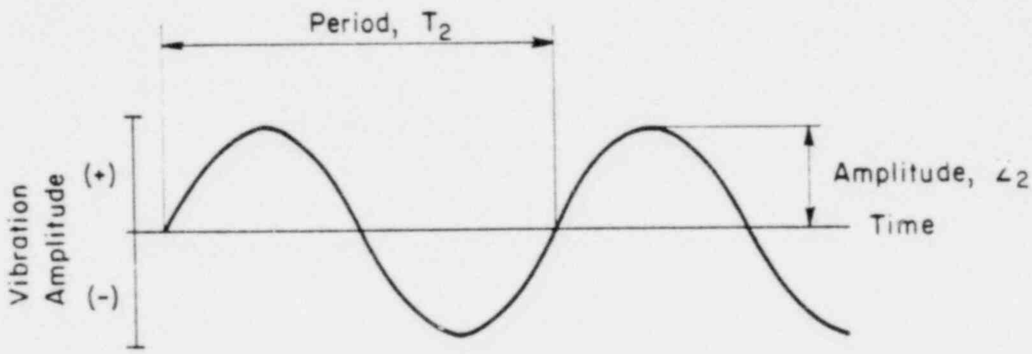
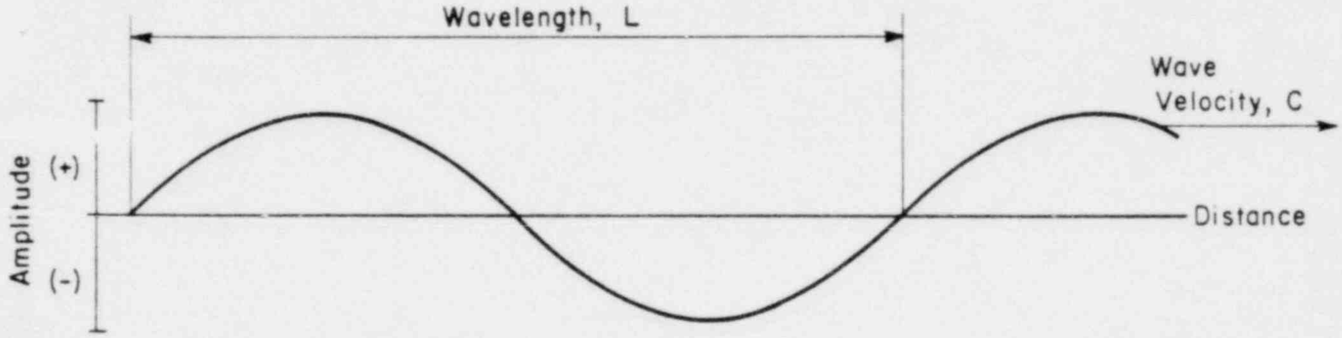
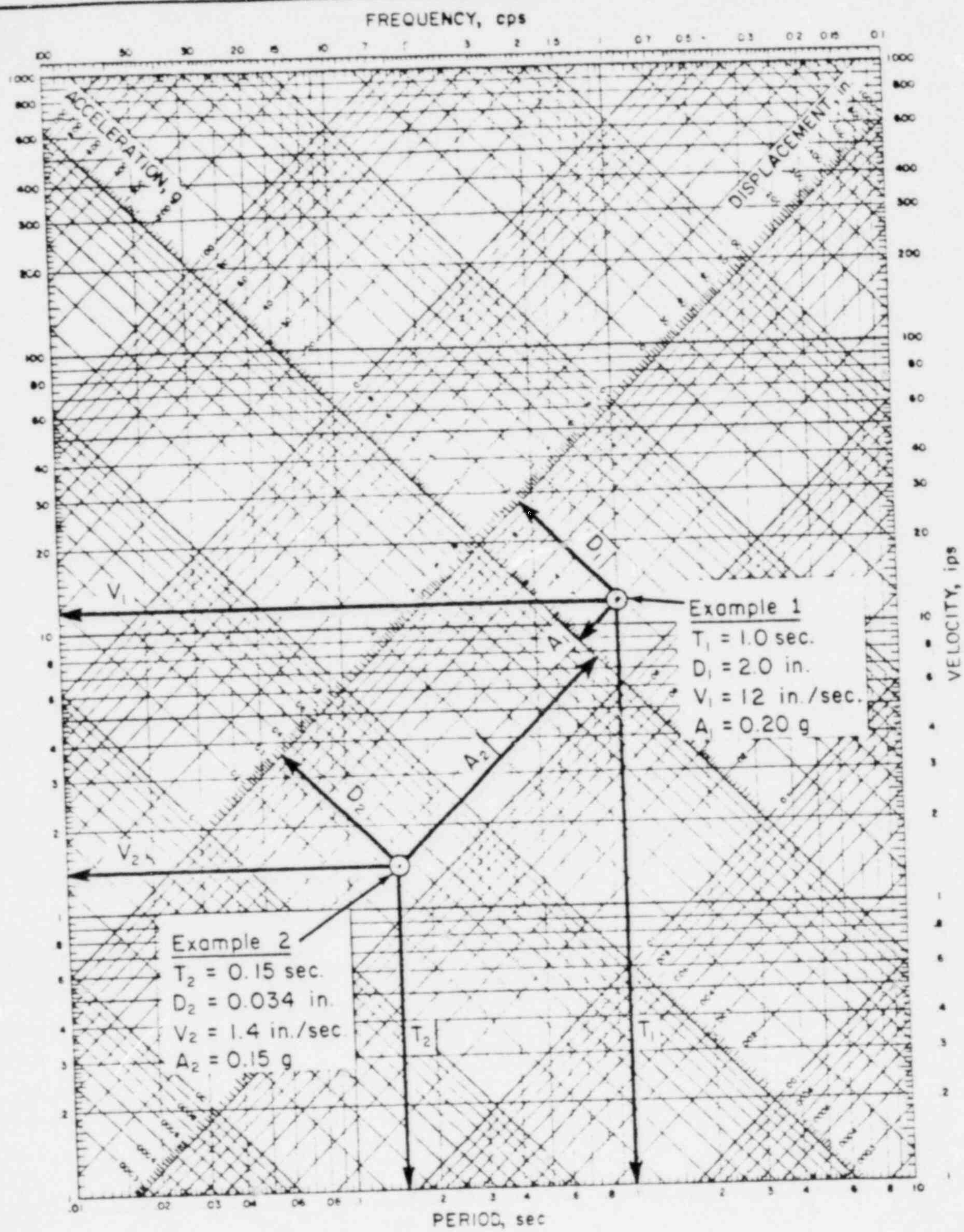




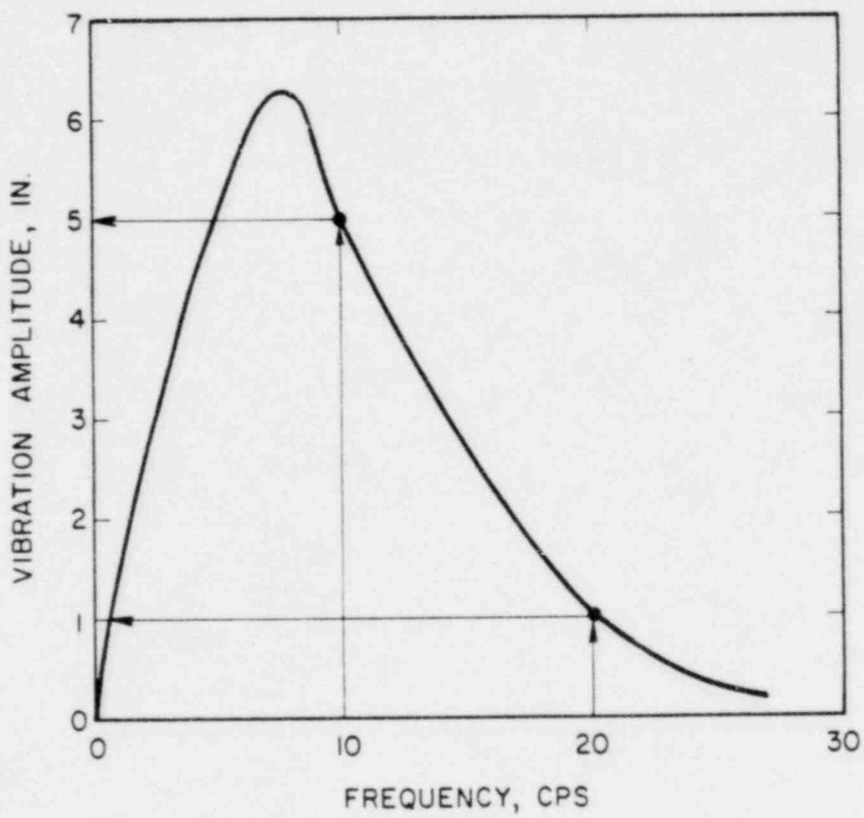
Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	<u>Definitions</u> (Time)	Fig. RLM-A



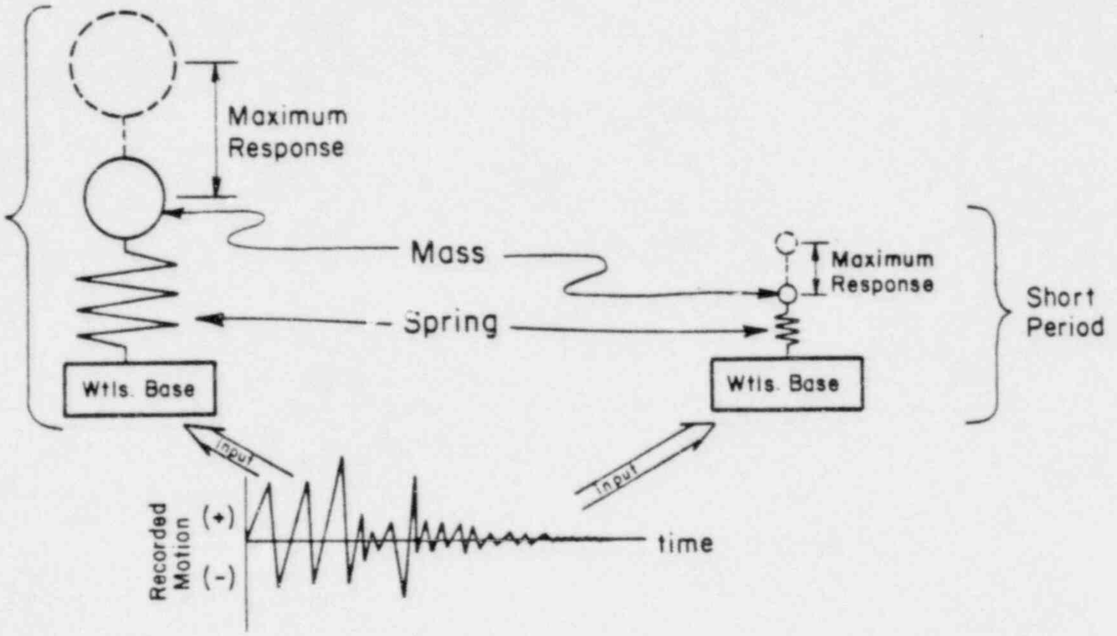
Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	<u>Definitions</u> (Space)	Fig. RLM-B



Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Examples of Use of Harmonic Paper	Fig. RLM-C



Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Simplified Example of a Spectrum, an ordered array of the motions	Fig RLM-D

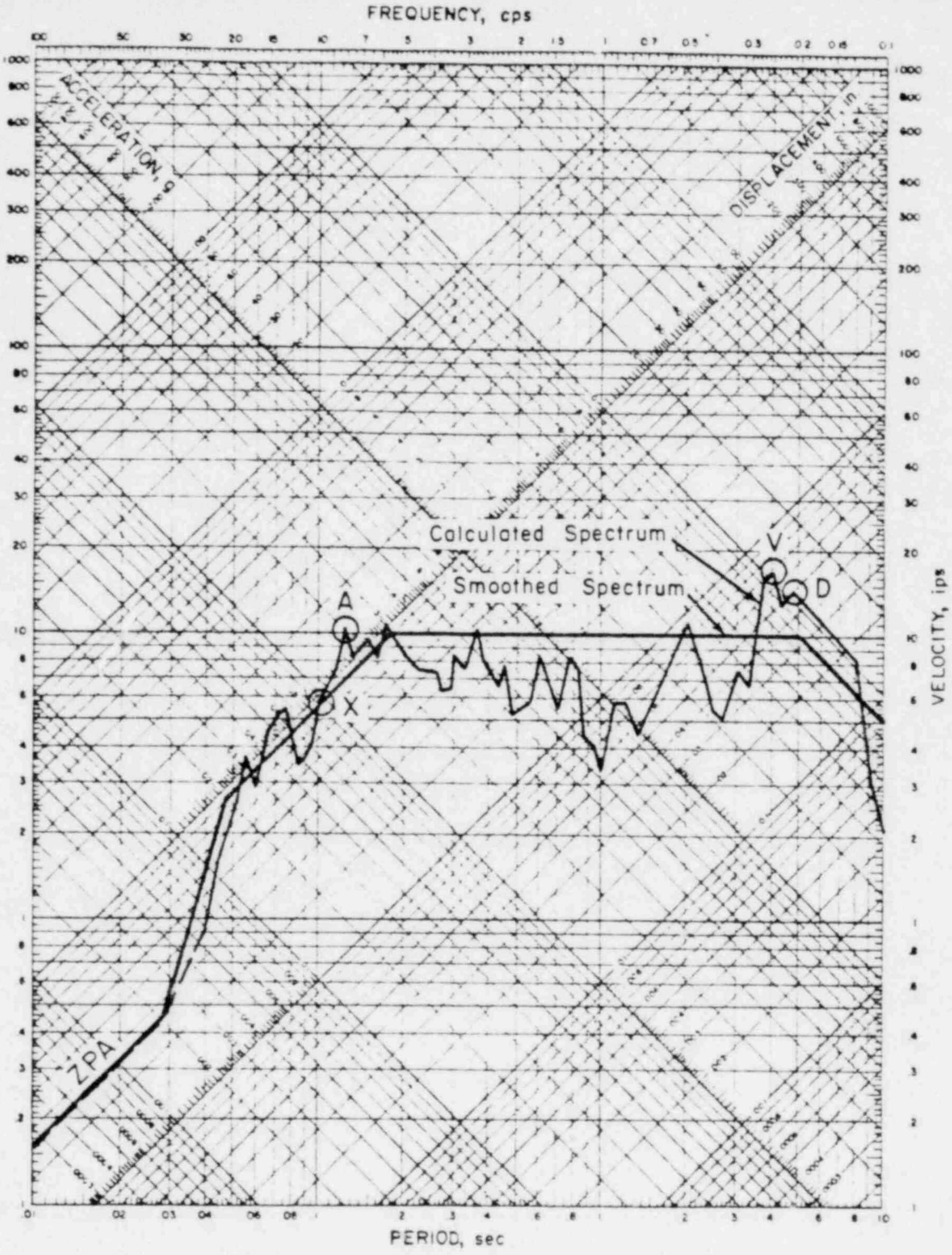


Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Calculation of Instrumental Spectrum	Fig. RLM-E

FIGURE 9(b)

WCC VERT RPT 09 MAY '80

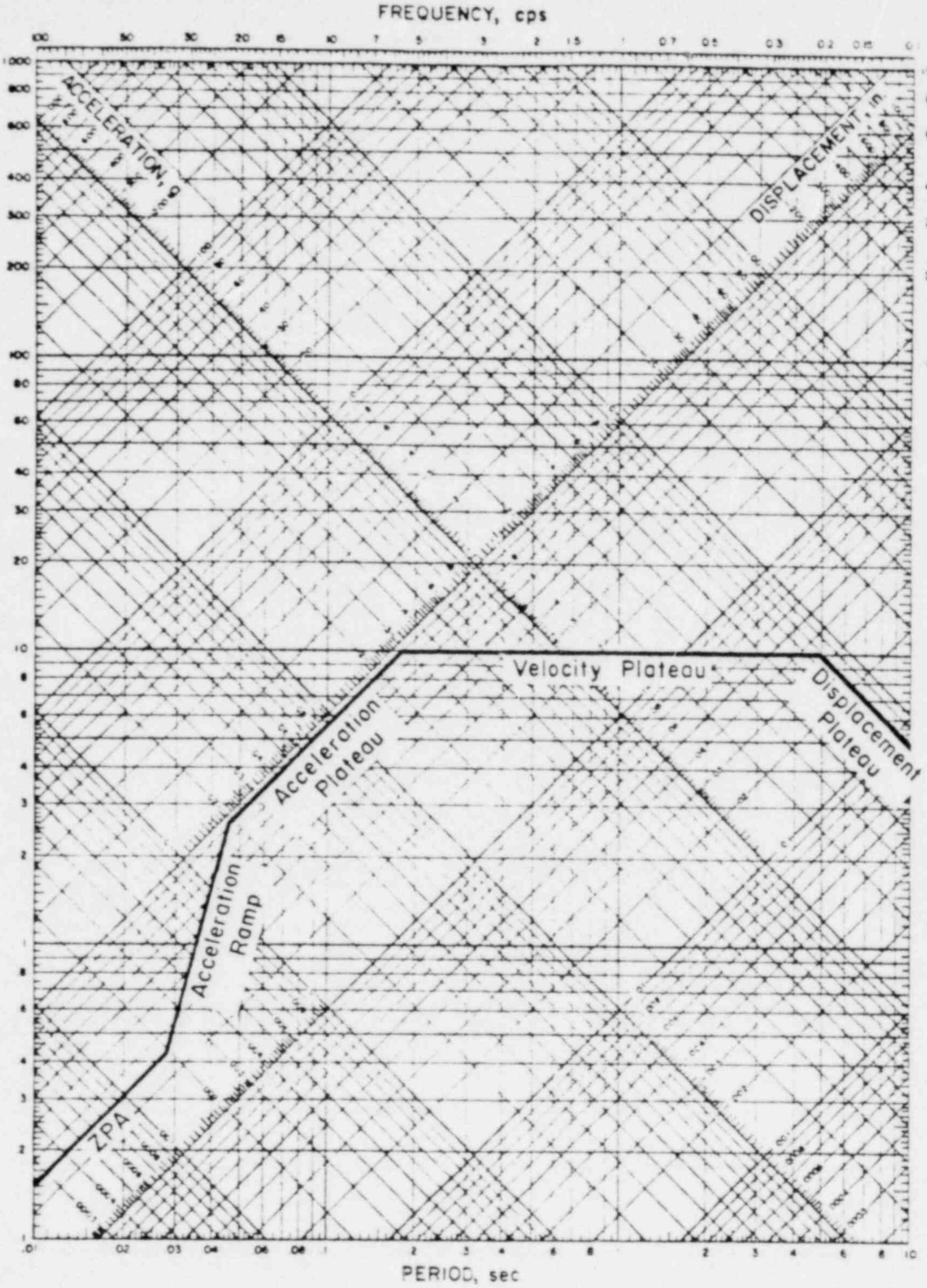
Witness: DR. ROBERT L. McNEILL	Example Accelerogram	Fig.
Date: 28 MAY 1981	IV-79, USGS 5055, vertical component	RLM-F



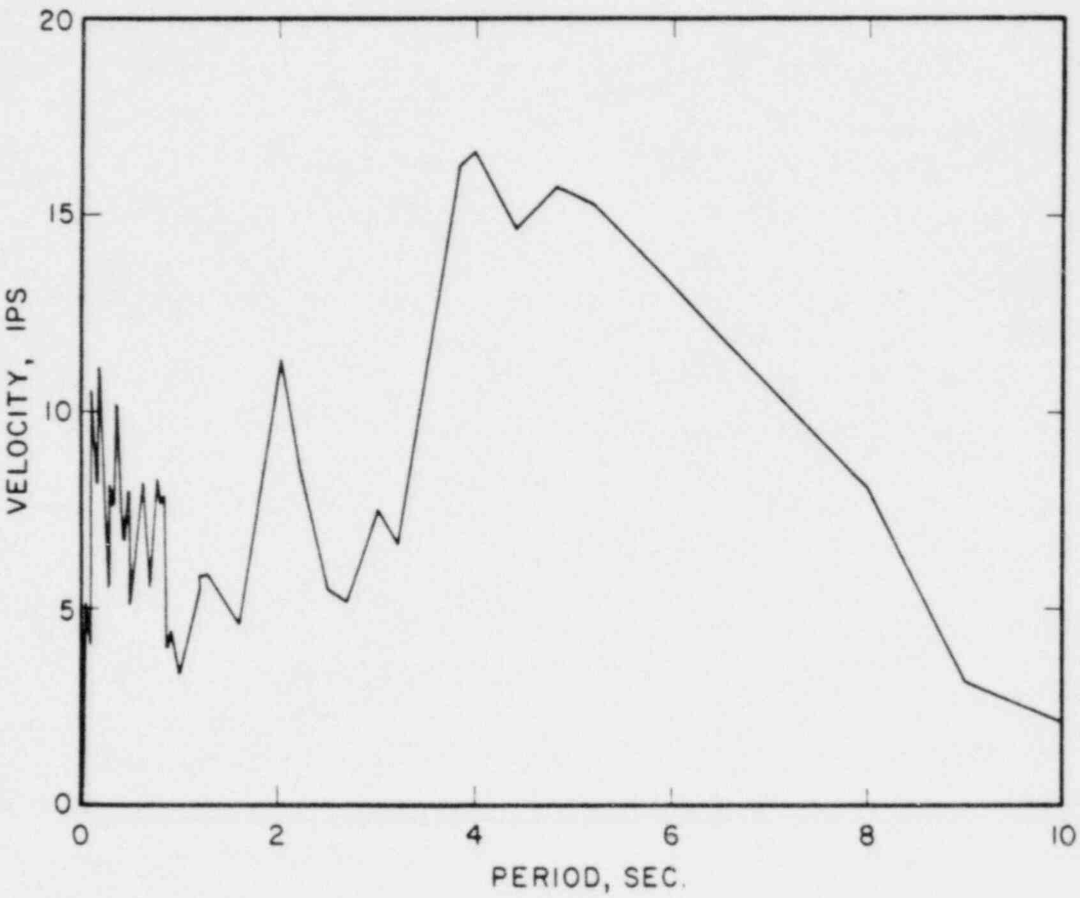
Damping = 2%

IV-79, USGS 5055, vertical component

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Instrumental Spectrum	Fig. RLM-G



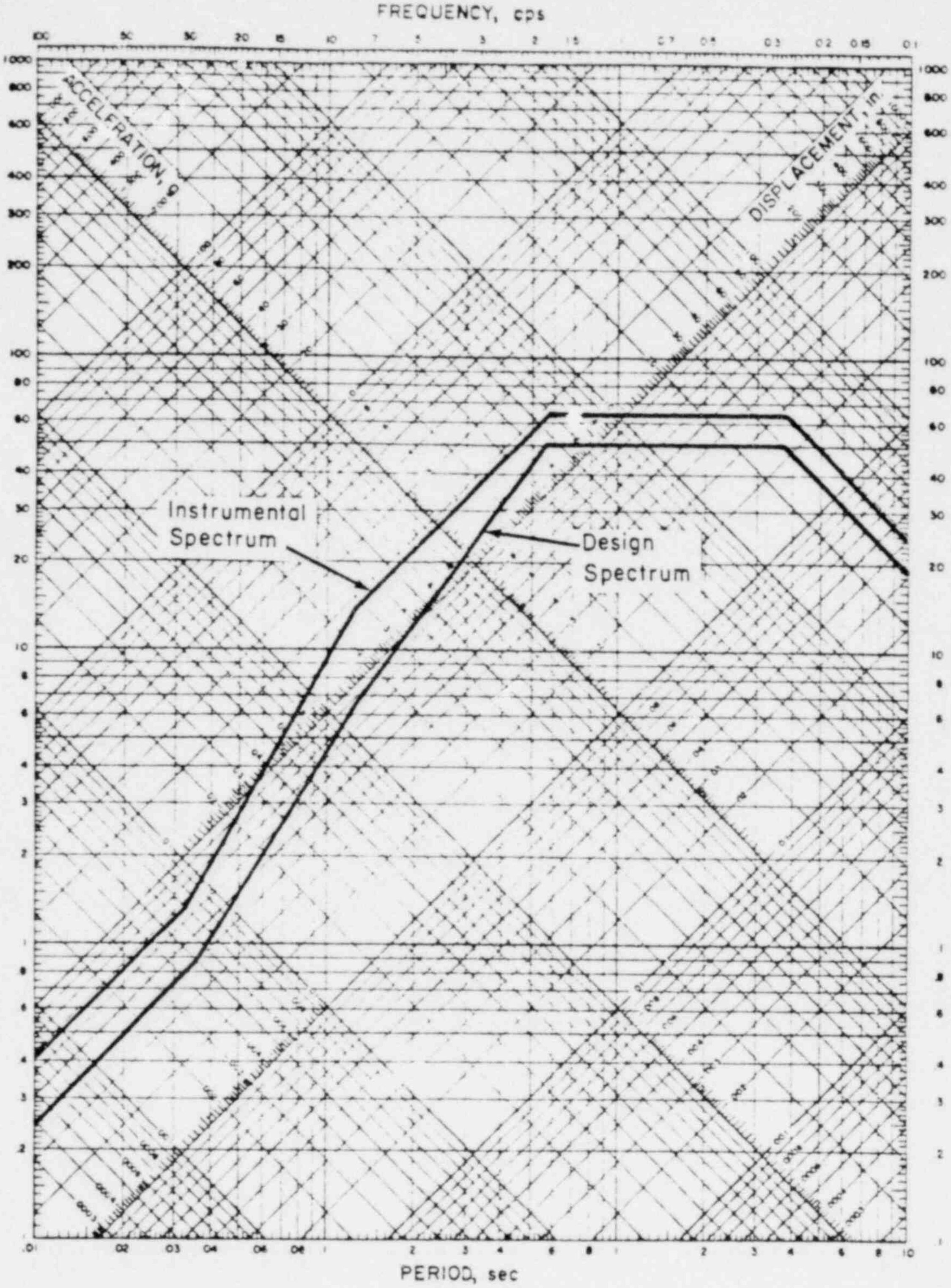
Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Smoothed Instrumental Spectrum	Fig. RLM-H



Damping = 2%

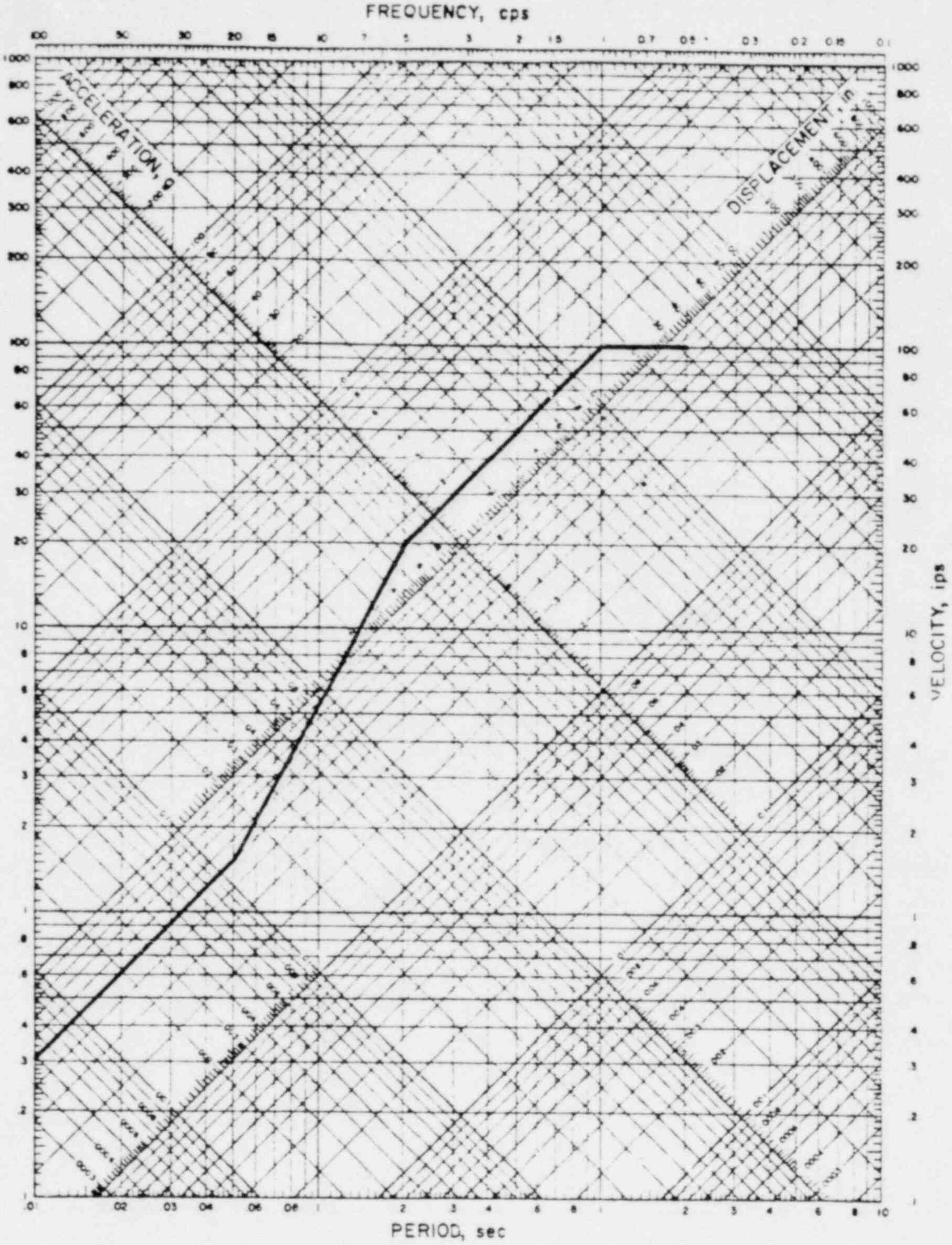
IV - 79, USGS 5055, vertical component.

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Instrumental Spectrum	Fig. RLM - I



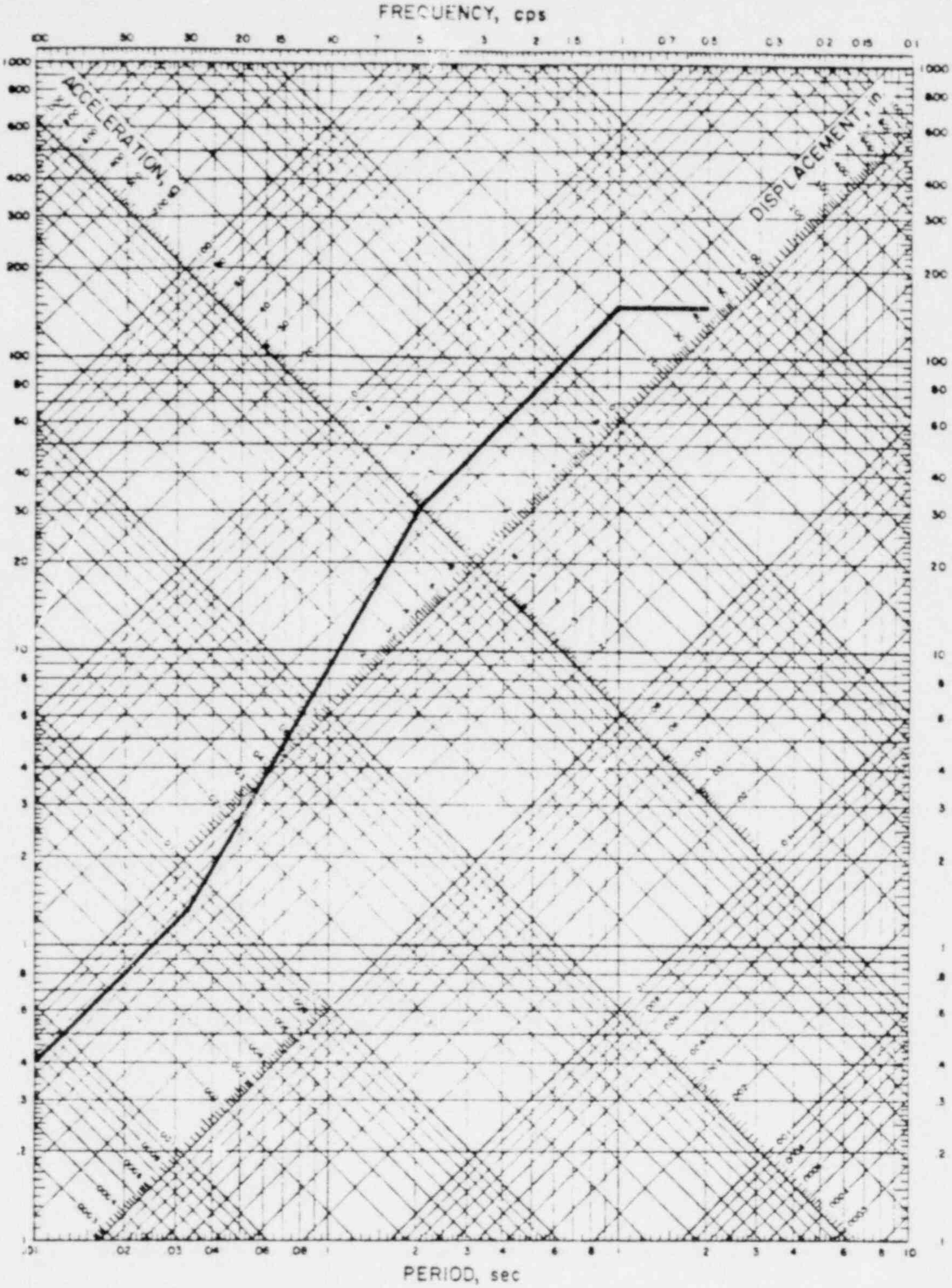
Based on NUREG/CR-0098, Damping = 2%,
SSI Factor = 0.60, Ductility = 1.3

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Example of Instrumental and Design Spectra	Fig. RLM-J



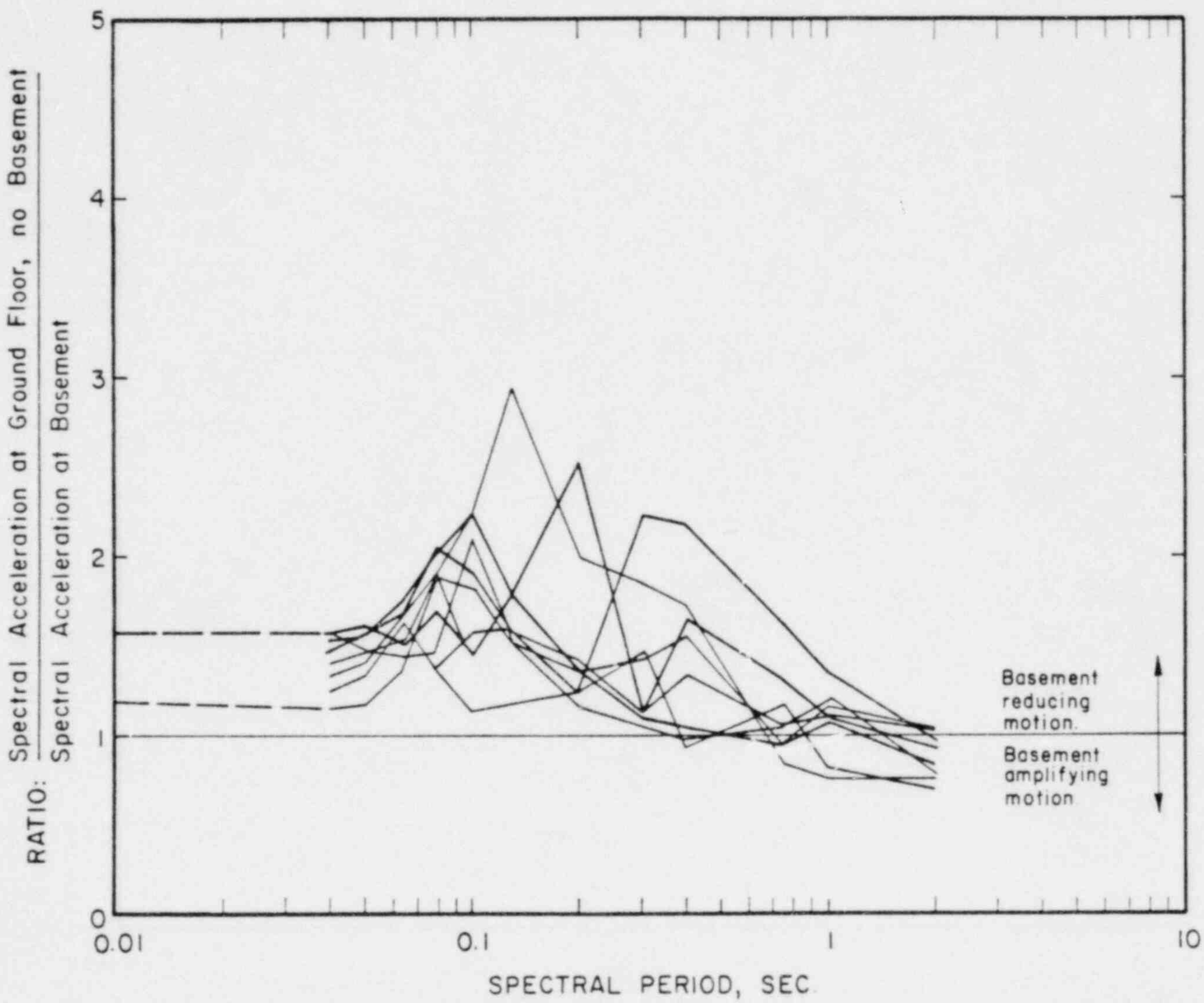
- 2% Damping
- Derived from calculations using instrumental records.

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Original Instrumental Form of DBE Spectrum	Fig. RLM-K



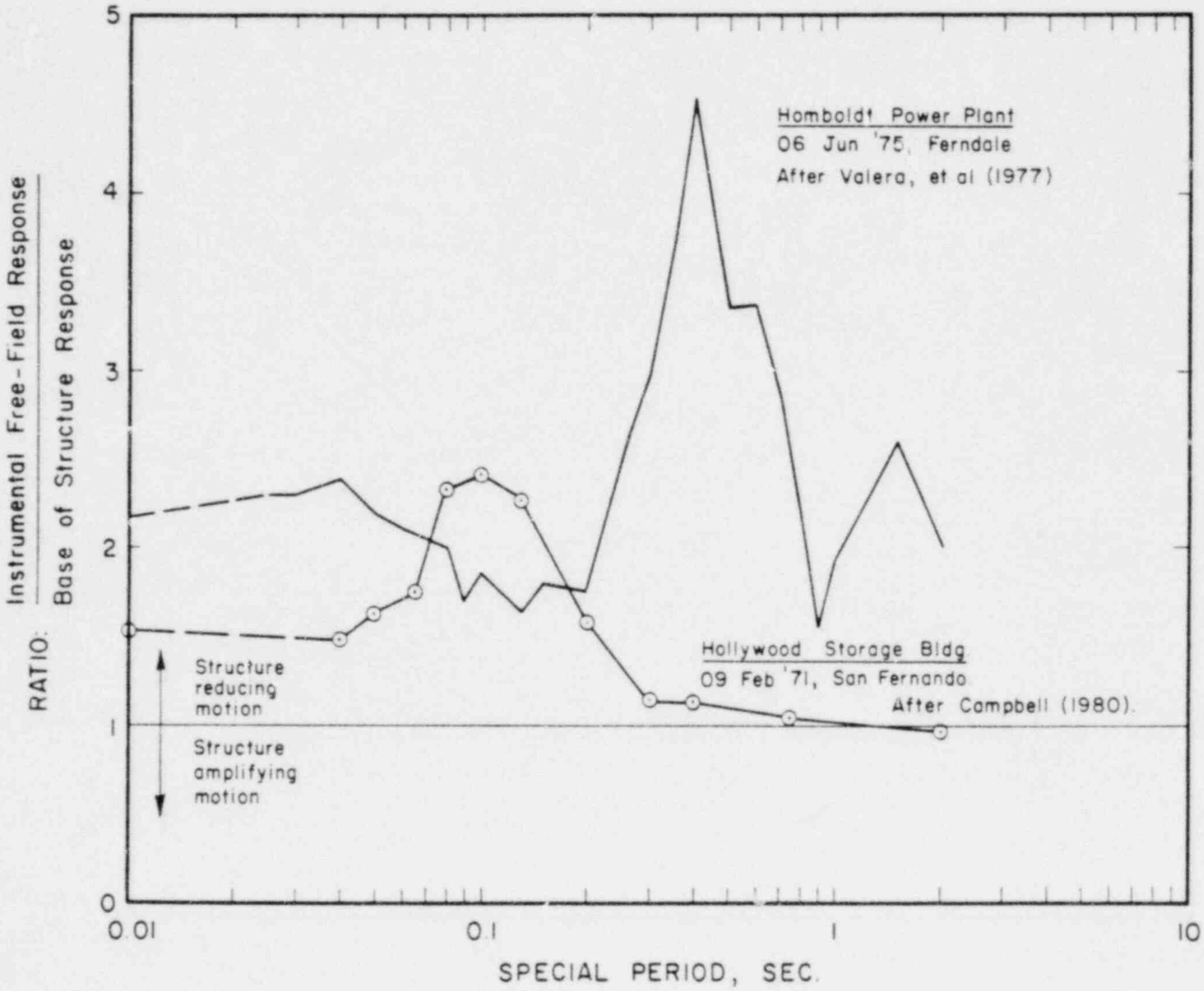
- 2% Damping

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Design Form of DBE Spectrum	Fig. RLM-L



Los Angeles, 09 Feb '81 San Fernando Earthquake
after Campbell (1980).

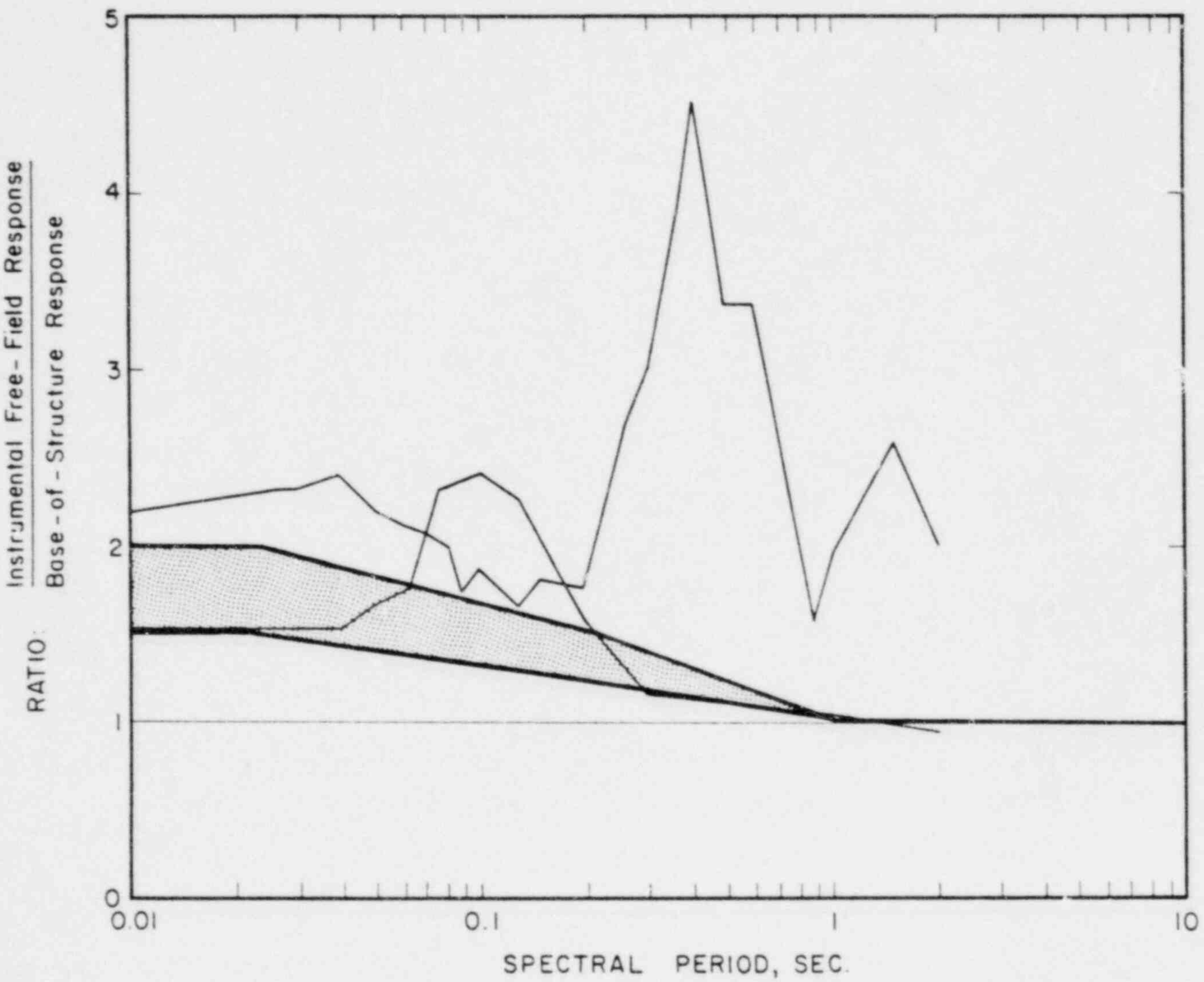
Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Examples of How Structures Without Basements Have Higher Spectral Accelerations than Structures with Basements	Fig RLM-M



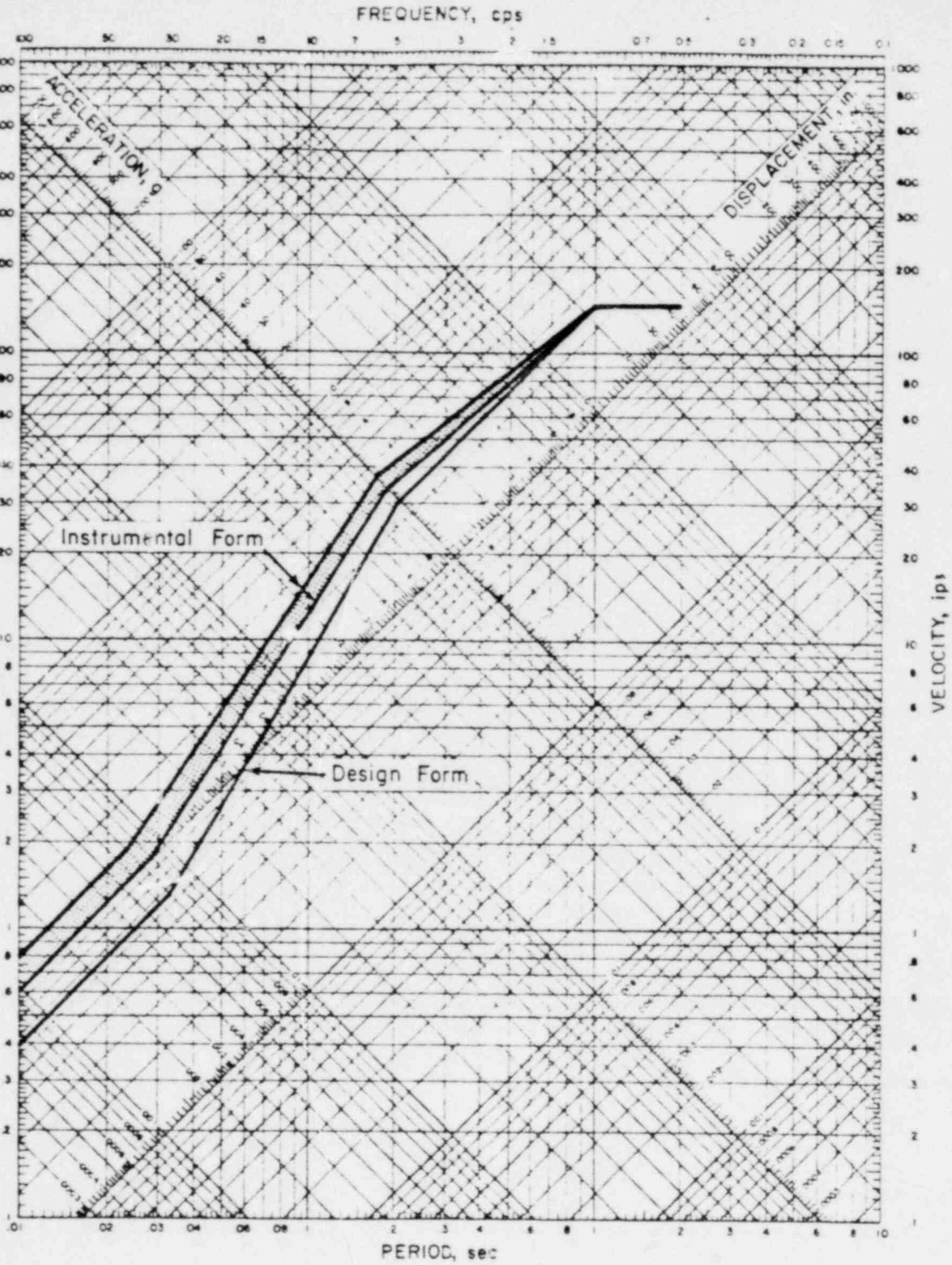
Damping = 5%.

- Hollywood Storage Bldg: Instrument at -3m.
- Humboldt Power Plant: Instrument at - 25m.

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Examples of How Structures Reduce Ground Motion	Fig. RLM-N

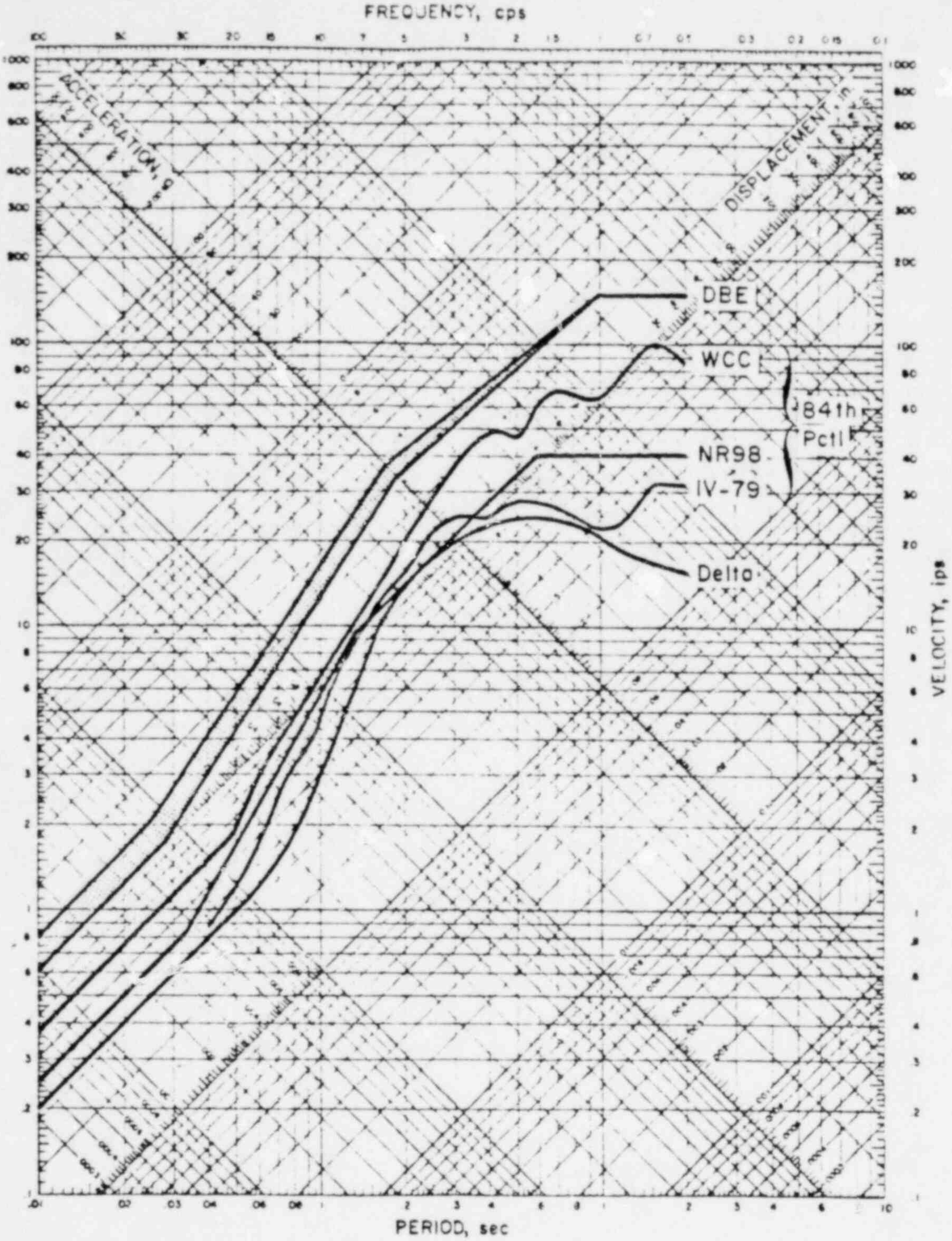


Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Values of Ratio Used to Construct Instrumental Form of DBE	Fig. RLM-0



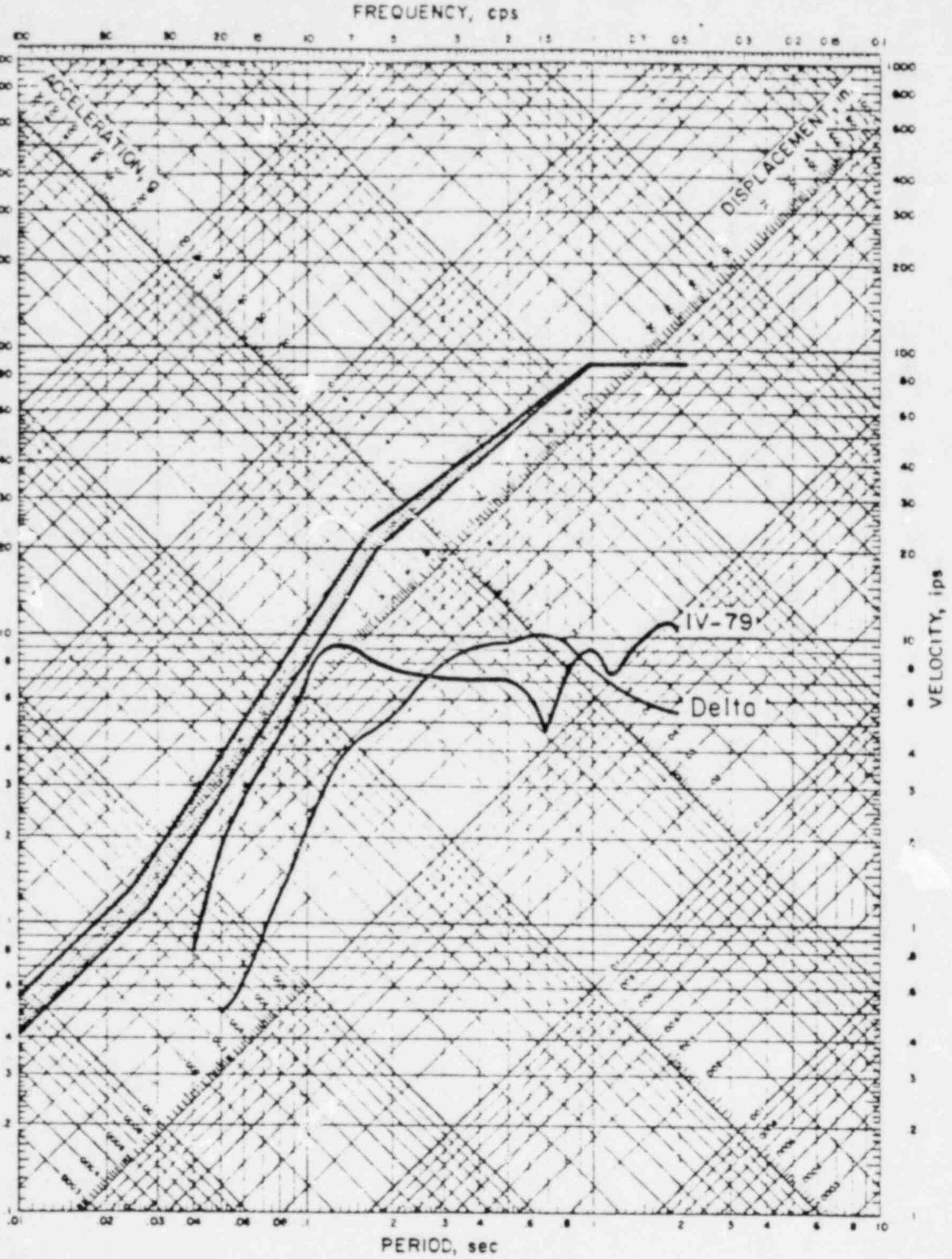
- 2% Damping

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Design and Instrumental Forms of the DBE	Fig. RLM-P



- 2% Damping
- IV-79, all stations 6-13 km from fault, Spectrum shown is 84th-percentile

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Instrumental Form of DBE Spectrum, Compared to Other Instrumental Spectra	Fig. RLM-Q



- 2% Damping
- IV-79, all stations 6 - 13 km from fault, Spectrum shown is 84th - percentile

Witness: DR. ROBERT L. McNEILL Date: 28 MAY 1981	Instrumental Form of Vertical DBE Spectrum, Compared to Other Instrumental Spectra	Fig. RLM-R