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Verification of Subsurface Conditions at Selected "Rock" Accelerograph Stations in California

Volume 2

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ABSTRACT

This is the second in a series of reports to investigate the subsurface soil conditions at accelerograph stations which have been categorized by other researchers as "rock" sites. Contained in this volume are our findings of the site conditions at 29 accelerograph stations in California. Subsurface conditions at the sites were investigated with a geologic reconnaissance and a review of available boring data. At three sites, where boring data was not available, a test hole was drilled to better define the depth to rock. Of the 29 "rock" sites that were investigated, less than half could be verified as being founded on or within about 20 feet of rock. This would imply that over half of the stations are really soil sites.

This report is divided into eight sections, with each section representing a geographic area in which the stations are located. Presented in each section is specific data on the individual stations, including descriptions of station housing, instrumentation, and subsurface conditions. Each section also contains discussions of the regional and local geology and seismicity of the study area.

Information on the earthquakes recorded at each of the stations, including ground motion time history plots and response spectra curves, is presented in a separate volume as an appendix to this report.

VERIFICATION OF SUBSURFACE CONDITIONS AT SELECTED "ROCK" ACCELEROGRAPH STATIONS IN CALIFORNIA

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FOREWORD

Very little is known about the geologic and subsurface conditions at most of the strong motion accelerograph station sites in the United States. To more fully benefit from the seismological information recorded during earthquakes, it is necessary to have a clear understanding of the subsurface characteristics at the various stations.

This report presents the results of a portion of an overall effort undertaken to evaluate the subsurface conditions at important accelerograph stations in the United States. This report presents geological and seismological information on 29 accelerograph station sites which were investigated in the state of California.

This work was accomplished under Contract No. AT(49-24)-0200 between the U.S. Nuclear Regulatory Commission and a joint venture of Shannon & Wilson, Inc. and Agbabian Associates (SW-AA), and represents a part of our continuing studies on soil behavior under earthquake loading conditions. Our program of investigating the subsurface conditions at selected strong ground motion accelerograph stations has consisted of the following:

a) Studies were performed at 19 accelerograph stations in southern California which have been classified by others as "rock" sites. The results of this investigation are presented in a first volume of reports on "rock" accelerograph stations (SW-AA, 1976a). As a continuation of this effort, studies were conducted at 29 additional "rock" stations in California, with the results of these studies presented in this report as Volume 2 of the series.

b) Studies and explorations were also conducted for three areas within the city of Los Angeles, containing 11 strong motion accelerograph stations. The results of this work are presented in SW-AA (1976c).

c) Additionally, we have performed specific site investigations for selected accelerograph stations in the west. The results of these studies are presented in three reports with each report containing investigations at several station sites:

Volume 1; Sections 1, 2, and 3 (SW-AA, 1975); includes geotechnical and earthquake data from accelerograph stations at Ferndale, Parkfield (Cholame No. 2), and El Centro, California. Volume 2; Sections 4, 5, 6 and 7 (SW-AA, 1976b); provides the results of studies performed at Pasadena, Santa Barbara, Taft, and Hollister, California. Volume 3 (SW-AA, 1977a) covers the work performed at Gilroy, California; Logan, Utah; Bozeman, Montana; Tacoma, Washington; and Helena, Montana.

This on-going study benefited from the efforts of various individuals. We wish to thank Dr. J. Harbour of the U.S. Nuclear Regulatory Commission for his recognition of the need for accurate geotechnical information at strong motion accelerograph station sites and for his support as Project Monitor.

We also wish to acknowledge various individuals and organizations, without whose cooperation this research could not have been completed. For granting drilling access, thanks go to Messrs. C. Carver and B. Maddox of the Las Flores Ranch, Ltd.; Mr. J. Stockton of the city of San Luis Obispo; and Mr. Escobar of the United California Bank in Wrightwood. The staff of the Seismic Engineering Branch of the U.S. Geological Survey, including the Messrs. E. Etheredge, L. Foote, R. Maley, and J. Newcomb has been particularly helpful in contributing geotechnical and seismic data relating to the strong motion stations. We also wish to thank the geotechnical firm of LeRoy Crandall & Associates of Los Angeles and Converse, Davis, Dixon and Associates in Pasadena for providing subsurface data for some of the stations investigated. Special appreciation goes to Mr. F. Springate of the Jet Propulsion Laboratory, Mr. D. Ostrom of Southern California Edison, Mr. J. Schlocker of the U.S. Geological Survey, and Mr. Fred Gillard of U.S. Santa Barbara for their contributions of geologic and geotechnical data.

The SW-AA joint venture efforts were directed by Dr. R. P. Miller, Project Manager. Dr. I. Arango, Project Engineer, supervised this task; and Mr. D. N. Clayton was the principal investigator. The borings drilled for this study were observed by Mr. R. D. Perry, who also assisted in organizing and writing Section 1 of the report.

VERIFICATION OF SUBSURFACE CONDITIONS AT SELECTED "ROCK" ACCELEROGRAPH STATIONS IN CALIFORNIA

VOLUME 2

INTRODUCTION

Currently, the seismic design of major structures; such as neclear power plants, buildings, dams, or bridges; requires a rigorous dynamic analysis to provide for the safety of the general public in the event of an earthquake. Many of the seismic design procedures currently available must use a representation of the ground motion in the form of an accelerogram or its corresponding response spectrum. The validity of the results of such an analysis depends, to a great extent, upon how accurately the design motion represents the motions to which the structure would be subjected during an actual earthquake.

To benefit from recent advances in analytical techniques, earthquake accelerograms or response spectra used in dynamic analyses must be carefully scrutinized for their applicability to the site under consideration. Such an examination is desirable because various investigators have found that earthquake ground motions are influenced by local soil conditions, topography, earthquake source mechanism, and the characteristics of the path along which the earthquake's energy is transmitted. Information on these factors at various accelerograph stations is often incomplete. Furthermore, current information (Duke, et al., 1972; EERI and NOAA, 1971; U.S. Geological Survey, 1975; Seed, et al., 1974 and 1975; Mohraz, 1976; Trifunac and Brady, 1975; etc.) indicates discrepancies in the interpretation of the geologic conditions at some stations.

This report presents the results of a continuing research effort directed towards obtaining geotechnical data at accelerograph stations. This report is the second volume in a series concerned with strong motion accelerograph stations in California that have previously been classified as "rock" sites by one or more investigators. In this research program, subsurface conditions at 48 "rock" accelerograph stations have been investigated: 19 reported in Volume 1 and 29 reported in Volume 2.

A literature search was conducted for each site to provide information on the station housing structure and instrumentation, the significant events recorded on the accelerograph, and the geology and seismic activity of the site area and region. Local subsurface soil conditions at each site were determined largely from available field explorations and laboratory reports by others. Some limited additional field and laboratory work was done at selected sites.

REPORT ORGANIZATION

General

The report is organized into eight major sections, each corresponding to different geographic areas within California where the accelerograph stations are located. These areas are: 1) the Eureka Region, 2) San Francisco Region, 3) San Luis Obispo Region, 4) Santa Barbara Region, 5) Lake Hughes Region, 6) San Bernardino Region, 7) Los Angeles Region, and 8) the Southern Coastal Region. The locations of these regions are shown on Fig. 1. Each report section describes the stations, the regional geology and seismicity, and the local geology near each instrument. A catalog of seismic events is then presented for each region. Also, the field explorations conducted and site subsurface conditions disclosed at each station are discussed. An appendix containing specific information on earthquakes recorded at the strong motion stations is presented as a separate document to this report.

The subsequent paragraphs briefly outline the material presented in each of the sections and the appendix.

Station Descriptions

This section presents information on the accelerograph station locations or former locations, the buildings or structures in which the stations are housed, and the specifications of the recording instruments. Figures showing the locations, plans, and photographs of the stations and instruments are also presented.

Geology and Seismicity

In this section, the geology and seismicity of each region are discussed, emphasizing general stratigraphy and tectonic framework. The tectonic activity of major structural features is discussed, as are the major seismic events that have affected the region. A regional geologic map showing faults, ranked by age, and epicenters of large earthquakes is presented in each section. The local geology of each strong motion station is also discussed. Here, the stratigraphy and structure of the stations are presented in more detail and are displayed on a geologic cross-section for each site.

Catalog of Seismic Events

This section briefly discusses the major earthquakes that have been felt in each region. Detailed information on earthquakes recorded at each of the accelerograph stations is presented in a companion report, Appendix A, Earthquake Records.

Field Explorations

The field explorations and investigations conducted at the stations are briefly discussed in this section.

Site Subsurface Conditions

The subsurface conditions at each of the strong motion accelerograph stations are discussed in this section. This information is compiled from available subsurface data provided by several foundation engineering firms and by additional borings and geological studies performed by the SW-AA joint venture. Boring logs are provided for stations where rock was not exposed at the surface.

Many of the accelerograph stations, particularly sites in Los Angeles, are underlain by Pleistocene, Pliocene, and Miocene sedimentary strata. Geologic maps and logs of available borings identify the material in these formations to consist of soft siltstone, sandstone, and shale. Engineering properties of these materials, however, are quite similar to those of hard clays and silts. That is, the upper portions of these sedimentary strata have shear strengths and shear wave velocities very similar to those of hard soil. Where possible, the text identifies these sites where the engineering properties and quite likely the earthquake behavior of the underlying sedimentary strata closely approximate the behavior of hard soil.

Appendix

The Earthquake Records Appendix presents, by geographic regions, a list of significant seismic events recorded at the accelerograph stations. When the accelerograph records have been digitized by the California Institute of Technology, time histories of acceleration, velocity and displacement, and response spectra are presented.

DISCUSSION OF FINDINGS AND CONCLUSIONS

General

The purpose of this study has been to investigate the subsurface conditions at 29 accelerograph stations in California that have been reported by others as being founded on "rock". An earlier report, Volume 1 of the series (SW-AA, 1976a), investigated the conditions at 19 other so-called "rock" sites in southern California. These studies, combined with the findings for the Ferndale and Taft accelerograph stations (SW-AA, 1975 and 1976b, respectively), account for the investigation of subsurface conditions at 50 "rock" sites in California.

Presented in summary form in Table 1 are the subsurface conditions at these 50 sites, as reported by others and as disclosed in the joint venture studies. As indicated in Table 1, there are many discrepancies among the different investigators in the reported site conditions. Some of these discrepancies exist due to different schemes used by others to classify the sites. The bases of these different classification schemes are discussed below. Following this section is a discussion of the findings of the joint venture studies, including a comparison with the conditions reported by others.

Site Classification Schemes of Others

Each of the 50 stations listed in Table 1 has been classified as a "rock" site by one or more researchers (Trifunac and Brady, 1975; Duke, et al., 1972; Mohraz, 1976; Seed, et al., 1974; Seed, et al., 1975; Maley and Cloud, 1971; EERI-NOAA, 1971; and the U.S. Geological Survey, 1975). The bases of the classification schemes used by these investigators are as follows:

Trifunac and Brady (1975)

The approach followed by these investigators is explained in the following excerpts taken from their original publication.

> "To determine the extent to which the geological conditions at a site might affect earthquake ground motion recorded there, the relationships of peak motion to intensity were calculated for three separate site classifications. The groupings were made on the basis of the hardness of the material at the instrument location together with a general knowledge of some of the individual sites in the following way."

"Eight members of the Earthquake Engineering Research Laboratory of the California Institute of Technology participated in the estimation of site hardness. Two lists were available to them, one describing briefly the site geology as prepared by the Seismic Engineering Branch of the U.S. Geological Survey (previously the Seismological Field Survey of the U.S. Coast and Geodetic Survey) and the other describing the surface geology read from geological maps in California, using the Geologic Atlas of California (published by the California Division of Mines and Geology). Coordinates of the accelerograph stations were available from the U.S.G.S. These two lists are reproduced in Table 4 (Trifunac and Brady's Report, 1975) with the corresponding estimates of the site classification, where 0 represents soft alluvium deposits, 1 represents hard sedimentary rock, or an intermediate site between 0 and 2, and 2 represents basement or crystalline rock. Also included in this table is a column labeled "U" where the site classifications of Duke, et al., 1972, have been included where available. Their classifications 3 and 4, for shallow and deep alluvium, are combined here into the grouping 0, their sedimentary rock classification (2) becomes 1, and igneous or metamorphic rock (1) becomes 2."

"It should be noted here that we did not make an attempt to describe our site classification in detail and precisely. We believe that it is virtually impossible to do this unequivocally and to satisfy all important constraints at the same time. This point is perhaps best illustrated by the perusal of the eight different estimates for the "Abbreviated Site Geology" and by the seven estimates for the "Data from Geological Map" which are both presented in Table 4. What is meant by "base rock" or "deep alluvium," for example, varies widely from one "expert" to another. The staff of the California Institute of Technology that participated in this simple site evaluations consisted of seismologists, geologists, and earthquake engineers. They are all well aware of what is meant by local geological conditions of a strong motion accelerograph site and have all thought about the problem on many occasions. Yet their assignments of 0's, 1's, or 2's to the same brief description on the local geological conditions is perhaps the best example of the ambiguities associated with such a simple classification."

"All estimates, including those in column "U", were averaged for each site with the result shown in the column "Ave.", with the following exceptions. In the Los Angeles area, eight groups of stations are sufficiently closely spaced that within each group one would expect the site classification to be the same. However, in several instances, indicated in the "Ave." column with a superscript ( ), this was not the case mainly because of the effects of changed wording in the abbreviated site geology listing. The "Ave." column contains seven such adjustments of site classification to ensure consistency across small geographical areas."

Duke, et al. (1972)

Shallow measurements of shear wave velocities at some 30 sites in the San Fernando earthquake area (1971), were used along with a survey of the local geology (Duke, et al., 1971) to establish the site classification scheme reproduced below:

Classification	Site Geology
1	Igneous or metamorphic rock
2	Sedimentary rock
3	Shallow alluvium, 20-60 feet
4	Deep alluvium, 60 feet

Mohraz (1976)

Brief geological descriptions of some of the accelerograph station sites were presented by the author. For those stations that recorded the San Fernando earthquake, Mohraz (1976) used the site descriptions of Maley and Cloud (1971). He also provided descriptions for a few stations from Wiggins and Hall (1961).

Seed, et al. (1974)

The authors analyzed the site-dependent spectra of approximately 30 strong motion records representative of four different site conditions. The conditions were defined as follows:

1 Rock

2 Stiff soils less than about 150 feet deep

3 Deep cohesionless soil with depths greater than about 250 feet

4 Soil deposits consisting of soft to medium stiff clays with associated strata of sands and gravels.

Seed, et al. (1975)

The authors developed a three-fold classification of site conditions at numerous strong motion stations for the purpose of analysis of site-dependent spectra. Their three divisions of site conditions were as follows:

1) Rock sites -- where rock was considered to be shale-like or similar in characteristics, as evidenced by a shear wave velocity greater than about 2,500 fps.

2) Stiff soil conditions — where rock as defined above was overlain by less than about 150 feet of stiff clay, sand, or gravel.

3) Deep cohesionless soil conditions -- where rock as defined above was overlain by at least 250 feet of generally cohesionless soils.

Maley and Cloud (1971)

Brief geologic descriptions of the station sites were given by the authors in their original paper. These descriptions indicate whether the stations are underlain by alluvium or rock and were compiled from available geological publications and foundation investigation reports on file with the Seismic Engineering Branch of the U.S. Geological Survey. No coded classification was adopted by the authors. The summary descriptions contained in Table 1 were taken from the author's work.

EERI-NOAA (1971)

This publication briefly describes the location, instrumentation, and geology at numerous strong motion stations in northern California. The geological descriptions are from sources referenced in the EERI-NOAA report and are based on regional, rather than detailed, studies at the station sites.

U.S. Geological Survey (1975)

Site conditions in this report are based on a compilation of information from various sources, including foundation engineering reports, geologic maps, site visits by U.S.G.S. personnel, and previous reports. The sources of information for individual sites are not given in the publication.

Findings of Joint Venture Study

One of the most significant findings of this study is that less than 50 percent of the sites listed in Table 1 are underlain by rock. Only 14 stations are founded on or within about 20 feet of crystalline rock or moderately hard sedimentary rock. The remaining sites are underlain by at least 50 feet of alluvium or material which behaves like a hard soil.

Of the stations not considered to be founded on rock, 22 sites are founded on or close to sedimentary deposits of Pleistocene, Pliocene, and Miocene age. These deposits typically consist of soft sandstone, siltstone, and shale. Calling these materials "rock" may be misleading since they possess the properties of a hard soil. Therefore, since these materials have strengths and shear wave velocities very close to hard clays and very dense sands, it is considered more appropriate to call these locations soil sites. Information about many of these sites is lacking in shear wave velocity data, and additional studies should be performed to further document the soil properties.

The remaining 14 sites not founded on rock are founded on alluvium of variable depth. Alluvium beneath each of these sites extends to depths of at least 50 feet. At some sites, such as Ferndale, the depth to rock exceeds 260 feet. At many sites, the boring data is inadequate to define the depth to rock, and additional geotechnical investigations are warranted.

Several comparisons may be made of the subsurface conditions at the accelerograph stations as reported by others and those as disclosed in the joint venture studies. First, sites reported in the literature to be located on crystalline rock have generally been verified by our studies. A few exceptions exist, however, where drilling performed in our studies indicated substantial thicknesses of soil overlying the crystalline rock (i.e., Fort Tejon, Wrightwood, Lake Hughes No. 1, and Cedar Springs Pump House).

Secondly, there is a correlation in the sites underlain by sedimentary deposits. Many of the sites in Table 1 have been reported in the literature as being underlain by hard sedimentary rocks. The findings of the joint venture studies indicate that these sites are underlain by sedimentary deposits of Pleistocene, Pliocene, and Miocene age. However, the near-surface material in these deposits has the engineering properties of hard clay or very dense sand. Therefore, it is more appropriate to call these locations "soil" sites.

Finally, a few stations that were identified by others as "rock" sites (Table 1) were actually found to be underlain by alluvium, at least 50 feet thick. This occurrence is primarily a result of the classification scheme used by a few individuals.

This study has attempted to better define the site subsurface conditions at selected accelerograph stations, and to compile geological, seismological, and descriptive information for each station. The results of this study should provide a more accurate depiction of the subsurface conditions at accelerograph stations whose earthquake records are currently being used in the design of structures.

TABLE 1

SUMMARY OF SITE SUBSURFACE CONDITIO

AT REPORTED "ROCK SITE" ACCELEROGRAPH STA

IN CALIFORNIA

U.S.G.S. Station No.	Accelerograph Station Name	Foundation Depth Below Grade (ft.)	Reported Site Geology and Subsurface Conditions					
			Trifunac and Brady (1975) Site Classification[1]	Duke et. al (1972) Site Classification[2]	Mohraz (1976) Site Geology	Seed et. al (1974) Site Classification[3]	Seed et. al (1975) Site Classification[3]	Maley & Cloud (1971) Site Geology
108	Carbon Canyon Dam (Standby generator house)	8	1	2	Thin alluvium over poorly cemented siltstone	--	Stiff soil	Thin alluvium over poorly cemented siltstone
110	Castaic Old Ridge Route	0	1	2	Sandstone	Stiff soil	Stiff soil	Sandstone
111	Cedar Springs Allen Ranch (Miller Canyon)	0	2	1	--	--	Rock	Granitic
112	Cedar Springs Pumphouse	0	1	2	--	--	--	Shallow gravelly alluvium
1438	Cholame-Shandon, Temblor	0	2	--	--	Rock	--	--
114	Costa Mesa 666 W. 19th Street	0	1	4	--	--	--	Terrace deposit
1027 (991,992)	Edmonston Pumping Plant	0	1	1	--	--	Stiff soil	15' of alluvium over gneiss
1022	Eureka Federal Bldg.	10	1	--	--	Deep cohesionless soil	Deep cohesionless soil	--
121	Fairmont Reservoir	0	2	1	Granitic	--	Rock	Granitic
1023	Ferndale City Hall	0	1	--	40 to 80 feet of alluvium over 100 feet of sandstone over siltstone	Deep cohesionless soil	Deep cohesionless soil	--
1096 (998)	Fort Tejon	0	2	3	--	--	Rock	Granitic
122	Glendale 633 E. Broadway	20	1	4	Alluvium	--	--	Alluvium
282	Goleta Fluid Mechanics Lab, UCSB	10-15	1	3	--	--	--	Alluvium veneer over sandstone
125 (828)	Lake Hughes Array Station 1 (A)	0	2	3	Granitic	--	Rock	Granitic
126	Lake Hughes Array Station No. 4	0	2	1	Weathered Granitic	Rock	Rock	Weathered Granit
127	Lake Hughes Array Station No. 9	0	2	1	Gneiss	--	Rock	Gneiss
128	Lake Hughes Array Station No. 12	0	1	2	Eocene sandstone below a shallow (10± ft) layer of alluvium	Rock	Stiff soil	Eocene sandston below a shallow (10± ft) layer of alluvium
	Los Angeles Sites							
145	222 Figueroa St.	5	1	3	--	--	Stiff soil	25' of alluvium over shale. Water at 20'
148	234 Figueroa St.	10-15	1	3	--	--	Stiff soil	25' of alluvium over shale. Water at 20'
157	445 Figueroa St.	40-50	0	7	--	--	Rock	Shale
172	800 W. First St.	10	1	2	--	--	Rock	Pliocene Siltstone

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TIONS

	EERI - NOAA (1971) Site Geology	U.S. Geological Survey (1975) Site Geology	Subsurface Conditions Reported by SW-AA	
			Conditions	Report
	--	Dam on alluvium, rock abutments	At generator house - 100-foot high embankment over soft sandstone and siltstone (Pliocene) At dam center - embankment underlain by about 100 feet of alluvium over soft sandstone and siltstone.	1977b
	--	--	Weathered sandstone (Miocene). Shear wave velocities: 0-20 feet at 530 fps; 20-68 feet at 1150 fps and >68 feet at 2150 fps.	1977b
	--	--	Granitic rock.	1977b
	--	--	At least 63 feet of sand and gravel. Pilo-Pleistocene.	1977b
	--	--	Weathered ultramafic igneous rock.	1977b
	-	Alluvium	23 feet of clayey sand overlying weathered Pliocene shale. Near surface shale (to 65 feet) has strengths similar to hard clay.	1977b
	--	--	17 feet of loose to dense sand overlying moderately hard granitic rock; very hard below 32 feet.	1976a
	200-400 feet of loosely consolidated gravel, sand, silt, and clay.	Sediments, part consolidated	At least 67 feet of sand and clay nearby. Probably about 200 feet of sand, clay, gravel, and silt.	1977b
	--	Granite	17 feet of loose to medium dense sand and gravel, and silty clay overlying moderately hard granitic rock.	1976a
	1500 feet of loosely consolidated massive conglomerate sandstone and claystone.	Alluvium	At least 260 feet of interbedded clay, silt, sand, and gravel. Measured $V_s \leq 1500$ fps above 180-foot depth.	1975
	--	Granite	69.5 feet of medium stiff to very stiff, sandy, silty clay, and dense, silty, clayey sand overlying very hard granitic rock.	1976a
	--	Alluvium, more than 8m	Approximately 300-500 feet of alluvium overlying sandstone and shale of Topanga Fm. Shear wave velocities: 0-35 feet at ≤ 1040 fps; 35-60 feet at 1640 fps - one mile away.	1977b
	--	Alluvium 4m, siltstone	0 to 15 feet of sand over medium, weathered siltstone having shear strengths characteristic of soil to at least 20-foot depth.	1977b
	--	Alluvium, 300m; granitics	At least 55 feet of loose to medium dense, silty sand with gravel.	1976a
ic	--	Weathered granite	Weathered granitic rock.	1977b
	--	Gneiss	9 feet of silty and gravelly sand overlying granite gneiss.	1976a
	--	Thin alluvium; conglomerate	Sandstone (Paleocene to Eocene) below a 5 to 10-foot veneer of colluvium.	1977b
	--	Fill, 7m; shale	Approximately 30 feet of fill and alluvial soil overlying stiff to very stiff clay (Miocene shale) to at least 90 feet.	1976a
	--	Fill, 7m; shale	20 to 30 feet of fill and alluvial soil overlying hard clay (Miocene shale) to at least 65 feet.	1976a
	--	--	At least 108 feet of stiff to hard clay (Pliocene shale). Nearby, measured V_s = 1475 fps at 150-foot depth.	1976a
	--	Sandstone and shale	80 feet of very stiff clay (Miocene shale). Below 80 feet, clay is hard and grades downward into shale.	1976a

TABLE 1
SUMMARY OF SITE SUBSURFACE CONDITIONS
AT REPORTED "ROCK SITE" ACCELEROGRAPH STATIONS
IN CALIFORNIA (Cont'd)

U.S.G.S. Station No.	Accelerograph Station Name	Foundation Depth Below Grade (Ft.)	Reported Site Geology and Subsurface Conditions								Subsurface Conditions Reported by SP-AA	
			Trifunac and Brady (1975) Site Classification[1]	Duke et. al (1972) Site Classification[2]	Mohraz (1976) Site Geology	Seed et. al (1974) Site Classification[3]	Seed et. al (1975) Site Classification[3]	Maley & Cloud (1971) Site Geology	EERI - NOAA (1973) Site Geology	U.S. Geological Survey (1975) Site Geology	Conditions	Report
	Los Angeles Sites (Cont'd)											
154	420 S. Grand	15	--	2	--	--	Rock	Shale and siltstone - several thousand feet	--	--	About 10 feet of fill and alluvium over hard clay (Pliocene siltstone) of Fernando Fm.) Shear wave velocities: 0-120 feet at 1260 fps.	1977b
141	Griffith Observatory	9	2	1	Granitic	Rock	Rock	Granitic	--	Granite	Weathered granitic rock.	1977b
220	3838 Lankershim Blvd.	15	1	3	--	Rock	Rock	Interlayered soft sandstone and shale	--	Shale and sandstone	Sandstone, conglomerate, and shale. (Miocene Topanga Fm.) Subsurface conditions are not well defined.	1977b
431	616 S. Normandie Ave.	10-15	1	3	Alluvium. Siltstone at 25 feet	--	Stiff soil	Alluvium. Siltstone at 25 feet	--	Alluvium, more than 16m	About 30 feet of soft to medium stiff fill and soil, overlying very stiff to hard sandy and clayey silt (Miocene siltstone) to at least 55 feet. Nearby, measured V_s = 2500 fps at 200-foot depth.	1976a
228	4867 Sunset Blvd.	15	1	3	Shallow alluvium over Miocene siltstone	--	--	Shallow alluvium over Miocene siltstone	--	--	About 12 feet of silty and sandy clays, overlying very stiff to hard (?) clay (Miocene shale) Characteristics of shale are poorly defined.	1977b
137	Water and Power Bldg.	0-30	1	2	Miocene siltstone	--	Rock	Miocene siltstone	--	--	At least 55 feet of interstratified stiff to hard, very silty clay and silt (Miocene shale and siltstone).	1976a
449	2500 Wilshire Blvd.	10-15	1	3	Alluvium. Siltstone at 20-30 feet, water table at 35 ft.	--	Stiff soil	Alluvium. Siltstone at 20-30', water table at 35'	--	Alluvium, 1-11m; siltstone	About 35 feet of medium stiff fill and alluvium overlying "siltstone and sandstone" (Miocene). Measured V_s = 2500 fps at 200-foot depth in Miocene strata one mile to the west.	1976a
282	3411 Wilshire Blvd.	60-70	1	2	--	--	Rock	Siltstone. Water table at basement level	--	--	About 30 feet of soft to medium stiff fill and soil overlying stiff to hard, clayey silt to at least 90 feet and probably to 200 feet (Miocene siltstone). Nearby, measured V_s = 2500 fps at 300-foot depth.	1976a
217	3710 Wilshire Blvd.	35	1	4	Alluvium	--	Stiff soil	Alluvium	--	--	At least 29 feet of alluvium over Fernando Fm.(Pliocene). Classified as dense sands and stiff clays to 61 feet.	1976a
223	4680 Wilshire Blvd.	10	1	4	Alluvium	--	Stiff soil	Alluvium	--	--	About 12 feet of alluvium over San Pedro Fm. (Pliestocene sands, silt and clays to at least 62 feet).	1976a
428	5900 Wilshire Blvd.	35-40	1	2	--	--	Stiff soil	Alluvium. Asphaltic sands	--	Alluvium, 43m; shale	About 23 feet of alluvium over San Pedro Fm. (Pliestocene sands, silts and clays to at least 150 feet).	1976a
463	6200 Wilshire Blvd.	5	1	2	--	--	--	Thin layer of alluvium over asphaltic sands	--	Alluvium, more than 19m	Alluvium over San Pedro Fm. (Pliestocene sands, silts, and clays to at least 130 feet).	1976a
190	2011 Zonal Avenue	15	1	2	--	--	Rock	Shale at east end of building. 8' of fill at west end	--	Alluvium, 0-10m; shale	At least 13 feet of very stiff clay and dense sand (Miocene shale and sandstone). Nearby, measured V_s = 1950 fps to at least 140-foot depth.	1976a
1049	Oak.and City Hall	10	1	--	--	--	--	--	100 feet of sand, clay and gravel. Very hard clay below 100 feet and to bedrock at about 1500 feet.	Alluvium, more than 30m	At least 96 feet of sand and clay; becoming very dense and very stiff at depth. May extend to about 1,000-foot depth, to bedrock.	1977b
1052 (993,994)	Oso Pumping Plant, Gorman	8	1	4	--	--	Stiff soil	Alluvium	--	--	117.5 feet of dense to very dense sand, with some silt, gravel, and clay, overlying silty claystone to at least 200 feet.	1976a
279	Pacoima Dam	0	2	1	Highly jointed diorite gneiss	Rock	Rock	Highly jointed diorite gneiss	--	--	Jointed diorite gneiss.	1977b
411	Palos Verdes Estates 2516 Via Tejon	0	1	2	--	--	Stiff soil	Shallow Pleistocene sands over shale - volcanic complex	--	--	Approximately 20 feet of gravelly clay and clayey sand overlying siltstone and chert (Miocene Monterey Shale). Shear wave velocities: 0-14 feet at 1000 fps; > 14 feet at 1850 fps.	1977b
264	Pasadena CIT Old Seism. Lab	18	2	1	Weathered Granitic	Rock	Rock	Weathered Granitic	--	Granite	Weathered granitic rock. Nearby, measured V_s = 2670 fps above 35-foot depth, and 4210 fps from 35 to at least 50 feet.	1977b
267	Pasadena Jet Propulsion Lab	10-15	1	4	--	Deep Cohesionless soil	Deep Cohesionless soil	Sandy-gravel	--	--	635 feet of sand, silty sand, and gravel, overlying at least 45 feet of fractured, decomposed granitic rock. See text for shear wave velocities.	1977b

TABLE 1

SUMMARY OF SITE SUBSURFACE CONDITIONS

AT REPORTED "ROCK SITE" ACCELEROGRAPH STATIONS

IN CALIFORNIA (Cont'd)

U.S.G.S. Station No.	Accelerograph Station Name	Foundation Depth Below Grade (Ft.)	Reported Site Geology and Subsurface Conditions								Subsurface Conditions Reported by [illegible]	
			Trifunac and Brady (1975) Site Classification¹	Duke et. al (1972) Site Classification²	Mohraz (1976) Site Geology	Seed et. al (1974) Site Classification³	Seed et. al (1975) Site Classification³	Maley & Cloud (1971) Site Geology	ERRI - NOAA (1971) Site Geology	U.S. Geological Survey (1974) Site Geology	Conditions	Report
276	Puddingstone Reservoir	0	2	2	--	--	Rock	Volcanic clastics and intrusions with associated shales	--	--	52 feet of volcanic conglomerate overlying breccia and basalt to at least 115 feet.	1977b
1083	San Luis Obispo City Recreation Bldg.	4	1	--	--	--	--	5' of clay loam over Franciscan shale.	--	--	Approximately 10 feet of clay overlying soft shale; becoming medium hard at 40 feet. Shear wave velocities: 5-21 feet at 1727 fps; ≥ 21 feet at 2599 fps.	1977b
1083	San Francisco Alexander Bldg.	18	1	--	--	Stiff soil	--	--	185 feet of sand and clay overlying Franciscan sandstone and shale.	Alluvium (60m)	About 140 feet of silty and clayey sands overlying Franciscan bedrock.	1977b
1117	San Francisco Golden Gate Park	0	1	--	Siliceous sandstone	Rock	--	--	Hard, brittle, dense chert and interbedded shale.	Chert	Thin-bedded Franciscan chert bedrock.	1977b
1080	San Francisco State Building	10	1	--	--	Stiff soil	--	--	200 feet of sand and clay overlying Franciscan bedrock.	Alluvium (60 m)	Approximately 210 feet of sand with some clayey sand overlying Franciscan bedrock.	1977b
280	San Onofre Nuclear Generating Station	4	1	2	--	Rock	Stiff soil	Lightly cemented Pliocene sandstone >325' depth	--	Soft sandstone	Approximately 900 feet of very dense, fine to coarse sand, slightly cemented.	1977b
104	Santa Anita Dam	0	2	1	Granitic diorite complex	Rock	Rock	Granite diorite complex	--	--	Granitic rock.	1977b
284 (285)	Santa Felicia Dam, Outlet Works	10	1	2	Sandstone-shale complex	Rock	Rock	Sandstone-shale complex	--	Sandstone and shale	Approximately 7 feet of alluvium overlying medium to moderately hard(?) sandstone and shale (Miocene).	1977b
1094	Taft Lincoln School	5-10	0	--	40' of alluvium over poorly cemented sandstone	Rock	Stiff soil	40' of alluvium over poorly cemented sandstone	--	Alluvium	300 feet of sand, silt, and clay overlying sandstone. Measured V_s = 2500 fps at 140 feet	1976b
290	Wrightwood 6074 Park Drive	0	1	1	Alluvium veneer on igneous metamorphic complex	Rock	Stiff soil	Alluvium veneer on igneous metamorphic complex	--	--	At least 88.5 feet of dense to very dense (?), silty, sandy gravel.	1977b

NOTES 1) Trifunac and Brady (1975) Site Classifications

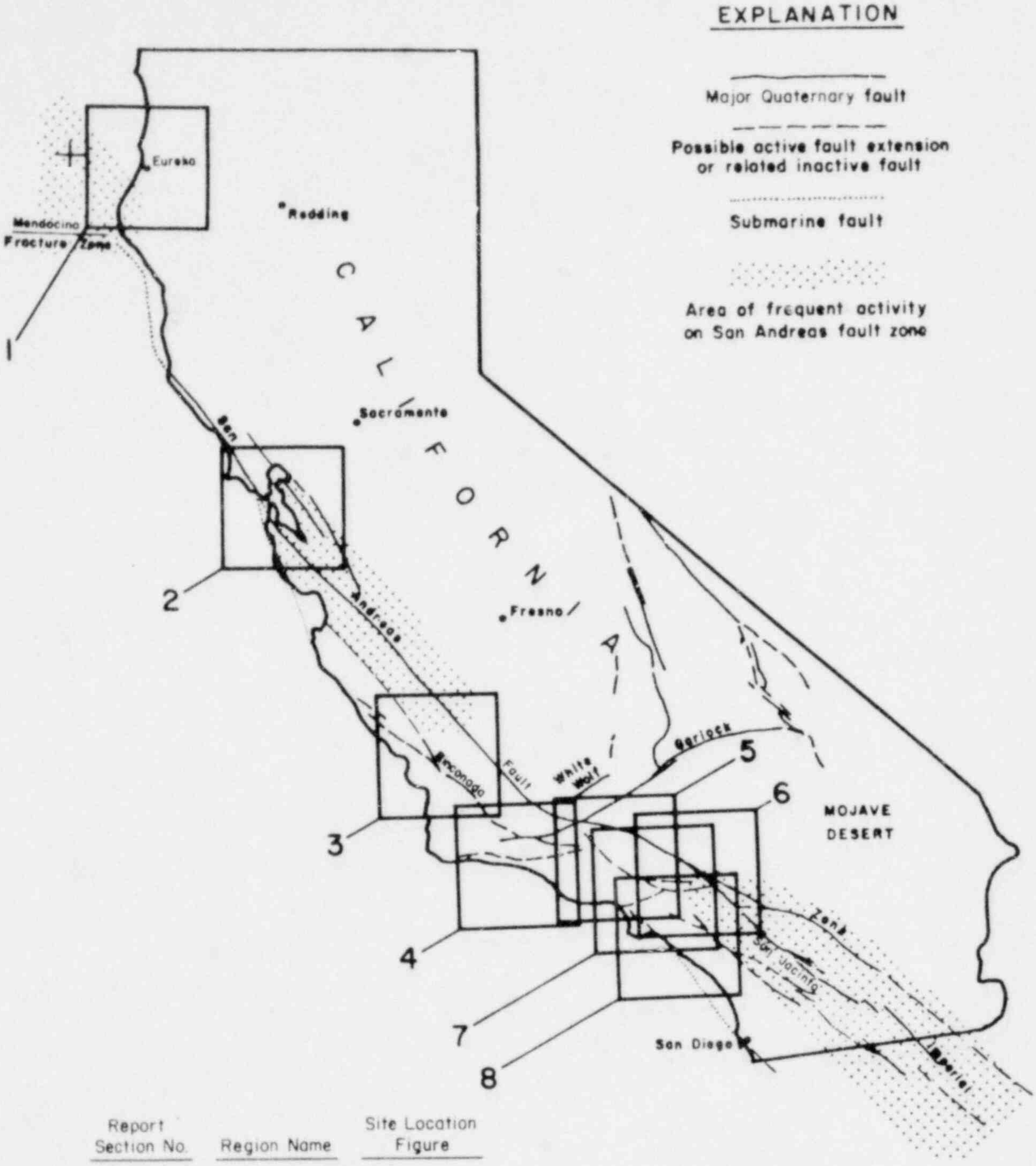
0 - Soft alluvium deposits
1 - Hard sedimentary rock, intermediate between 0 and 2
2 - Basement or Crystalline rock

2) Duke et. al. (1972) Site Classifications

1 - Igneous or Metamorphic rock
2 - Sedimentary rock
3 - Shallow alluvium, 20 - 60 feet
4 - Deep alluvium, 60 feet

3) Seed, et al. (1974 & 1975)

1. Rock Sites - Where rock was considered to be shale - like or sounder in characteristics, as evidenced by a shear wave velocity greater than about 2500 fps.
2. Stiff Soil Conditions - Where rock as defined above was overlain by less than about 150 ft. of stiff clay, sand or gravel.
3. Deep Cohesionless Soil Conditions - Where rock as defined above was overlain by at least 250 ft. of generally cohesionless soils.
4. Soft Clays - Where rock as defined above was overlain by soil deposits consisting of soft to medium stiff clays with associated strata of sands and gravels.



Report Section No.	Region Name	Site Location Figure
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INDEX MAP OF REGIONS INVESTIGATED

FIG. 1

Section 1
Eureka Region

SECTION 1

EUREKA REGION

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SECTION 1
EUREKA REGION

1.1 INTRODUCTION

The Eureka region, as defined for this report, is the geographic area centered around the city of Eureka, California. This region is situated on the Pacific Coast, approximately 225 miles north of San Francisco, California, as shown on Fig. 1.

The Eureka Federal Building accelerograph station is the only so-called "rock" site in this region that is discussed in this report. Although other accelerograph stations exist in the region, they reportedly are founded on soils or their subsurface conditions have not been reported in the literature.

Seismological and geotechnical data for the Ferndale accelerograph station, located approximately 20 miles south of Eureka, were reported in SW-AA (1975). Where applicable, the regional geology and seismicity information included in that volume are integrated into this report.

The location and instrumentation, along with geological, seismological, and subsurface information for the Eureka Federal Building accelerograph station are discussed and illustrated in this section. Earthquake data, including ground motion time histories and response spectra for selected earthquakes recorded at the station, are presented in the appendix.

1.2 STATION DESCRIPTION

1.2.1 Eureka Federal Building

1.2.1.1 Location and building. The city of Eureka is located on the coast of northern California in Humboldt County, approximately 225 miles north of San Francisco. The city is situated on a coastal plain at the foot of the California Coast Ranges.

The strong motion accelerograph is located in the basement of the Federal Building. The Federal Building is three stories high and has a full basement. The building is constructed of brick and stone with a reinforced concrete frame. As indicated in Fig. 1-1, the Federal Building occupies the southwest corner at the intersection of 5th and "H" Streets. A photograph and plan view of the building are shown on Fig. 1-2. The accelerograph station (U.S.G.S. No. 1022) was established on May 24, 1933, by the U.S. Coast and Geodetic Survey.

1.2.1.2 Instrumentation. The recording instrument originally installed in the Federal Building was a Coast and Geodetic Survey Standard accelerograph, Serial No. 30. The original accelerometers in the instrument were as follows: Longitudinal - No. 13; Transverse - No. 8; Vertical - No. 29. In October 1948, the original accelerometers were removed and replaced with the following: Longitudinal - No. 251; Transverse - No. 252; Vertical - No. 250. The Standard accelerograph had the following instrument characterisitcs at the time of the December 21, 1954, Eureka earthquake, as reported by Hudson, et al. (1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
S11E	13.5	.067
N79E	13.3	.066
Vertical	12.7	.066

The original instrument installed at the Federal Building also included a Carder displacement meter (Serial No. 13). This displacement meter was removed in March 1947, and subsequently a seismoscope (Serial No. 1642) was installed on the old displacement meter pier.

On September 17, 1975, the Standard accelerograph was replaced by an RFT-250 accelerograph (Serial No. 460) manufactured by Teledyne-Geotech. The RFT-250 was bolted to the concrete pier formerly occupied by the

Carder displacement meter with the same orientation as that reported for the Standard accelerograph. The RFT-250 instrument is currently in use at the station. A photograph of this instrument is presented in Fig. 1-3 along with a plan view of the accelerograph room.

1.3 GEOLOGY AND SEISMICITY

1.3.1 Regional Geology

Eureka lies within the California Coast Range province, an area characterized by a series of northwest-trending mountain ranges and intermontane valleys. As indicated on the Regional Geologic Map, Fig. 1-4, the Coast Ranges in the Eureka region are principally comprised of Franciscan Assemblage (KJf) and Great Valley Sequence sedimentary rocks (TK) which are chiefly Mesozoic in age and are locally capped as at Eureka, by thick sequences of Tertiary sedimentary rock (Ts) and unconsolidated Quaternary deposits (Qc) (Bailey, 1966; Bailey, Irwin, and Jones, 1964; and Strand, 1962 and 1963). These rocks are generally folded and faulted along west-northwesterly trends.

The Coast Ranges are bordered about 20 miles to the northwest of Eureka by the severely deformed Paleozoic and Mesozoic rocks (m, Ju) of the Klamath Mountains province (Bailey, 1966). To the east, the Coast Ranges province consists of relatively undeformed Mesozoic and Tertiary sedimentary rocks. On the west, the Coast Ranges merge with the narrow continental shelf and the steep continental slope of the Pacific Ocean. Fifty miles southwest of Eureka, a prominent submarine ridge, the Gorda Escarpment, trends westward from Cape Mendocino across the Pacific Ocean basin (Strand, 1962 and 1963; and Jennings, 1975).

1.3.2 Seismicity

The Eureka region is an area of continuing seismic activity characterized by weak to moderately strong earthquakes. Many of the largest historic earthquakes that have occurred in the region had epicenters on or near the Mendocino fault zone, an oceanward extension of the highly active San Andreas fault zone. Other off-shore earthquakes have no apparent relationship to known faults.

The largest earthquake recorded on the Eureka Federal Building instrument occurred on December 12, 1954, about 4 miles east of the station. The epicentral location was close to the Freshwater fault, a long northwest-trending structure with known Quaternary displacement but with no historic record of tectonic activity. It is not known if this earthquake, which has a Richter magnitude of 6.5, resulted from slippage of Freshwater fault.

There are no known faults in the Eureka region that have had historic displacement. The term "historic" is used after Jennings (1975) to designate a fault that has undergone recognizable displacement during the past 200 years.

1.3.3 Local Geology

Eureka is situated on a coastal plain at the shore of Humboldt Bay. Elevation varies from sea level at the bay front to over 200 feet at the southern city limits. Mountains of the Coast Ranges rise to the south and east of Eureka to elevations of over 2,000 feet. The local geology of this area is depicted on the Geologic Cross-Section A-A', Fig. 1-5.

The Eureka area is underlain at depth by basement rocks of the Franciscan Assemblage. Where exposed, these rocks generally consist of sheared, hard graywacke sandstone, with minor amounts of shale, chert, basalt, and schist. The Yager Formation, which underlies the Eel River Valley and the Eureka area, unconformably overlies the Franciscan Assemblage but is usually found in fault contact with the Franciscan rocks (Ogle, 1953). The Yager Formation, late Cretaceous in age, consists of dark gray indurated mudstone, shale, graywacke, and conglomerate. The base of the formation has not been defined in the area; however, the thickness is thought to be in the order of 10,000 feet (Ogle, 1953).

Consolidated Tertiary sedimentary rocks of the Wildcat Group unconformably overlie the Yager Formation. The Wildcat Group is divided from older to younger into the Pullen, Eel River, Rio Dell, Scotia Bluffs, and Carlotta Formations (the Carlotta Formation is Plio-Pleistocene in age). Rocks of the Wildcat Group consist primarily of mudstone, sandstone, siltstone, and conglomerate. Mudstone is the most common rock type.

Unconsolidated sedimentary deposits ranging from late Pleistocene to Holocene in age overlie the Wildcat Group and have an aggregate maximum thickness of approximately 500 feet (Ogle, 1953). These sediments are divided into the Hookton Formation and Quaternary alluvium. The Hookton Formation ranges up to 400 feet thick, and may have a thickness of approximately 200 feet beneath Eureka. It consists of yellow-orange gravel, sand, silt, and clay. The alluvium includes Rohnerville Formation terrace deposits, other undifferentiated terrace deposits, floodplain deposits, and dune sands. These deposits consist of gravel, sand, silt, and clay.

The Geologic Cross-Section A-A' (Fig. 1-5) illustrates the structural conditions at Eureka. The major structural feature in the area is the Eel River syncline, an assymmetrical westward-plunging fold. The Eel River syncline and other minor folds in the area are generally eastward trending. Coarse-grained continental and marginal deposits of the Quaternary Hookton Formation have been complexly warped into a series of northwest-trending anticlines and synclines (Evenson, 1959).

A complex zone of highly sheared rocks bounds the Eel River syncline on the south. The Little Salmon and Yager faults bound the syncline on the north and have no historic record of surface displacement (Jennings, 1975). The Little Salmon fault, however, does show evidence of movement during Quaternary time.

Other faults that have been active during Quaternary time but have not had a historic record or confirmation of surface rupture include the northern portion of the Freshwater fault and all of the recognized offshore faults (see Fig. 1-4). The Mendocino fault is considered to be the seaward extension of the San Andreas fault (Jennings, 1975).

1.4 CATALOG OF SEISMIC EVENTS

The Eureka region is characterized by frequently occurring moderate earthquakes. The epicenters for several of these events are shown on Fig. 1-4. Many of the historic earthquakes have originated offshore on the continental shelf and are commonly associated with the Mendocino fault zone in the southwestern part of the region and beyond.

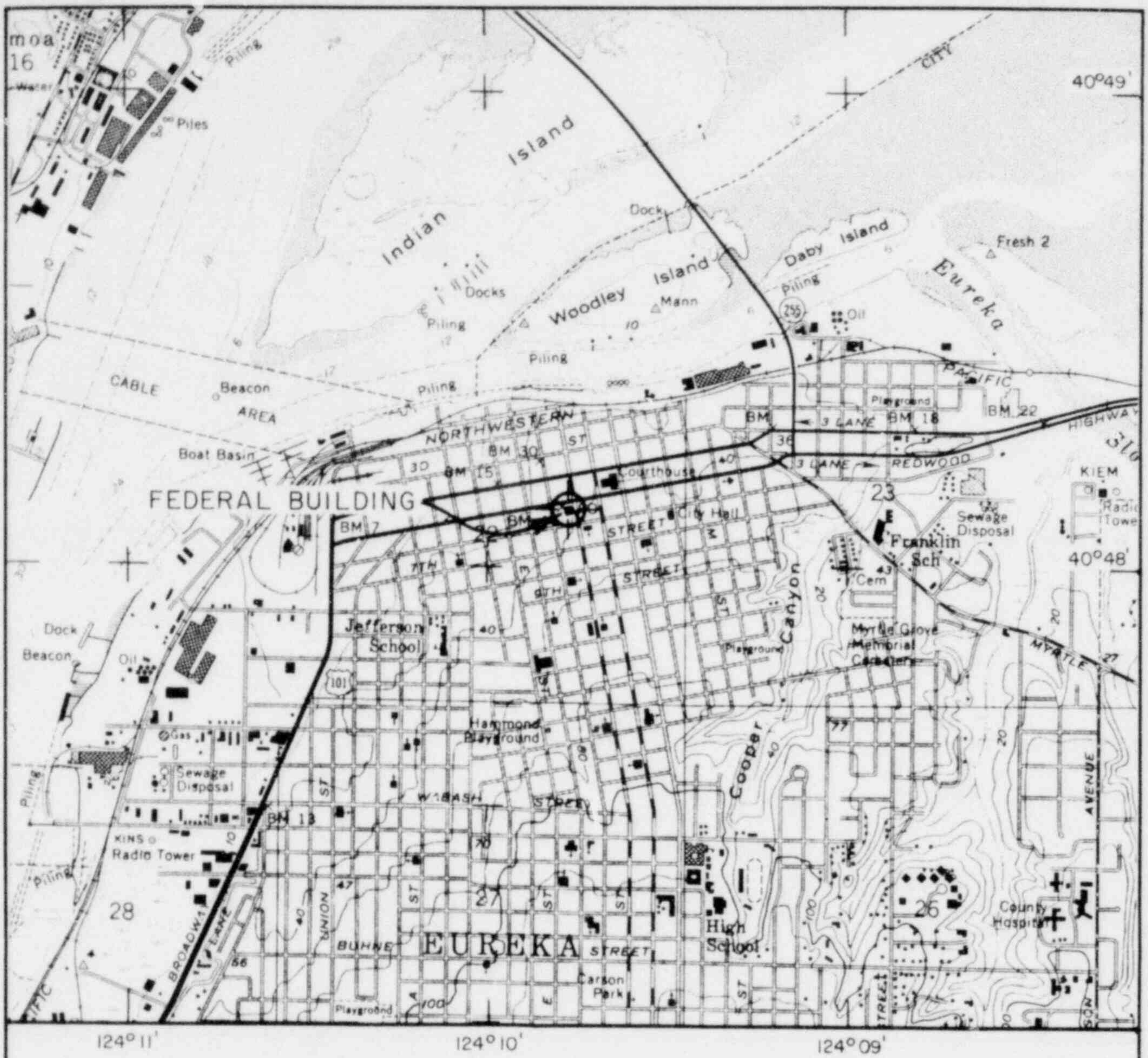
A list of selected earthquakes recorded at the Eureka Federal Building strong motion accelerograph station between 1934 and 1968 is presented in Table A1-1 of the appendix. Selected ground motion time histories and their corresponding response spectra are also presented in that appendix, as Figs. A1-1 through A1-18. These earthquakes ranged in Richter magnitude from 4.0 to 6.5, but only Modified Mercalli Intensities of IV and V are known for two of the smaller events. The largest temblor recorded at the station was the December 21, 1954, Eureka earthquake, which had an epicentral location approximately 4 miles east of the station. This earthquake had a magnitude of 6.5 on the Richter scale.

1.5 FIELD EXPLORATIONS

Field studies at the Eureka strong motion station consisted of a visit to the instrument site, conversations with local geotechnical engineers, and a brief reconnaissance of rock outcrops in the vicinity. The instrument site was visited and photographed, and the location of the instrument within the housing structure was documented. Local government officials and geotechnical engineers were contacted and queried about subsurface conditions in the area. A brief geologic reconnaissance was made to verify the presence of the rock units shown on published geologic maps of the area. Subsurface information at the Federal Building was compiled from available boring logs. No borings were made for this investigation.

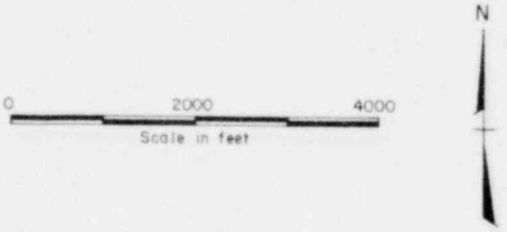
1.6 SITE SUBSURFACE CONDITIONS

Information on the subsurface conditions in the vicinity of the site was primarily obtained from unsampled auger borings that were made by the California Department of Transportation (CALTRANS). The CALTRANS borings, which are located about 900 feet south of the Federal Building, were made to investigate a new freeway alignment. The borings that were reviewed extended to depths of 44 to 67 feet and encountered sand and clay. These findings are in agreement with geological data which indicates that the general site area is underlain by unconsolidated alluvial sediments consisting of gravel, sand, silt, and clay. These sediments may be approximately 200 feet thick at the site.



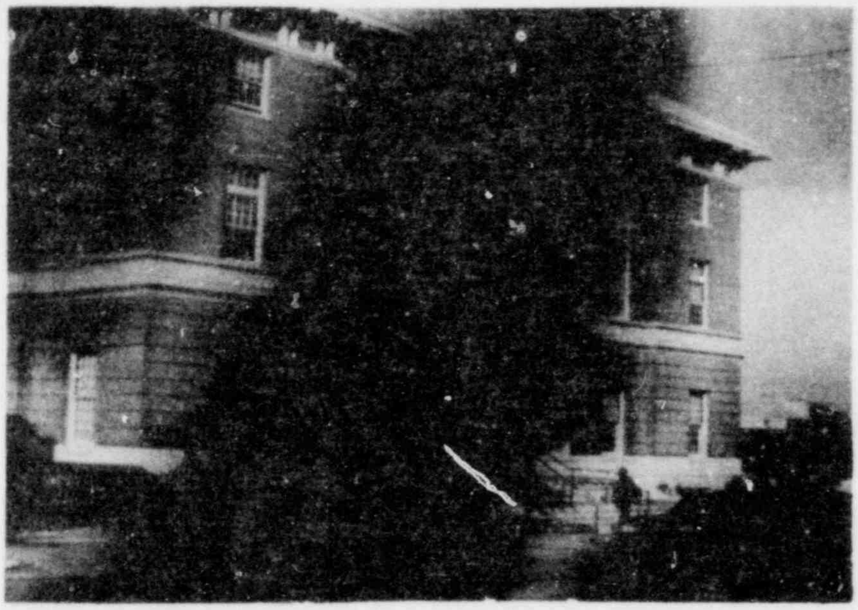
FEDERAL BUILDING

USGS Topographic Quadrangle:	Eureka, California.
Coordinates:	40° 48' 07" N. 124° 09' 46" W.
Location:	Southwest corner at intersection of Fifth and H Streets
Structure:	Three-story reinforced concrete frame building with basement.

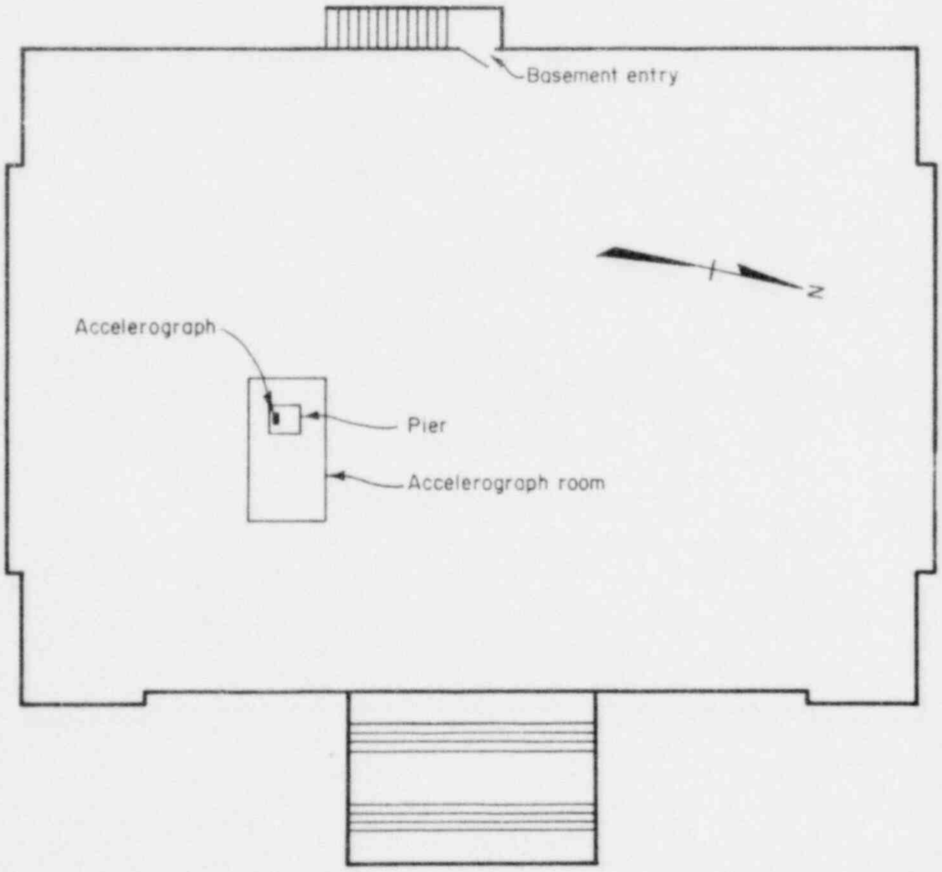


STATION LOCATION PLAN
EUREKA FEDERAL BUILDING
EUREKA, CALIFORNIA

FIG. 1-1



Eureka Federal Building
View to the Northwest

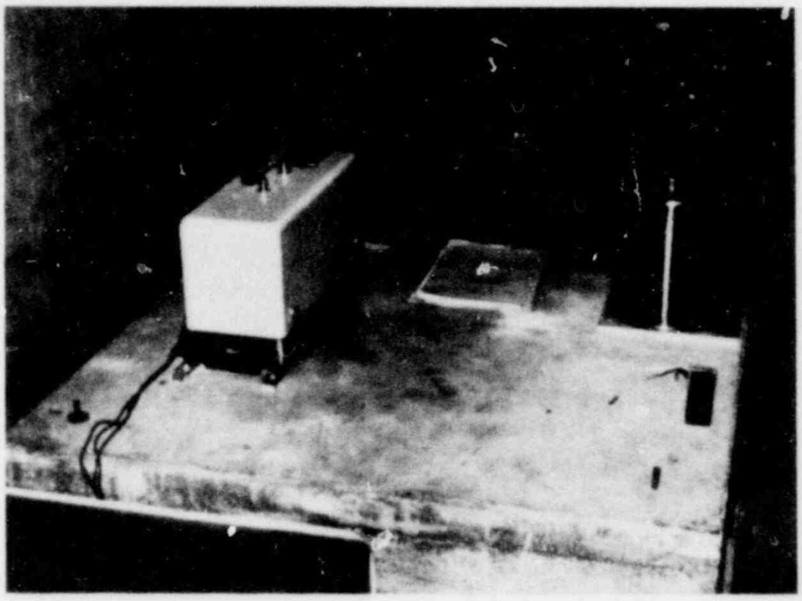


Building Outline Plan

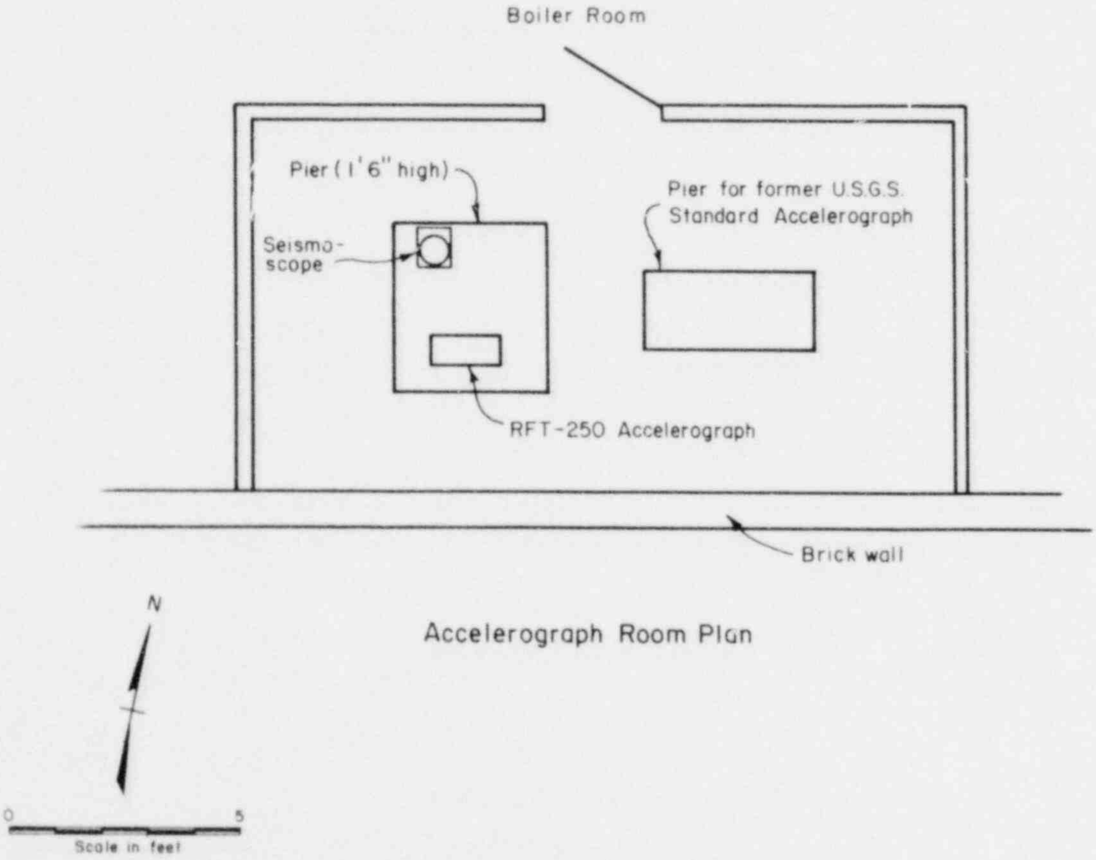
Note: Accelerograph room plan shown on Fig. I-3.

ACCELEROGRAPH STATION
EUREKA FEDERAL BUILDING
EUREKA, CALIFORNIA

FIG. I-2



RFT-250 Accelerograph, U.S.G.S. No. 1022
Eureka Federal Building, Basement

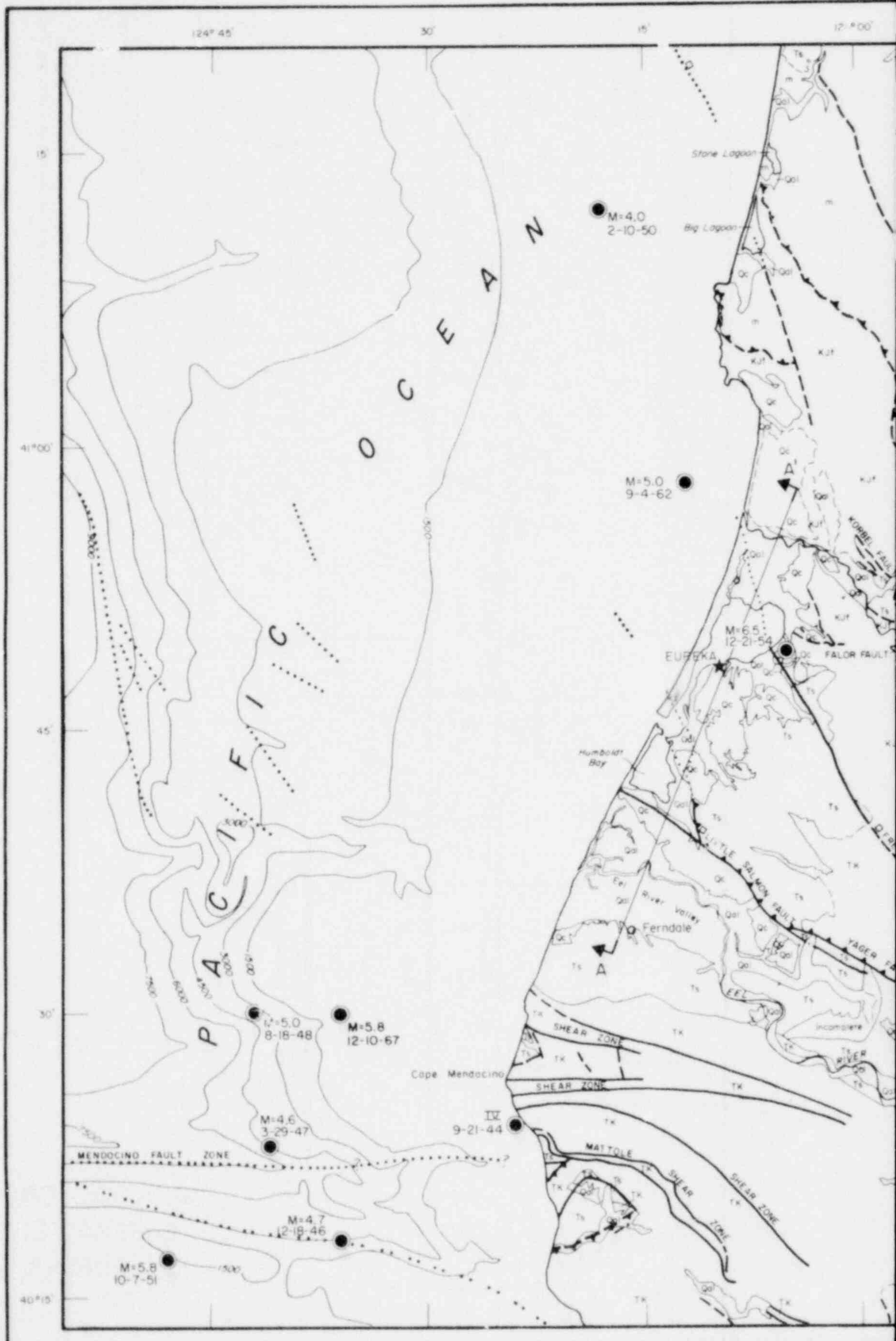


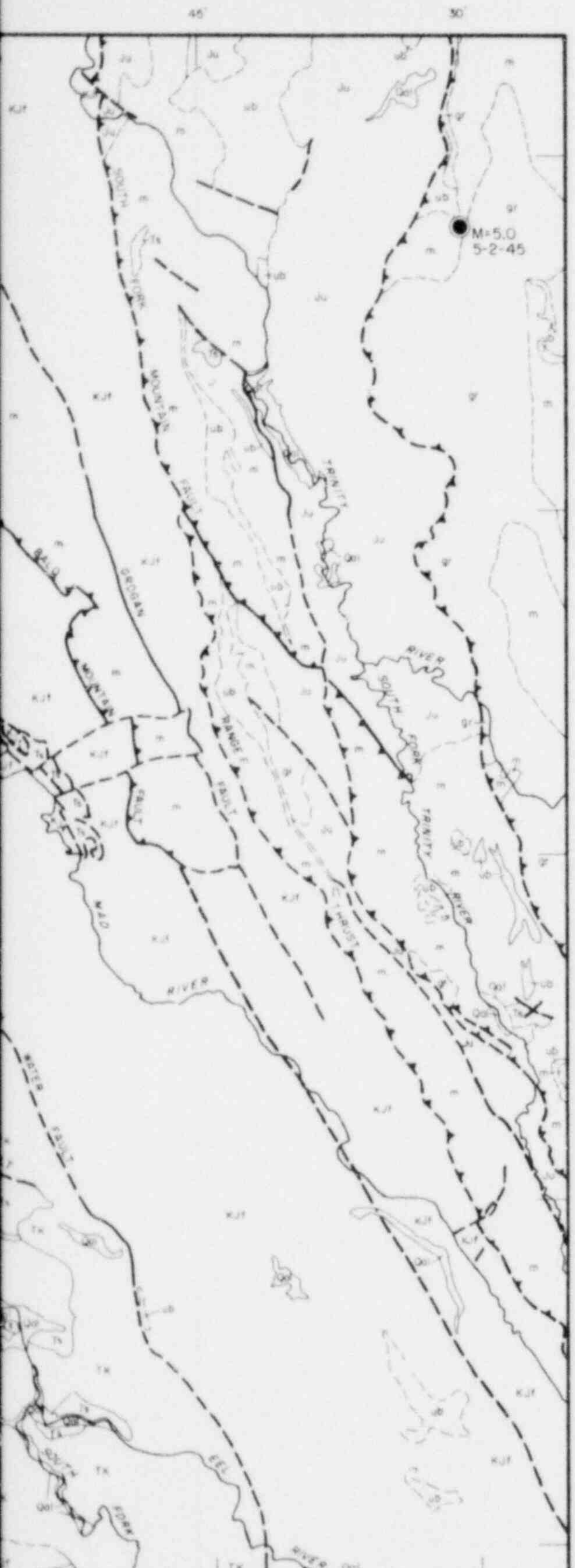
Accelerograph Room Plan

Note: Location of accelerograph room within the structure is shown on Fig. 1-2.

STATION INSTRUMENTATION
EUREKA FEDERAL BUILDING
EUREKA, CALIFORNIA

FIG. 1-3


124°45'
30'
15'
124°00'
15'
41°00'
45'
30'
40°15'
PACIFIC OCEAN
Stone Lagoon
Big Lagoon
M=4.0
2-10-50
M=5.0
9-4-62
M=6.5
12-21-54
EUREKA
FALOR FAULT
KORBEL FAUL
Humboldt Bay
LITTLE SALMON FAULT
YAGER F
Eel River Valley
Ferndale
A
A'
EEL RIVER
SHEAR ZONE
SHEAR ZONE
Cape Mendocino
IV
9-21-44
MATTOLE SHEAR ZONE
SHEAR ZONE
M=5.0
8-18-48
M=5.8
12-10-67
M=4.6
3-29-47
MENDOCINO FAULT ZONE
M=4.7
12-18-46
M=5.8
10-7-51
500
1500
3000
4500
6000
7500
Qal
Qc
Ts
TK
KJf
m



EXPLANATION

Qal	Undifferentiated alluvium, Quaternary in age; includes Rohnerville Formation terrace deposits	KJf	Franciscan Assemblage, Mesozoic in age
Qc	Hookton Formation, upper Pleistocene in age	ub	Ultramafic rocks, Mesozoic in age
Ts	Sedimentary rocks, Tertiary in age; includes the Pullen, Eel River, Rio Dell, Scotia Bluffs and Carlotta Formations	gr	Granitic rocks, Mesozoic in age
TK	Yager Formation, Upper Cretaceous in age; includes undifferentiated Cretaceous and Tertiary sedimentary rocks	m	Metasedimentary rocks including crystalline limestone, pre-Cretaceous in age
Ju	Marine sedimentary and metasedimentary rocks, Upper Jurassic in age		

★	Accelerograph Station location	Contact	Dashed where approximately located
● M=5.0(IV) 9-4-62	Epicenter location, magnitude - Richter (or intensity - Modified Mercalli) and date of occurrence	Fault	Dashed where approximately located, dotted where concealed
□	Faults having moved during Quaternary time without historic record (approx. past 2 million years)	Thrust Fault	Barbs on upper plate, dashed where approximately located
■	Faults having moved during historic time, (approx. 200 years)	Offshore Fault	Location approximate, spaced dots where fault is inferred, queried where continuation is uncertain

NOTES

1) Geology is simplified from Strand (1962 and 1963). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975).

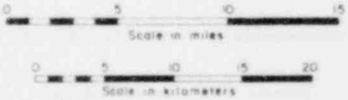
2) Information on fault activity (Quaternary activity, historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity (See Jennings, 1975, for details)

3) All offshore faults shown on this figure have evidence of Quaternary activity.

4) Earthquake magnitudes and epicentral locations from Hudson, et al. (1959-1975 a and b) and Coffman and Von Hake (1973).

5) Cross-section A-A' is shown on Fig. 1-5.

Location of Geologic Map



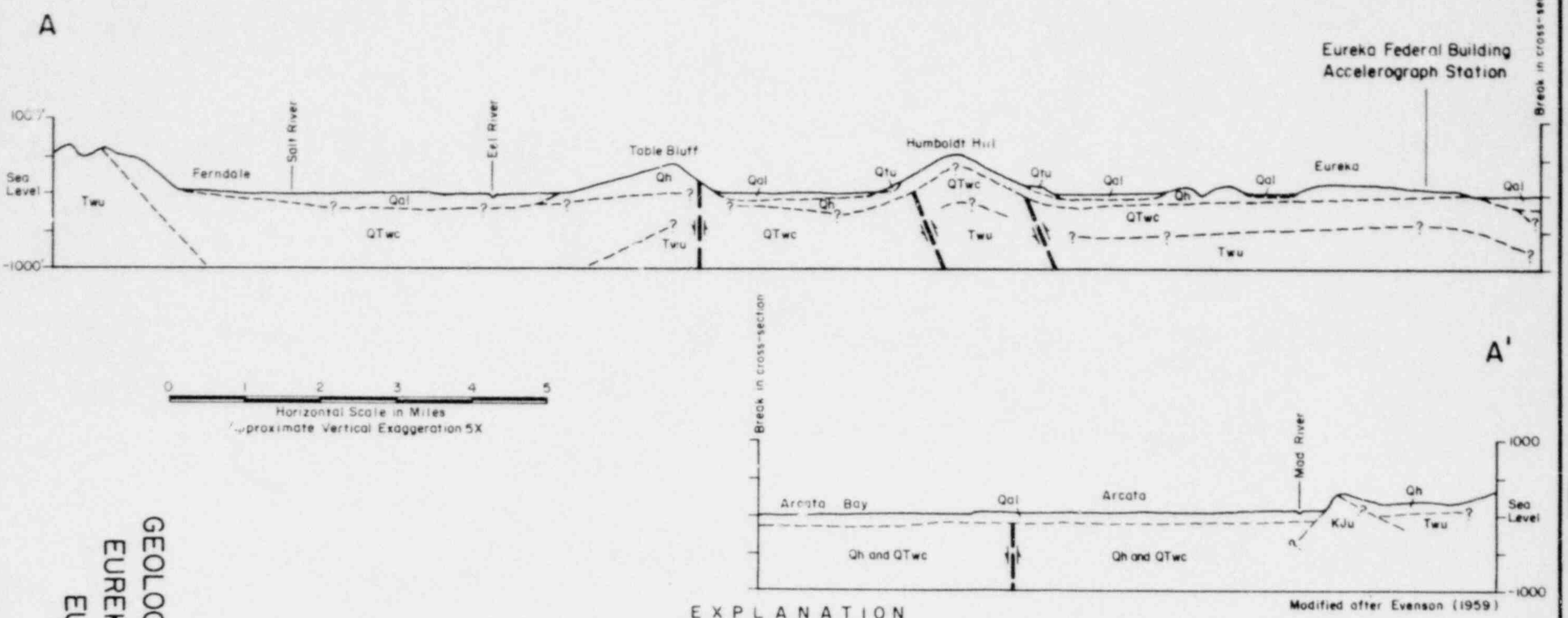
Submarine contour interval 1500 feet

GEOLOGIC MAP
EUREKA REGION
EUREKA, CALIF ORNIA

FIG. 1-4

GEOLOGIC CROSS-SECTION A-A'
EUREKA FEDERAL BUILDING
EUREKA, CALIFORNIA

FIG. 1-5



Modified after Evenson (1959)

EXPLANATION

Holocene	Qal	Alluvium; gravel, sand, silt, and clay (Qal)
Pleistocene	Qtu	Terrace deposits; gravel, sand, silt, and clay (Qal)
	Qh	Hookton Formation; gravel, sand, silt, and clay (Qc)
Pliocene	QTwc	Carlotta Formation; conglomerate, sandstone, and claystone (Ts)
Miocene-Pliocene	Twu	Scotia Bluffs, Rio Dell, Eel River, and Pullen Formations; mudstone, sandstone and siltstone (Ts)
Cretaceous-Jurassic	KJu	Pre-Tertiary Formations; includes the Franciscan Assemblage and Yager Formation (KJf)

Notes:

1) For plan view of cross-section see Fig. 1-4.

2) Abbreviations in parentheses refer to geologic symbols used on Fig. 1-4.

Section 2
San Francisco Region

SECTION 2

SAN FRANCISCO REGION

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SECTION 2
SAN FRANCISCO REGION

LIST OF FIGURES

SECTION 2

SAN FRANCISCO REGION

2.1 INTRODUCTION

The San Francisco region in coastal northern California is defined for this report as an area within about 40 miles of San Francisco Bay. This region, outlined in Fig. 1, includes four accelerograph stations classified by one or more researchers (Table 1) as "rock" sites; that is, stations which are supported on or within a few feet of bedrock. Three of these stations are located in San Francisco (the State Building, the Alexander Building, and Golden Gate Park) and the fourth, the Oakland City Hall, is located in Oakland.

The location and instrumentation along with geological, seismological, and subsurface information for each of the accelerograph stations are discussed and illustrated in this section. Earthquake data, including ground motion time histories and response spectra for selected earthquakes recorded at the stations, are presented in the appendix.

2.2 STATION DESCRIPTIONS

2.2.1 State Building, San Francisco

2.2.1.1 Location and building. The State Building is located at 350 McAllister Street between Larkin and Polk Streets, as shown in Fig. 2-1. It is a seven-story, reinforced-concrete office building with a full basement and a two-level penthouse. The accelerograph (U.S.G.S. No. 1080) is located in the basement of the building. A plan view and photograph of the building are shown in Fig. 2-2.

The strong motion station was established in 1933 by the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey. This building was among the first to be instrumented in California.

2.2.1.2 Instrumentation. The strong motion instrument originally installed in the State Building was a U.S. Coast and Geodetic Survey (U.S.C.G.S.) Standard triaxial accelerograph, Serial No. 19D. Along with this accelerograph, a displacement meter, Serial No. 14, was installed.

The Standard accelerograph, Serial No. 19D, was replaced on January 17, 1957, by another U.S.C.G.S. Standard instrument, Serial No. 63-S. However, the same accelerometers and orientation were maintained from the old instrument. In 1958, this new instrument was also replaced by yet another U.S.C.G.S. Standard accelerograph, Serial No. S-60, still maintaining the same accelerometers and orientations. That accelerograph was finally removed on March 25, 1965, for installation in the basement of the nearby Federal Building. Currently, the State Building is instrumented with the original displacement meter and a seismometer, Serial No. 1619, which was installed prior to 1960.

At the time of the March 22, 1957, San Francisco earthquake, the U.S.C.G.S. Standard accelerograph, Serial No. 63-S, had the following instrument characteristics, as reported by Hudson, et al. (1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
S09E	13.2	.0658
S81W	12.8	.0650
V	12.6	.0648

The State Building basement accelerographs have been bolted to a concrete pier that is cemented to the concrete floor slab of the building. This pier is 1.5 feet high and has a rectangular shape with approximately the same horizontal dimensions as a U.S.C.G.S. Standard accelerograph. The displacement meter is bolted to a similar, but larger, concrete pier adjacent to the accelerograph pier. A plan view and photograph of the room are shown in Fig. 2-3.

2.2.2 Alexander Building, San Francisco

2.2.2.1 Location and building. The Alexander Building, at 155 Montgomery Street, San Francisco, is located at the southwest corner of Bush and Montgomery Streets in the downtown area, as shown on Fig. 2-4. It is a 16-story, steel-frame structure with one basement. It is adjoined on the south side by a four-story building. The Alexander building has a slab on grade and rests on spread footings. It is currently owned by the Cahill Construction Company. A photograph and plan view of the structure are presented in Fig. 2-5.

The accelerograph station discussed in this study (U.S.G.S. No. 1065) is in the basement of the building in a storeroom adjacent to the boiler. It was established on November 12, 1934, by the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey.

2.2.2.2 Instrumentation. The original strong motion instrument installed in the basement of the Alexander Building was a U.S.C.G.S. Standard 12-inch drum recorder triaxial accelerograph, Serial No. 37. It was replaced on July 23, 1943, by a U.S.C.G.S. Standard 6-inch drum recorder triaxial accelerograph, Serial No. 10. The latter instrument was equipped with pivot suspension accelerometers until March 17, 1947, when they were replaced by accelerometers with unifilar suspensions. At the time of the March 22, 1957, San Francisco earthquake, the accelerograph had the following instrument characteristics as reported by Hudson, et al. (1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
N09W	0.0650	12.7
V	0.0639	12.0
N81E	0.0635	12.6

In 1959, a 12-inch paper, camera-type recorder replaced the 6-inch drum recorder, and Carder displacement meters were installed parallel to the horizontal accelerometers to record horizontal displacements. Each of the Standard instruments was bolted to a concrete pier that is cemented to the concrete slab floor of the building. The pier is 1.5 feet high and has approximately the same horizontal dimensions as a U.S.C.G.S. Standard accelerograph pier.

The Standard accelerograph in the basement of the Alexander Building was replaced on July 22, 1972, by an SMA-1, triaxial accelerograph, Serial No. 599, manufactured by Kinemetrics, Inc. The SMA-1 was also installed on the pier.

The SMA-1 instrument was removed in 1976, and the U.S. Geological Survey is now planning to equip the building with instrumentation capable of recording torsional and transverse response of the structure. The only instrument currently located in the basement of the Alexander Building is a seismoscope, Serial No. 1636. It was originally installed, adjacent to the basement accelerograph, on July 12, 1966. A photograph and plan view of the accelerograph pier and storage room is provided in Fig. 2-6.

The 11th floor and the roof of the Alexander Building have also been instrumented with various accelerographs. After July 1972, these instruments were interconnected with the basement accelerograph for simultaneous start and sychronous timing.

2.2.3 Golden Gate Park, San Francisco

2.2.3.1 Location and housing structure. The recording instrument at Golden Gate Park is installed in a small building near the Prayer Book Cross. This site is on a hill near the northern boundary of the park between Park-Presidio Drive and John F. Kennedy Drive (Fig. 2-7). The building is a one-room, concrete structure with a concrete slab on grade. It was previously used as an electrical control room for nearby lighting fixtures, but currently is used only to house the accelerograph. A photograph and plan view of the building and vicinity are shown in Fig. 2-8.

The Golden Gate Park strong motion station (U.S.G.S. No. 1117) was established prior to October 1934 by the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey.

2.2.3.2 Instrumentation. The strong motion instrument first installed at the Golden Gate Park station was a U.S.C.G.S. Standard triaxial accelerograph. At the time of the March 22, 1957, San Francisco earthquake, that instrument had the following specifications as reported by Hudson et al. (1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
N10E	17.1	.0754
S80E	18.1	.0779
V	17.2	.0764

The U.S.C.G.S. Standard accelerograph was replaced on August 8, 1969, by an RFT-250, Teledyne-Geotech accelerograph, Serial No. 163. This RFT-250 was temporarily removed between June 23, 1970, and January 19, 1971, and was finally replaced by a second RFT-250, Serial No. 161, on September 23, 1971. This accelerograph remained in placed until October 4, 1971. The present instrument is a SMA-1 accelerograph, Serial No. 291. It has the following specifications, as indicated in the U.S. Geological Survey files (unpub.):

Component Direction	Sensitivity (cm/g)	Period (sec)
N10E	1.76	.38
N80W	1.96	.38
Down	1.93	.38

The various accelerographs located at the Golden Gate Park station have been bolted to a concrete pier that stands 20 inches above the floor slab of the structure. A seismoscope, Serial No. 1610, is mounted on the pier beside the accelerograph. A photograph of the instruments and a plan view of the station are provided on Fig. 2-9.

2.2.4 Oakland City Hall

2.2.4.1 Location and building. The Oakland City Hall is at 1421 Washington Street between 14th and 15th Streets in downtown Oakland (Fig. 2-10). The City Hall is a steel-framed structure with brick walls faced with rock. It has fifteen floors in addition to a mezzanine, basement, and cupola. The foundation is a concrete mat with dropped footings under the columns (U.S. Geological Survey files, unpub.). A photograph and plan view of the City Hall are provided in Fig. 2-11.

The recording instrument (U.S.G.S. No. 1049) is located in an electrical control room in the basement of the City Hall (Fig. 2-11). The station was established in June 1933 by the U.S. Coast and Geodetic Survey, and was among the earliest instrumented buildings in California.

2.2.4.2 Instrumentation. The strong motion accelerograph initially installed in the Oakland City Hall was a 6-inch drum recorder, Serial No. 29, with three quadrafilar-type accelerometers. Within a few months, the instrument was modified to record on 6-inch photographic film with pivot suspension-type accelerometers. A second instrument was installed in the tower of the building in November 1934, and the two instruments were connected for simultaneous starting.

On December 5, 1935, the original instrument was replaced by a U.S. Coast and Geodetic Survey Standard accelerograph, Serial No. 33. It remained in the station until October 29, 1953, when it was replaced by another U.S.C.G.S. Standard accelerograph, Serial No. 16-D, with a drum-type recorder. At the time of the March 22, 1957, San Francisco earthquake, instrument No. 16-D had the following characteristics as reported by Hudson et al. (1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
N26E	12.5	.0662
S64E	13.2	.0673
V	13.0	.0668

The Standard accelerograph No. 37 was replaced in 1976 by a Kinemetrics RFT-250 accelerograph, Serial No. 514. This instrument is currently in use at the station along with a seismoscope, Serial No. 1639, that has been operative since July 22, 1960.

All of the accelerographs that have been installed in the basement of the Oakland City Hall have been bolted to a 1.5-foot high concrete pier cemented to the floor slab of the building. The seismoscope is bolted to the floor adjacent to the instrument pier. A photograph of the instrument and pier are shown in Fig. 2-12 along with a plan view of the room where they are located.

2.3 GEOLOGY AND SEISMICITY

2.3.1 Regional Geology

The San Francisco region is situated in the Coast Ranges province, a series of northwest-trending mountain ranges and intermontane valleys bounded to the east by the Great Valley and to the west by the Pacific Ocean. The geology of the San Francisco region is depicted on the geologic map, Fig. 2-13. Symbols shown in parentheses for geologic units in the following discussion refer to symbols used on that map.

The Coast Ranges province is underlain by two structurally distinct and mutually exclusive types of basement rock that are separated by the San Andreas-Pilarcitos and Nacimiento fault zones. These two types of basement rocks are: 1) a complex of upper Jurassic to upper Cretaceous eugeosynclinal rocks of the Franciscan Assemblage and 2) a granitic-metamorphic basement complex of late Paleozoic and Mesozoic age (Oakeshott, 1966; and Page, 1966).

The Franciscan Assemblage comprises the basement rock to the east of the San Andreas-Pilarcitos fault zone. This basement complex is composed of a disordered and heterogeneous accumulation of probably more than 50,000 feet of graywacke, shale, altered mafic volcanic rocks or greenstone, chert, limestone, and metamorphic rocks (Mz) (Bailey, et al., 1964). The Franciscan Assemblage is profusely intruded by dikes, sills, and plugs of serpentinite and associated ultramafic rocks (included with Mz).

In contrast to the Franciscan Assemblage to the east of the San Andreas fault zone, the western block is underlain by the granitic-metamorphic basement complex known as the "Salinian" block. The crystalline complex is composed mostly of granitic intrusives of Cretaceous age (gr) and associated high-grade gneisses, schists, and granulites (not shown). South of the region, the Salinian block is also bounded on the west (across the Nacimiento fault) by the Franciscan basement complex.

A thick sequence of upper Jurassic to Cretaceous marine clastic sedimentary strata (Mz and K, in part), known as the Great Valley sequence, are disposed around the Franciscan Assemblage, primarily to the east of the Hayward fault (Page, 1966). Although these strata are nearly contemporaneous with the Franciscan rocks, they have distinctly different characteristics and are everywhere in fault contact with the Franciscan basement complex. The juxtaposition of these divergent crustal masses is strong evidence of large-scale tectonic movements. The Great Valley sequence is not known to exist in the area underlain by the Salinian basement complex. If these strata were indigenous to that area, they are now part of the metamorphic complex invaded by granitic instrusives in Cretaceous time.

Upper Cretaceous strata, unrelated to the Great Valley sequence, are present on the Salinian block as demonstrated by exposures of the Asuncion Group (Taliaferro, 1943). These strata consist mostly of sandstone and shale and are partially derived from the underlying granitic basement rocks.

A thick sequence of Tertiary strata constitutes the bedrock for much of the San Francisco region. A wide variety of lithologies, both sedimentary (Ts) and volcanic (Tv), are present in this sequence, which ranges from Paleocene to Pliocene in age. The sedimentary strata are primarily of shallow marine origin and are composed mostly of sandstones and shales. Volcanic deposits are prevalent in the Miocene and Pliocene strata, particularly north of San Francisco Bay.

Quaternary surficial deposits cover large portions of the San Francisco region, particularly in areas adjoining San Francisco Bay and the Sacramento and San Joaquin Rivers. These Quaternary deposits consist of Holocene stream and basin alluvium, including bay mud (Qal, Qf), dune sands, and artificial fill (grouped with Qal), and Pleistocene marine and non-marine terrace deposits.

The San Francisco region is dominated by major northwest-trending faults. The great San Andreas fault zone is the area's most spectacular structural feature. This master fault is known to extend for over 600 miles northwestward from the Gulf of California to Point Area, California. It is the boundary between the North American and Pacific Ocean crustal plates and has been undergoing major right-lateral displacement since at least late Miocene time (Crowell, 1975). Owing to varied geologic evidence, investigators have not agreed upon a cumulative offset across the San Andreas fault zone; it may have as much as tens of miles to perhaps hundreds of miles of displacement. In any case, fault displacements of several feet have accompanied major earthquakes in historic time.

The Calaveras and Hayward fault zones are major branches of the San Andreas fault. Like the San Andreas, they are strike-slip faults that are known to be active along parts of their traces. In recent years, both faults have been undergoing active fault displacement or "tectonic creep" (Nason, 1971).

Numerous other faults in the region are also known to have been active in Quaternary time, but have no historic record of displacement. These include the San Gregorio, Rogers Creek, Green Valley, and Livermore faults to name a few (Jennings, 1975).

Folding, like the accompanying faulting in this region, has been complex and active as recently as the Quaternary, as evidenced by deformed Plio-Pleistocene deposits. Fold axes generally parallel the fault trends and suggest crustal shortening in a northeast-southwest direction (Page, 1966).

2.3.2 Seismicity

The San Francisco region is an area of high seismicity where historic earthquakes have been frequent and occasionally strong. The larger of these temblors have resulted from displacement along the San Andreas, Hayward, and Calaveras faults, although other instrumentally located epicenters indicate activity on other faults as well. The famous San Francisco earthquake of April 18, 1906, which destroyed a large part of San Francisco, was centered on the San Andreas fault zone near Olema, California (Fig. 2-13). There was as much as 20 feet of right-lateral displacement across the fault in that area (Oakeshott, 1966). The 1906 earthquake was preceded by major earthquakes along the fault zone in June 1838; October 8, 1865; and April 24, 1890; all of which occurred in or near the San Francisco region. Major earthquakes centered on the Hayward fault include the June 10, 1836, and October 21, 1868, events, both of which resulted in surface rupture.

More recently, the most destructive earthquake in the region was the magnitude 5.3, March 22, 1957, earthquake, which had an epicenter on the San Andreas fault near Mussel Rock (Fig. 2-13).

2.3.3 Local Geology

2.3.3.1 State Building, San Francisco. The State Building is located in the city of San Francisco near the northeastern end of the San Francisco Peninsula. The geology of this area is depicted on the Geologic Cross-Section B-B' (Fig. 2-14).

The northeastern Peninsula is underlain by bedrock of the Franciscan Assemblage and associated ultramafic intrusive rocks. The Franciscan rocks in this area consist mostly of graywacke sandstone, shale, siltstone, and mafic volcanic rocks (Schlocker, 1974).

The Franciscan bedrock, for the most part, is mantled by a variety of unconsolidated Quaternary surficial deposits, ranging in thickness from a trace to over 200 feet. These Quaternary deposits include a sequence of Pleistocene marine sand and dune sand known as the Colma Formation, younger Pleistocene to Holocene dune sands, Holocene alluvium, and artificial fill (Schlocker, 1974).

The State Building is located in an area underlain by about 25 feet of the younger dune sands overlying the sands of the Colma Formation. According to mapping by Schlocker (1974) in the vicinity of the State Building, approximately 200 feet of these surficial deposits overlie intensely sheared shale and serpentinite of the Franciscan bedrock.

The nearest trace of the San Andreas fault is about 8 miles west of the State Building station. Smaller and apparently inactive faults, including the City College fault, have been mapped within about 4 miles of the station (Jennings, 1975).

2.3.3.2 Alexander Building, San Francisco. The Alexander Building is in the northeastern part of San Francisco near the northern tip of the San Francisco Peninsula. The geology of this area is depicted on the Geologic Cross-Section B-B', Fig. 2-14. This area is underlain by bedrock of the Franciscan Assemblage consisting mostly of graywacke sandstone, siltstone, shale, and mafic volcanic rocks with lesser amounts of chert, conglomerate, limestone, and metamorphic rocks (Schlocker, 1974). These rocks are associated with serpentinite and ultramfic intrusives.

Quaternary surficial deposits mantle the bedrock over much of the Peninsula. These unconsolidated deposits are quite varied, consisting of Pleistocene and Holocene dune and beach sands, Pleistocene marine sands, Holocene alluvium, and artificial fill. They range in thickness from a trace to 200 feet or more in this area (Schlocker, 1974).

The Alexander Building is located near the edge of an area underlain by artificial fill. This fill was placed on a thick accumulation of dune sands and undifferentiated surficial deposits overlying Franciscan bedrock at a depth of between 125 and 175 feet in the station vicinity according to mapping by Schlocker (1974).

The San Andreas fault zone is about 9 miles west of the Alexander Building, whereas the Hayward fault is about 10 miles to the east. A few faults, including the City College fault, have been mapped within about 5 miles of the station, but are not considered to be active (Jennings, 1975).

2.3.3.3 Golden Gate Park, San Francisco. Golden Gate Park is in western San Francisco near the northern tip of the San Francisco Peninsula. The general geology of this area is depicted on the Geologic Cross-Section B-B', Fig. 2-14. The northern Peninsula area is underlain by bedrock of the Franciscan Assemblage. This basement complex locally consists of graywacke sandstone, shale, siltstone, and mafic volcanic rocks with lesser amounts of chert, conglomerate, limestone, and metamorphic rocks; pervasively intruded by serpentinite and associated ultramafic rocks (Schlocker, 1974).

In much of the area, the Franciscan rocks are mantled by Quaternary surficial deposits, locally exceeding 200 feet in thickness. These deposits are comprised of Pleistocene and Holocene dune and beach sands, Pleistocene marine sands, Holocene alluvium, and artificial fill.

The Golden Gate Park accelerograph station is located on a hill adjacent to the Prayer Book Cross. This hill, which protrudes above the surrounding mantle of dune sands, is formed from a resistant knob of Franciscan radiolarian chert and interbedded shale. Within 1/4 mile of the knoll, the dune sands are locally as much as 150 feet thick over the Franciscan bedrock (Schlocker, 1974).

The station is located within 1 mile of the City College fault, and is about 5 miles east of the trace of the active San Andreas fault zone.

2.3.3.4 Oakland City Hall. The Oakland City Hall is situated in a lowland area approximately 1 mile from the east shore of San Francisco Bay. The geology of this area is depicted on the geologic Cross-Section B-B', Fig. 2-14.

The Oakland area is underlain at considerable depth by the Franciscan basement complex, a disordered assemblage of sedimentary, volcanic, and metamorphic rocks, intruded by serpentinites and associated ultramafic rocks. Overlying the Franciscan Assemblage is a thick sequence of Quaternary sediments. These strata include the following units as recognized by Radbruch (1969):

a) The Pleistocene Alameda Formation, consisting locally of over 1,000 feet of continental and marine sand, clay, and gravel.

b) The Merritt Sand, a Pleistocene sequence of well sorted sands.

c) A soft, organic, clayey to sandy silt known as the bay mud.

d) Artificial fill.

To the east of the station, the Hayward fault separates the lowlands of Oakland from the Berkeley Hills. For the most part, this fault also separates two rather diverse geologic terrains. On the east side of the fault, the Berkeley Hills are primarily underlain by Cretaceous and Tertiary bedrock. These units, which also overlie the Franciscan Assemblage, are strongly deformed by northwest-trending folds and faults.

The Oakland City Hall is underlain by a thick accumulation of Quaternary surficial deposits, including the Merritt Sand and the older Alameda Formation. The depth to the underlying Franciscan basement is thought to be about 1,000 feet (Seed and Idriss, 1969).

The active Hayward fault at its closest approach is about 3.5 miles east of the Oakland City Hall. This fault has had surface displacements during historic time and is known to be actively undergoing tectonic creep (Jennings, 1975).

2.4 CATALOG OF SEISMIC EVENTS

The accelerograph stations in the San Francisco region are situated between the active San Andreas and Hayward faults. The Calaveras fault zone, parts of which are also active, is located about 10 miles east of the Oakland City Hall station (Fig. 2-13). These faults have produced frequent and occasionally strong earthquakes in historic time, thus the region is considered an area of continuing high seismicity. Some of the major historic earthquakes that have shaken the region are discussed in Section 2.3.2.

The San Francisco region accelerograph stations were established in 1933 and 1934 and are among the oldest strong motion stations in the country. They have produced many earthquake records in their long history of operation. A list of selected earthquakes recorded at each of the stations is presented in Table A2-1 of the Appendix. Selected ground motion time histories and their corresponding response spectra are also presented in the Appendix as Fig. A2-1 through A2-36.

The most significant earthquake recorded at the stations was the March 22, 1957, event centered near Mussel Rock (Fig. 2-13). Although this earthquake had a relatively low magnitude (5.3), it caused considerable damage and was recorded by all the stations in the area. The Arvin-Tehachapi earthquake of July 21, 1952, had the highest magnitude of any of the earthquakes thus far recorded in the San Francisco region. This event, with a 7.7 magnitude, had an epicenter approximately 265 miles to the south, and was recorded at two of the stations considered in this section.

2.5 FIELD EXPLORATIONS

The San Francisco region accelerograph station sites discussed in this chapter were visited to verify published information about the instrumentation, housing units, and site conditions. At each site, the instrumentation and housing structure were photographed and details were gathered on the housing structure and instrumentation history. Also, a brief geologic reconnaissance was made in the vicinity of each site to verify the presence of rock and other units shown on published geologic maps. Detailed subsurface information at each site was compiled from available boring logs. No borings were made for this investigation.

2.6 SITE SUBSURFACE CONDITIONS

2.6.1 State Building, San Francisco

Subsurface boring data in the vicinity of the State Building (Fig. 2-15) indicate that approximately 210 feet of Quaternary sediments overlie the Franciscan bedrock. These sediments are primarily medium to very dense sand with occasional layers of clayey sand and gravel below 100 feet. Depth to bedrock in the area is quite variable. The bedrock contour map by Schlocker (1974) indicates that the depth to rock varies from about 150 to over 200 feet within two blocks of the site. The bedrock is part of the Franciscan Assemblage, a complex of sedimentary and metasedimentary basement rock (Section 2.3.3.1).

2.6.2 Alexander Building, San Francisco

Data on the subsurface conditions in the vicinity of the Alexander Building (Fig. 2-16) indicate that approximately 140 feet of Quaternary sediments overlie the Franciscan bedrock. The surficial stratum at the site is an artificial fill which extends to a depth of about 10 feet (U.S.G.S., unpub.). The natural sediments underlying the fill are primarily silty and clayey sands. Index and engineering properties for these materials are not cited in the data source (Seed and Idriss, 1969). Bedrock at the site exists at a depth of about 140 feet (Schlocker, 1974). Depth to bedrock in the site area is quite variable and may range from 100 feet to as much as 200 feet within a distance of several blocks.

2.6.3 Golden Gate Park, San Francisco

The accelerograph station at Golden Gate Park is located on a knoll which is underlain by thin, alternating beds of radiolarian chert and shale. Below a few feet of weathered rock, the chert is hard and brittle and the shale is moderately hard and brittle. This bedrock is part of the Franciscan basement complex that underlies the Quaternary sediments throughout San Francisco.

2.6.4 Oakland City Hall

Subsurface conditions encountered in a 90-foot boring advanced in the immediate vicinity of the site are depicted in Fig. 2-17. The materials in the upper 37 feet of the boring are primarily medium to very dense sands of the Merritt Sand group. Below a depth of 37 feet, the boring encountered stiff to very stiff clay and dense to very dense sand of the Alameda Formation. Geologic data indicate that the Alameda formation may be as much as 1,000 feet thick at the site. Underlying the Alameda Formation is bedrock of the Franciscan Assemblage.

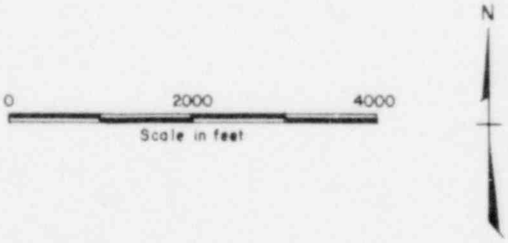
350 Mc ALLISTER STREET

USGS Topographic Quadrangle:
San Francisco North, California

Coordinates: 37° 46' 50" N.
122° 25' 00" W.

Location: 350 Mc Allister St. between Larkin and Polk Streets.

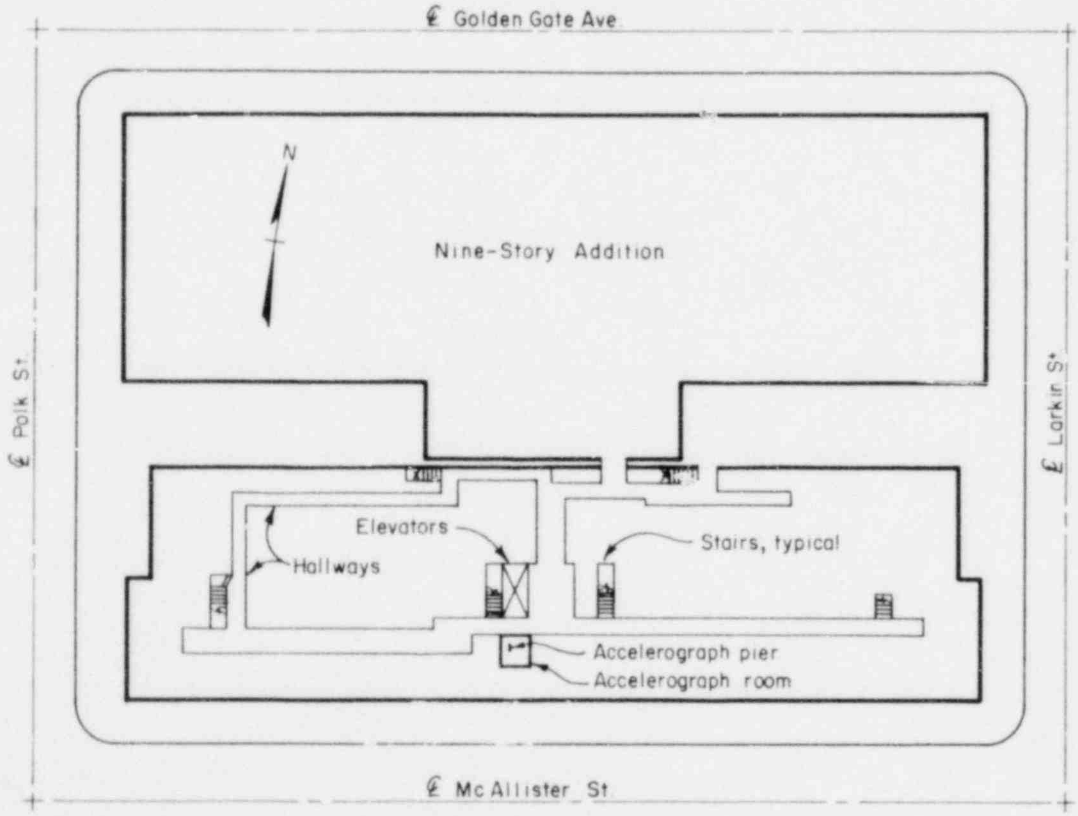
Structure: 7-story reinforced concrete office building.



STATION LOCATION PLAN
STATE BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-1

350 Mc Allister Street
South and West Elevations



Basement Floor Plan

0 100
Scale in feet

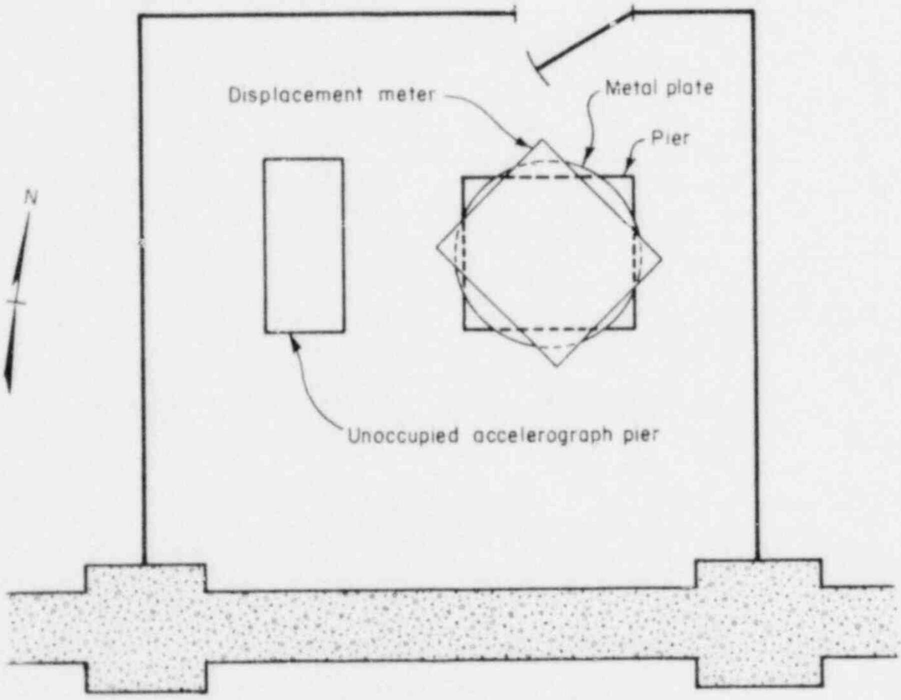
Notes: 1) Boring B-1 is located 300 ft. north of the State Bldg. and the Log of Boring is shown on Fig. 2-15.

2) Accelerograph room plan is shown on Fig. 2-3.

ACCELEROGRAPH STATION
STATE BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-2

U.S. Coast and Geodetic Survey Displacement Meter (Left)
and Unoccupied Accelerograph Pier, U.S.G.S. Station 1080



Accelerograph Room Plan, Basement

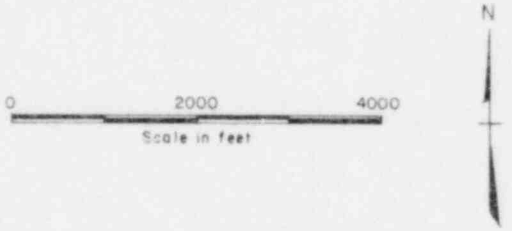
Note: Location of Accelerograph Room within the structure is shown on Fig. 2-2.

STATION INSTRUMENTATION
STATE BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-3

155 MONTGOMERY STREET

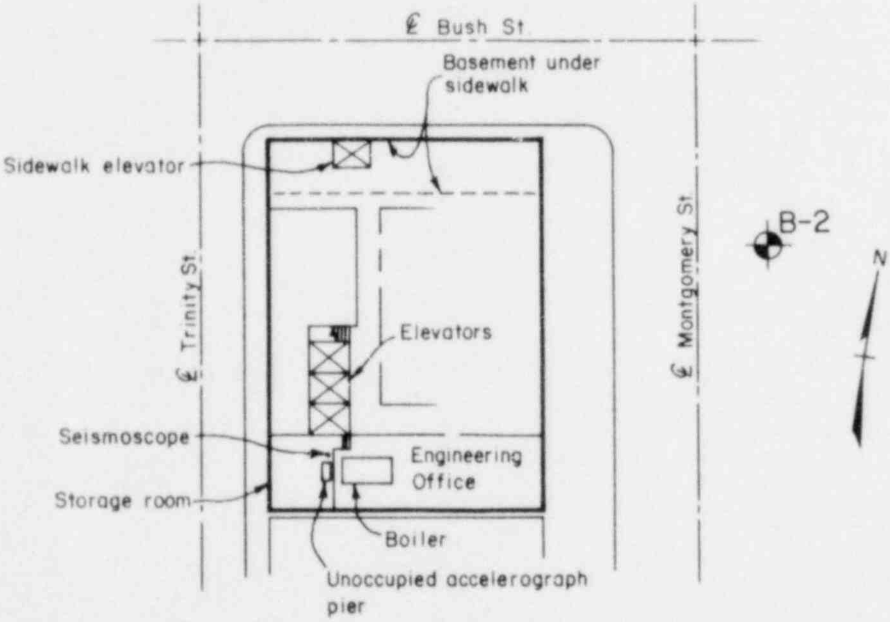
USGS Topographic Quadrangle:	San Francisco North, California
Coordinates:	37° 47' 27" N. 122° 24' 08" W.
Location:	Southwest corner of Bush and Montgomery Streets.
Structure:	16-story steel frame office building.



STATION LOCATION PLAN
ALEXANDER BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-4

155 Montgomery St., East Elevation
from Bush Street



Basement Floor Plan

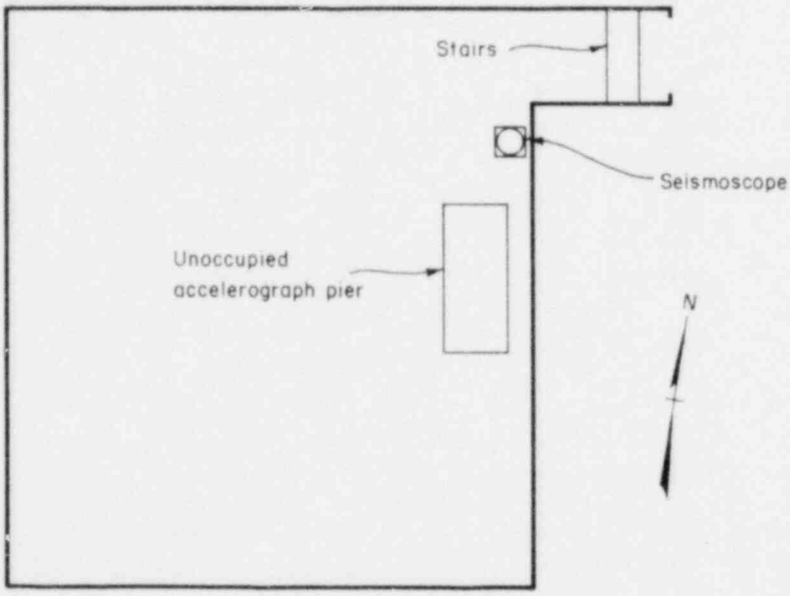
Notes: 1) Log of Boring for B-2 is shown on Fig 2-16.

2) Storage room plan is shown on Fig. 2-6.

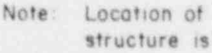
ACCELEROGRAPH STATION
ALEXANDER BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-5

Accelerograph Pier, U.S.G.S. Station 1065
155 Montgomery St., Basement



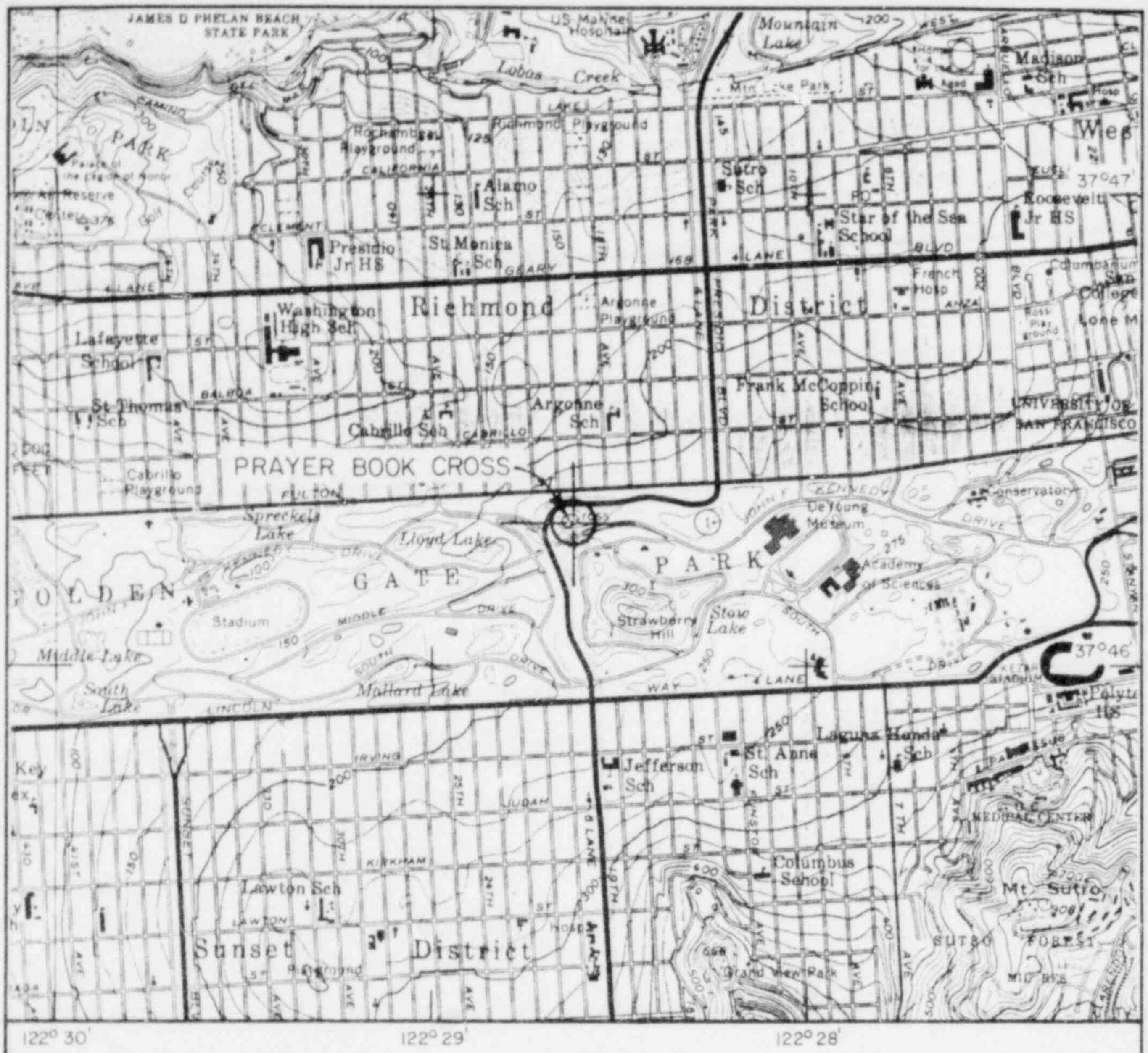
Storage Room Floor Plan, Basement



Note: Location of Storage Room within the structure is shown on Fig. 2-5.

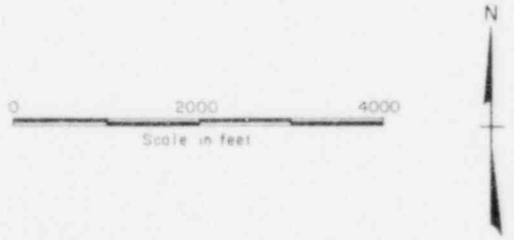
STATION INSTRUMENTATION
ALEXANDER BUILDING
SAN FRANCISCO, CALIFORNIA

FIG. 2-6



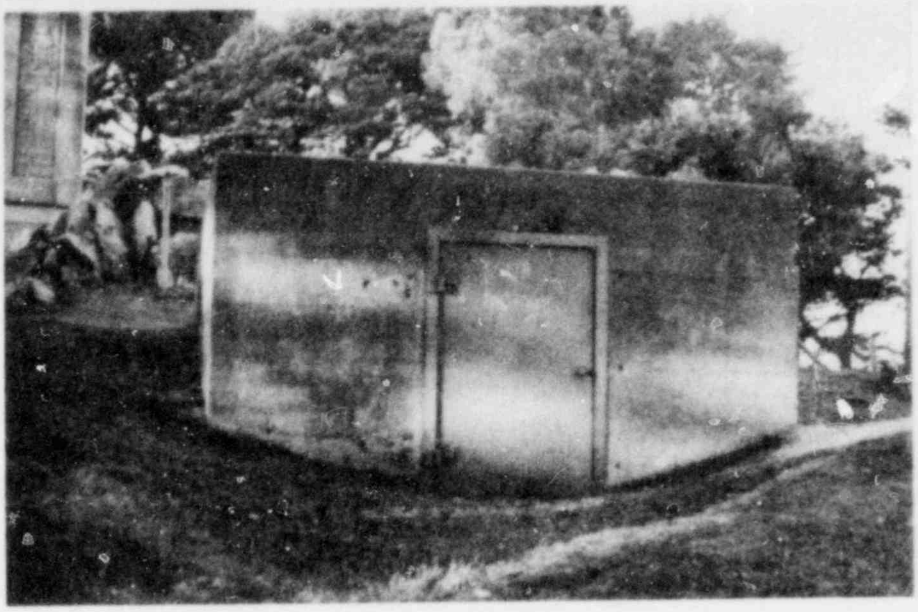
PRAYER BOOK CROSS

USGS Topographic Quadrangle:	San Francisco North, California
Coordinates:	37° 46' 19" N 122°28' 37" W
Location:	50 feet south of Prayer Book Cross.
Structure:	Concrete one-room building.

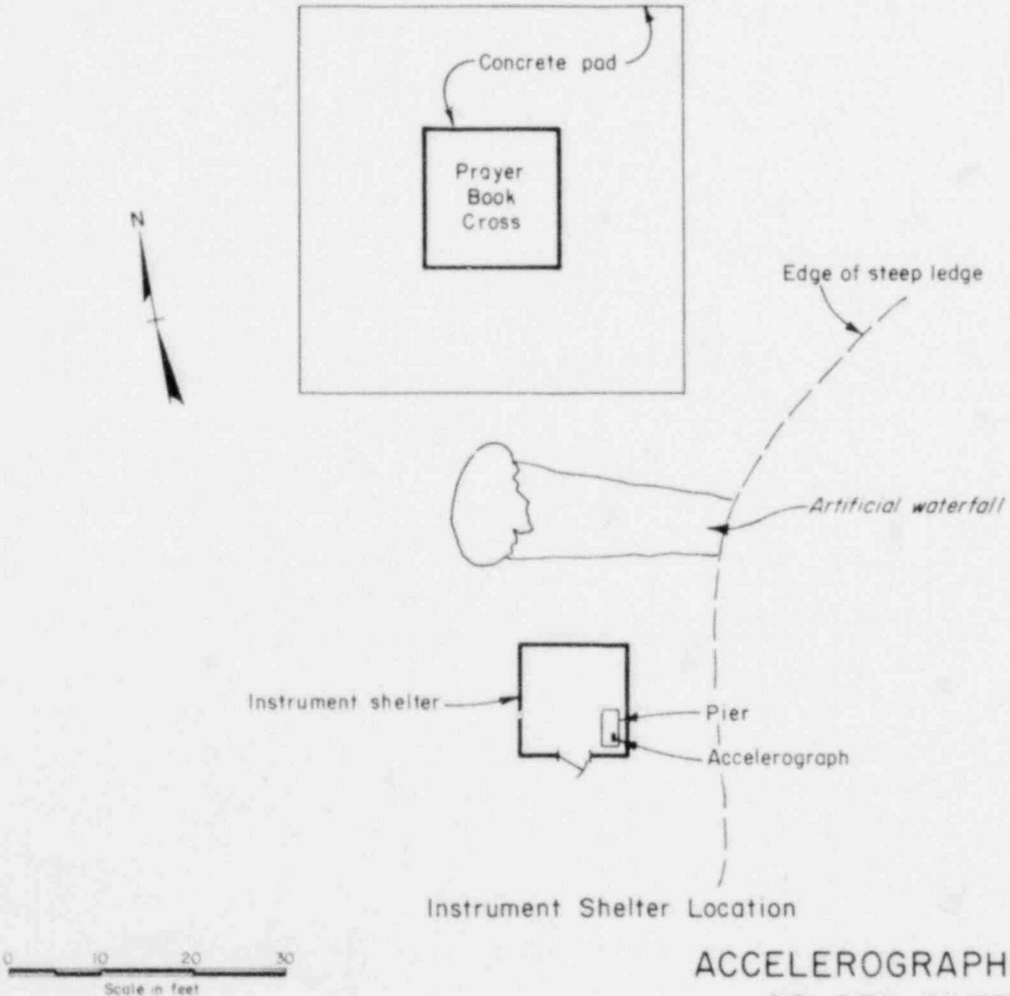


STATION LOCATION PLAN
GOLDEN GATE PARK
SAN FRANCISCO, CALIFORNIA

FIG. 2-7



Instrument Shelter
View to the North



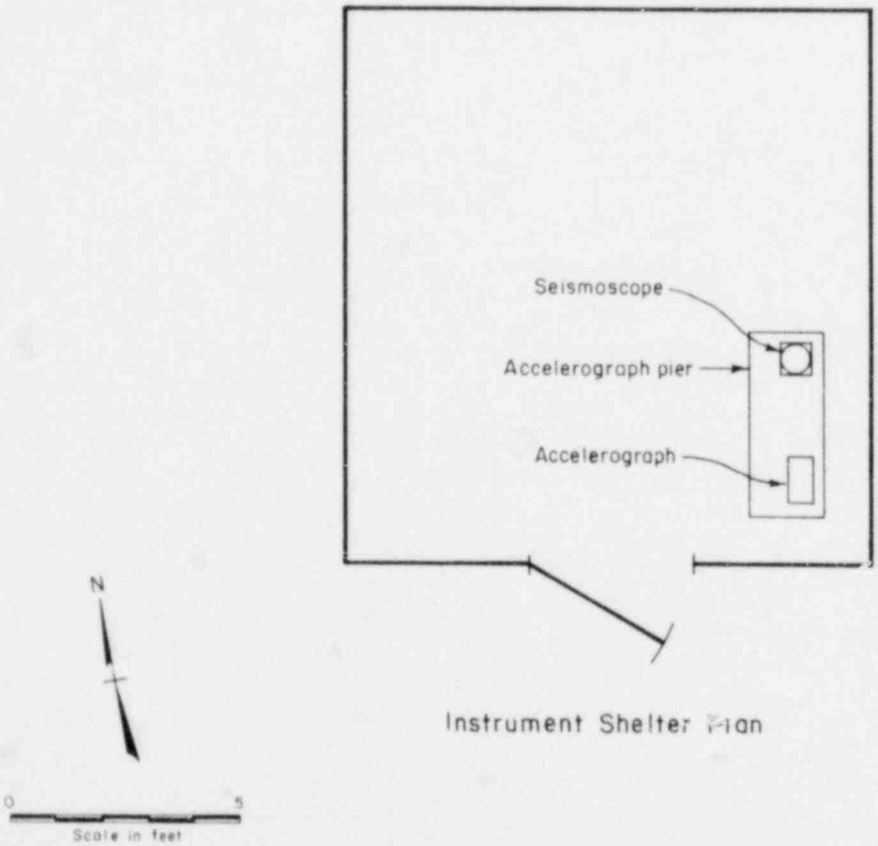
Instrument Shelter Location

Note: Instrument shelter plan is shown on Fig. 2-9.

ACCELEROGRAPH STATION
GOLDEN GATE PARK
SAN FRANCISCO, CALIFORNIA

FIG. 2-8

SMA-1 Accelerograph
U.S.G.S. Station 1117

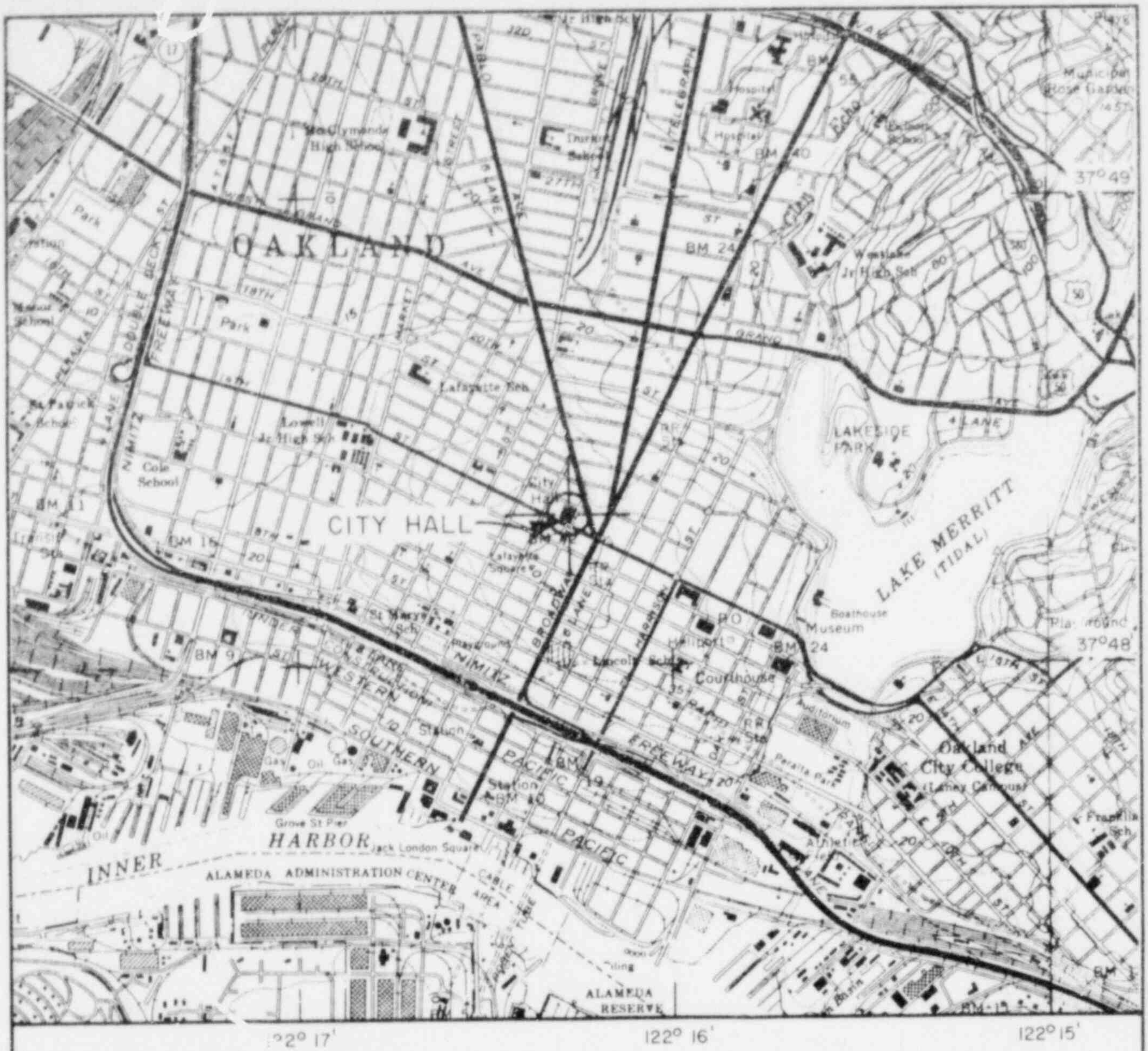


Instrument Shelter Plan

Note: Location of Instrument Shelter is shown on Fig. 2-8.

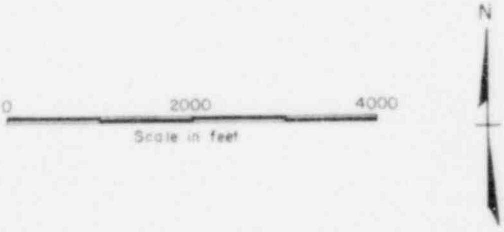
STATION INSTRUMENTATION
GOLDEN GATE PARK
SAN FRANCISCO, CALIFORNIA

FIG. 2-9



OAKLAND CITY HALL

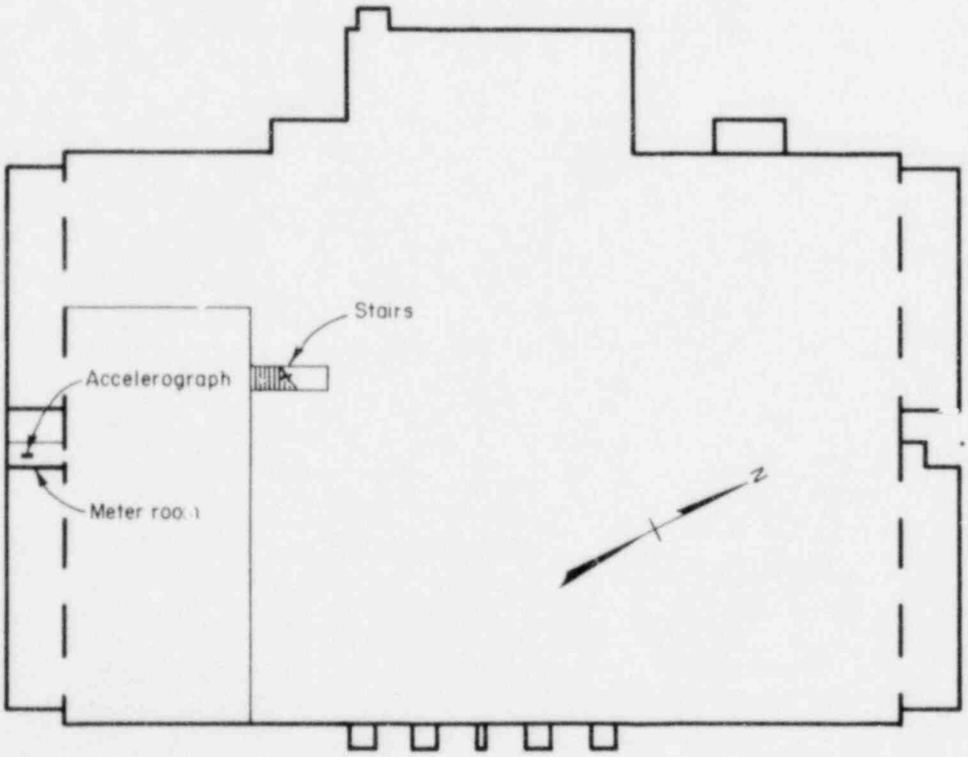
USGS Topographic Quadrangles:	Oakland West and Oakland East, California
Coordinates:	37° 48' 20" N. 122° 16' 17" W.
Location:	Northwest corner of 14th St. and Washington St.
Structure:	15-story building with steel frame and brick walls faced with granite.



STATION LOCATION PLAN
OAKLAND CITY HALL
OAKLAND, CALIFORNIA

FIG. 2-10

Oakland City Hall
View to the North

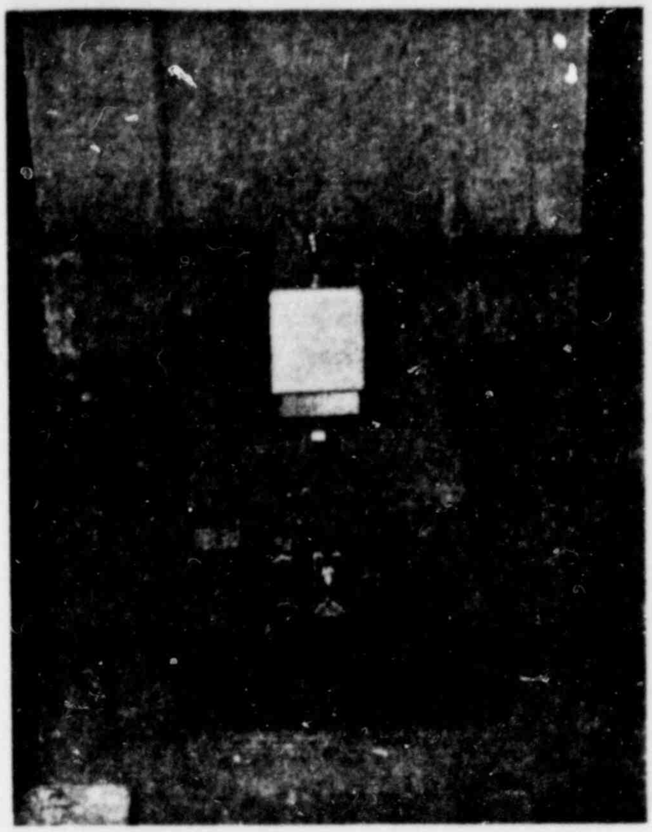


Basement Floor Plan

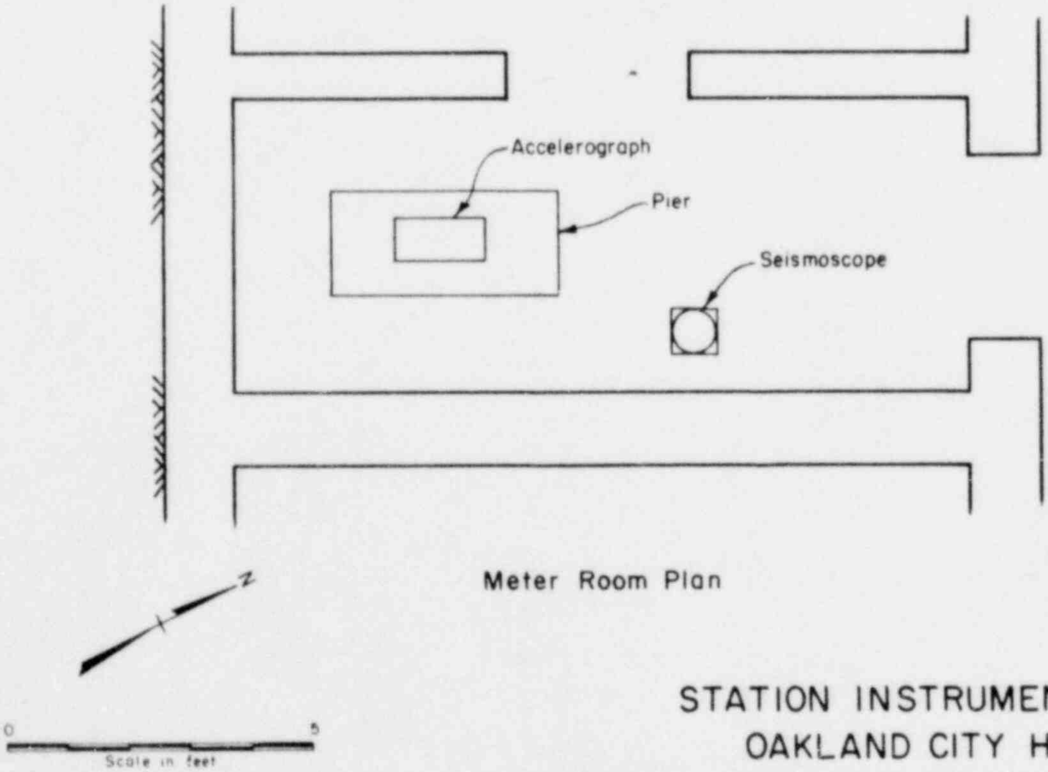
Note: Meter room plan is shown on Fig. 2-12.

ACCELEROGRAPH STATION
OAKLAND CITY HALL
OAKLAND, CALIFORNIA

FIG. 2-11



RFT-250 Accelerograph, U.S.G.S. Station 1049
Oakland City Hall, Basement

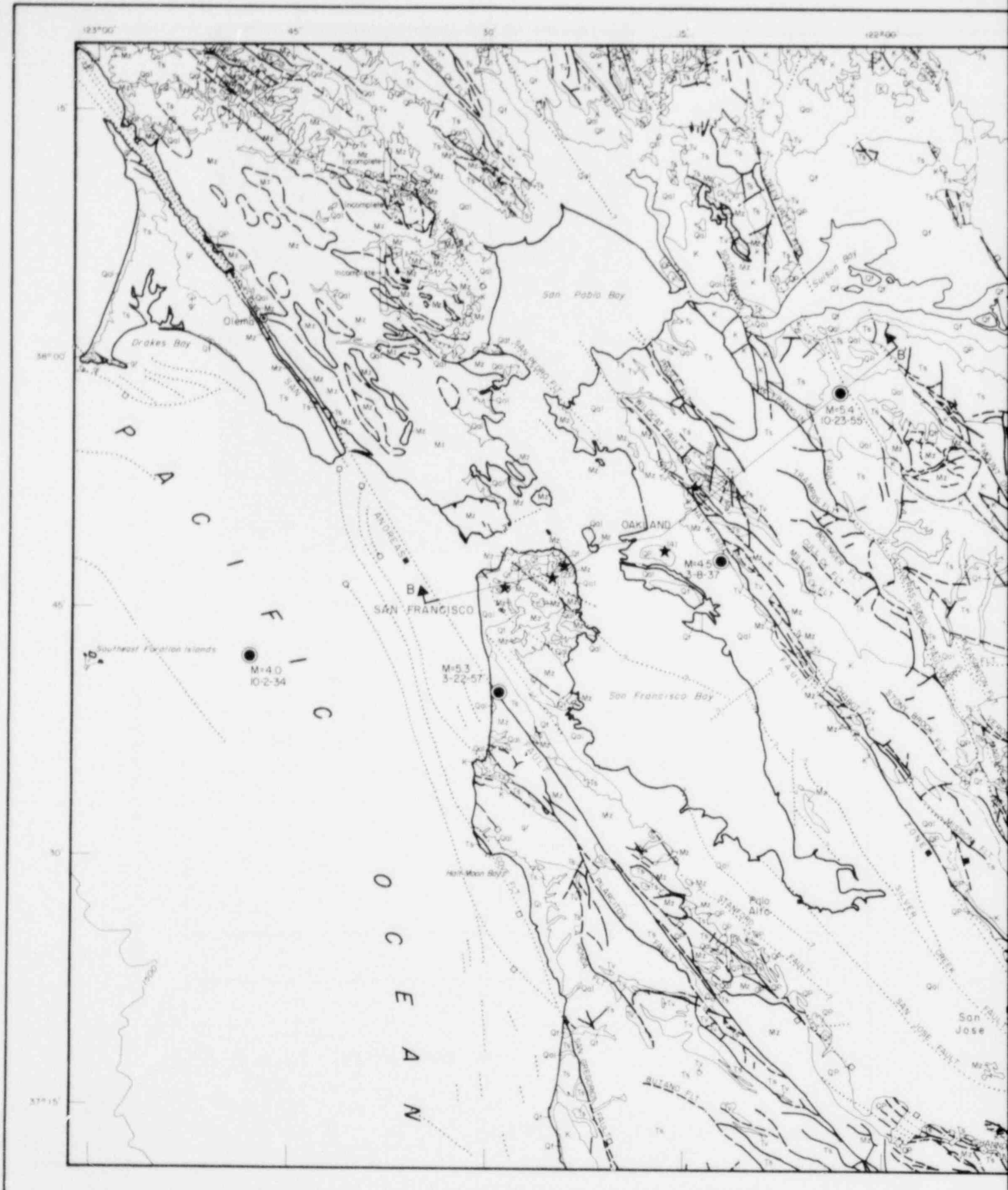


Meter Room Plan

Note: Location of Meter Room within the structure is shown on Fig 2-11

STATION INSTRUMENTATION
OAKLAND CITY HALL
OAKLAND, CALIFORNIA

FIG. 2-12


123°00'
45'
30'
15'
122°00'
15'
38°00'
45'
30'
37°15'
PACIFIC OCEAN
Drakes Bay
Olema
San Pablo Bay
Suisun Bay
OAKLAND
SAN FRANCISCO
San Francisco Bay
Palo Alto
San Jose
Half Moon Bay
Southeast Farallon Islands
SAN ANDREAS
SAN PEDRO FLT
HAYWARD FAULT
CALAVERAS FAULT ZONE
SILVER CREEK FAULT
SAN JOSE FAULT
STANFORD FAULT
PILARCITOS FAULT
BUTANO FLT
SAN GREGORIO FAULT
STONY BROOK FLT
B
B'
M=4.0
10-2-34
M=5.3
3-22-57
M=4.5
3-8-37
M=5.4
10-23-55
Mz
Ts
Tv
K
Qal
Qt
Incomplete

EXPLANATION

Qal	Alluvium, **Holocene in age**, includes dune deposits
Qf	Stream channel, fan, and basin deposits, **Holocene in age.**
Ql	Lake deposits, Quaternary in age
Qt	Marine deposits, marine and nonmarine terrace deposits, Quaternary in age; includes upper Pliocene marine deposits
QP	Nonmarine sedimentary deposits, Plio-Pleistocene in age
Tv	Volcanic rocks and igneous intrusive rocks, Tertiary in age
Ts	Sedimentary rocks, Tertiary in age
K	Sedimentary rocks, Cretaceous in age
Mz	Mesozoic sedimentary and metamorphic rocks; includes Franciscan Assemblage
gr	Mesozoic granitic rocks; also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks
m	Metamorphic and metasedimentary rocks, pre-Cretaceous in age
P	Sedimentary and volcanic rocks, Paleozoic in age
p€g	Precambrian igneous and metamorphic rocks; includes crystalline rocks which may be as young as Mesozoic

★	Accelerograph Station location
● M=5.8 9-4-55	Epicenter location, Richter magnitude, and date of occurrence
☐	Faults that have moved during Quaternary time without historic record (approx. past 2 million years)
■	Faults that have moved during historic time (approx. 200 years)
Contact	Dashed where approximately located
Fault	Dashed where approximately located, dotted where concealed, queried where existence is uncertain
Thrust Fault	Barbs on upper plate, dashed where approximately located, dotted where concealed
Offshore Fault	Location approximate

NOTES:

1) Geology is simplified from Jennings and Burnett (1961), Koenig (1963), Strand and Koenig (1965), and Rogers (1966). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975).

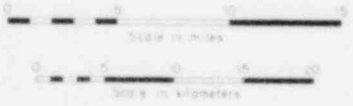
2) Information on fault activity (Quaternary activity and historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1975, for details).

3) Individual faults within the San Andreas fault zone show evidence of Quaternary and historic activity. (See Jennings, 1975, for details).

4) Heavy border on boxes indicates units that appear on this figure.

5) Earthquake magnitudes and epicentral locations are from Hudson, et al. (1969-1975 a and b).

Location of Geologic Map

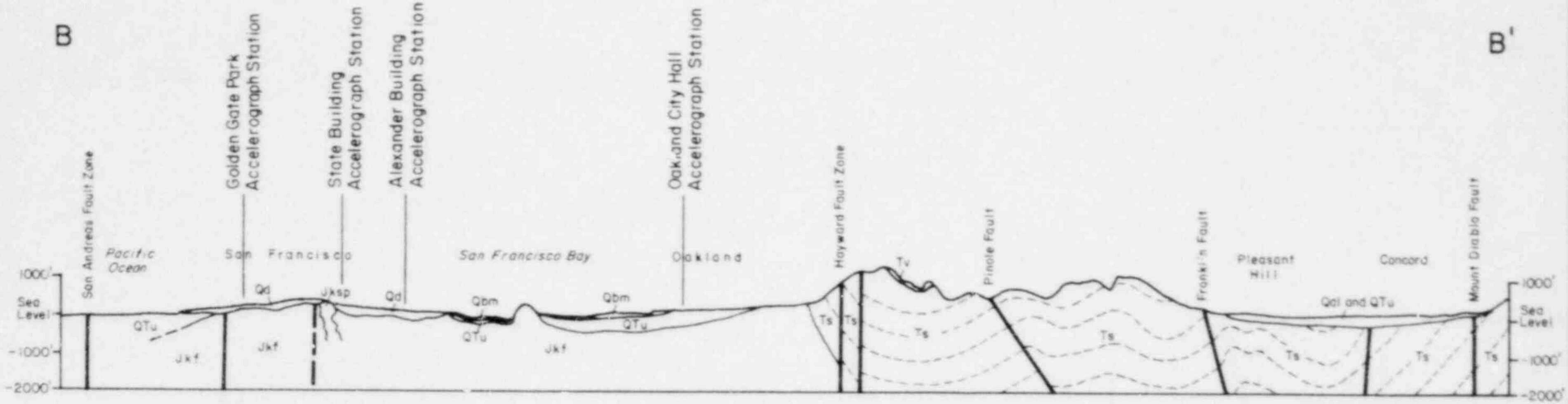


Submarine contour interval 1500 feet

STATION	CROSS-SECTION & FIG. NO.	
State Building (1)	B-B'	2-14
Alexander Building (2)	B-B'	2-14
Golden Gate Park (3)	B-B'	2-14
Oakland City Hall (4)	B-B'	2-14

GEOLOGIC MAP
SAN FRANCISCO REGION
CALIFORNIA

FIG. 2-13



Modified from Schlocker (1971) and Jennings and Burnett (1961)

EXPLANATION

Holocene	Qal	Alluvium and artificial fill (Qal)
Pleistocene to Holocene	Qbm	Bay mud; clayey to sandy organic silt (Qal)
	Qd	Dune sands (Qal)
Pliocene to Holocene	QTu	Undifferentiated unconsolidated sediments; includes the Merritt Sand and Alameda Formation in Oakland (Qal and Qt)
Pliocene	Tv	Moraga Formation; andesite and basalt flows, and rhyolite tuff (Tv)
early Pliocene to Eocene	Ts	Marine and non-marine sandstone, shale, siltstone, and conglomerate (Ts)
Cretaceous to Jurassic	Jkf	Franciscan Assemblage; complex of graywacke sandstone, shale, chert, conglomerate, greenstone, and glaucophane schist with associated bodies of serpentinite (Mz)
	Jksp	Serpentinite and serpentinized peridotite (Mz)

Notes:

1) Abbreviations in parentheses refer to geologic symbols used on Fig. 2-13.

2) For plan view of cross-section see Fig. 2-13.

0 2 4 6 8 10

Scale in miles

Vertical Exaggeration X 5.28

GEOLOGIC CROSS-SECTION B-B'
SAN FRANCISCO REGION

FIG. 2-14

LOG OF BORING

BORING NO. B-1

STATION LOCATION State Building, San Francisco, CA

SHEET 1 **OF** 2

BORING LOCATION Approximately 300' N. of State Building

SOURCE OF DATA[1] 1958 Dames & Moore foundation investigation for Federal Bldg.(Boring 4) -Logs in Woodward-Lundgren & Assoc. (1973)

EQUIPMENT USED NA

ELEVATION 67.6'

TOTAL DEPTH 217'

DATE DRILLED 7-11 August 1958

DEPTH IN FEET	LOG[2]	USC[2]	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	BLOWS/FT.
						16
		SP	(Medium to very dense ?), brown, fine to medium SAND.			
20 ▽						18
				20	100	35
				20	111	54
				21	109	55
40				19	110	78
				19	112	38
				18	113	37
		SM-SP	(Medium to dense ?),light brown,silty SAND.			
				23	99	47
		SP-SM	(Medium to dense ?),light brown,fine to medium SAND.			
60				21	110	37
				22	108	60
		SP	(Very dense ?), reddish-brown, fine to medium SAND.	20	125	90
80						
				21	112	150
				23	106	125
100						
		SC	(Dense ?), reddish-brown, clayey SAND.	19	114	55
				22	106	60
				20	105	94
120		SP-SM	(Very dense ?), reddish-brown, fine SAND, partly cemented.	21	110	80
				22	105	90
				25	104	167
		SP	(Grading brown and less fines)	25	102	136
				23	105	125
140						
		SP	(Grading fine to medium)			

FIG. 2-15

LOG OF BORING
(CONTINUATION)

BORING NO. B-1

STATION LOCATION State Building, San Francisco, CA

SHEET 2 OF 2

DEPTH IN FEET	LOG	USC	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	BLOWS/FT.
		SP-SM	(Very dense ?), reddish-brown, fine SAND, partly cemented.			
140						
				22	107	125
			(Grading without cementation).			
						250
160			(Grading partially cemented).			
				19	114	250
				21	110	250
180						
				19	112	55
		SC	(Very dense ?), mottled greenish gray and brown, clayey SAND with occasional fine gravel.	12	131	105
200		GC	(Very dense ?), yellowish-gray, clayey, sandy GRAVEL.			
		CL	(Hard ?), yellowish-brown, sandy CLAY with occasional small fragments of gray shale.	20	111	47
			Brown SHALE.			125
220			Bottom of Exploration.			

NOTES: 1) Original foundation engineering data has been modified for use in this report, including rewording of descriptions, omission of data, and format changes.

2) See Fig. 2-18 for explanations.

FIG. 2-15

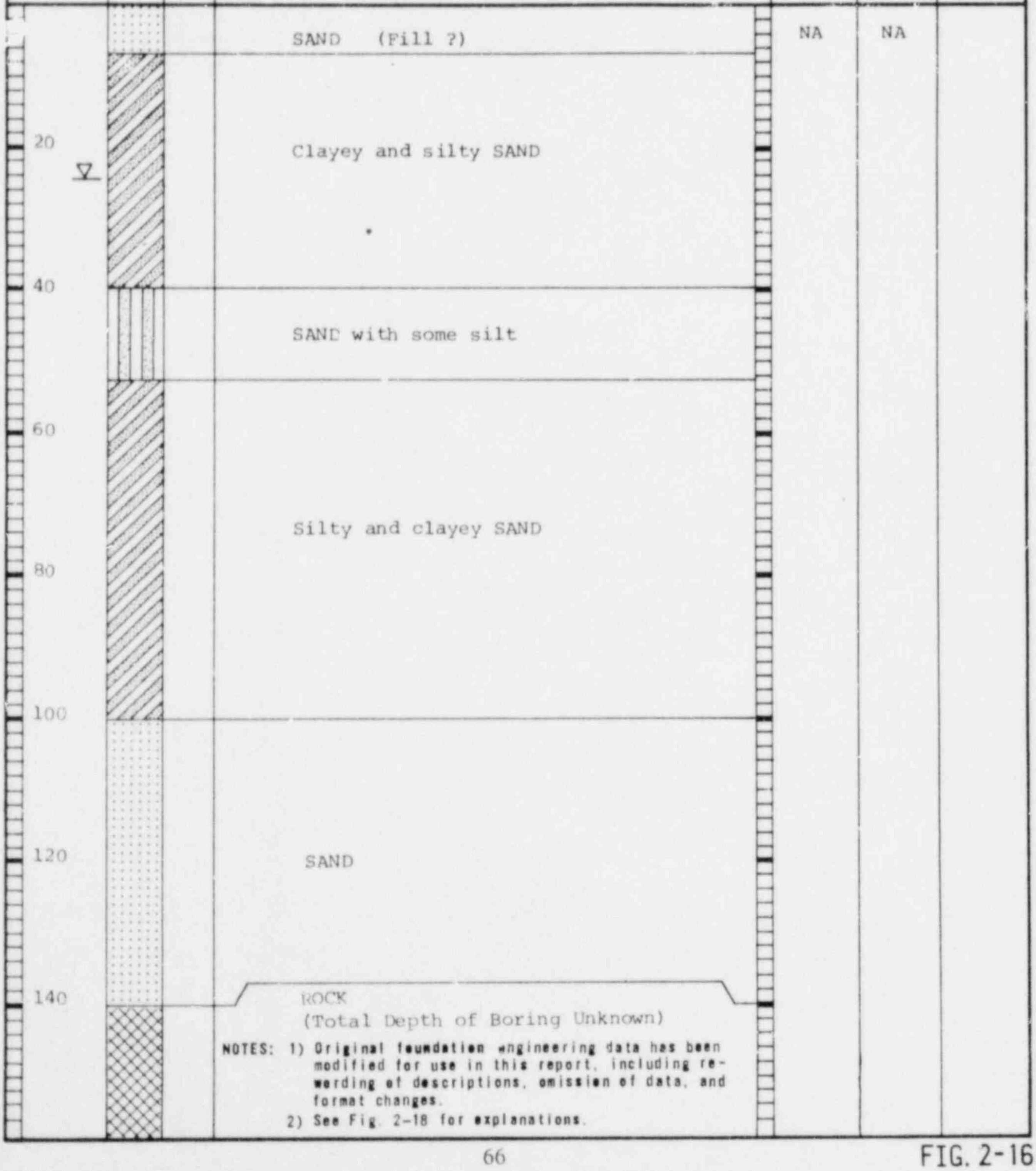
LOG OF BORING

BORING NO. B-2

STATION LOCATION	Alexander Building, San Francisco, CA	SHEET 1	OF 1
BORING LOCATION	NA		
SOURCE OF DATA[1]	Seed & Idriss (1969)		
EQUIPMENT USED	NA		

ELEVATION (site) Approx. 35 ft. MSL	TOTAL DEPTH NA	DATE DRILLED NA

DEPTH IN FEET	LOG[2]	USC[2]	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	
			SAND (Fill ?)	NA	NA	
			Clayey and silty SAND			
			SAND with some silt			
			Silty and clayey SAND			
			SAND			
			ROCK (Total Depth of Boring Unknown)			



NOTES: 1) Original foundation engineering data has been modified for use in this report, including rewording of descriptions, omission of data, and format changes.
2) See Fig. 2-18 for explanations.

FIG. 2-16

LOG OF BORING

BORING NO. B-3

STATION LOCATION	Oakland City Hall, Oakland, CA	SHEET 1 OF 3	
BORING LOCATION	At City Hall		
SOURCE OF DATA[1]	Woodward-Clyde-Sherard & Assoc. (1965) Log of Boring B-2 reprinted in Woodward-Lundgren & Assoc. (1973)		
EQUIPMENT USED NA	ELEVATION 36'	TOTAL DEPTH 91'	DATE DRILLED 1965

DEPTH IN FEET	LOG[2]	USC[2]	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	SPT BLOWS/FT
			4" concrete over loose to medium dense, clayey SAND base.			
5			Loose black silty SAND, becoming medium dense and brown below 4'.			
			Medium dense, yellow-brown, clayey SAND.			
10						
			Medium dense, yellow-brown SAND, with some clay, becoming dense with some clayey layers below 13'.	12	127	46
15						
20			Very dense, yellow-brown, fine to medium SAND, with some clayey layers.			
				16	116	130
25						
∇						
30						
				19	105	136
35						
			Very stiff, blue CLAY.			

FIG. 2-17

LOG OF BORING
(CONTINUATION)

BORING NO. B-3

STATION LOCATION Oakland City Hall, Oakland, CA

SHEET 2 OF 3

DEPTH IN FEET	LOG	USC	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	SPT BLOWS/FT.
40	▨		CLAY as above, becoming medium stiff and sandy below 39'.			
45	▨		Stiff to very stiff, gray-tan, silty CLAY, becoming sandy below 43'.	21	107	41
	▨		Stiff, gray, sandy CLAY.			
50 55	░		Dense, blue, fine SAND, with some clayey SAND and scattered gravel.	21	109	39
60	▨		Dense to very dense, yellow, clayey SAND.			
65	░		Very dense, yellow-brown SAND with pea gravel and some clay and silt.	13	122	73
	▨		Stiff, brown, sandy CLAY.			
70	░		Dense, brown SAND.			
75	░		Very dense, yellow-brown, gravelly coarse SAND.	11	120	72
	▨		Stiff to very stiff, gray, silty, sandy CLAY, with layers of stiff clay and dense SAND 2-3' thick.			

FIG. 2-17

LOG OF BORING
(CONTINUATION)

BORING NO. B-3

STATION LOCATION	SHEET 3 OF 3
Oakland City Hall, Oakland, CA	

DEPTH IN FEET	LOG	USC	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	SPT BLOWS/FT.
80	▨		CLAY as above.			
85	▨					
90	▨			21	109	72
			Bottom of Exploration			

NOTES: 1) Original foundation engineering data has been modified for use in this report, including rewording of descriptions, omission of data, and format changes.

2) See Fig. 2-18 for explanations.

FIG. 2-17

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 50% of material is LARGER than No. 200 sieve size)	GRAVELS (More than 50% of coarse fraction is LARGER than the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	GW	Well graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH FINES (Appreciable amt. of fines)	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS (More than 50% of coarse fraction is SMALLER than the No. 4 sieve size)	CLEAN SANDS (Little or no fines)	SW	Well graded sands, gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH FINES (Appreciable amt. of fines)	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE GRAINED SOILS (More than 50% of material is SMALLER than No. 200 sieve size)	SILTS AND CLAYS (Liquid limit LESS than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS AND CLAYS (Liquid limit GREATER than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils
ROCK 1)				Sandstone, siltstone, and shale
				Conglomerate

BOUNDARY CLASSIFICATION: Soils possessing characteristics of two groups are designated by combinations of group symbols.

1) Rock in the geologic sense (as shown in the logs of borings) often has physical engineering properties of stiff to hard soils.

Reference:
The Unified Soil Classification System, Corps of Engineers (1953).

LOG OF BORING EXPLANATION

FIG. 2-18

Section 3
San Luis Obispo Region

SECTION 3

SAN LUIS OBISPO REGION

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SECTION 3

SAN LUIS OBISPO REGION

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SECTION 3
SAN LUIS OBISPO REGION

3.1 INTRODUCTION

The San Luis Obispo region, located in coastal central California, extends across the Coast Ranges from the Pacific Coast to the western edge of the San Joaquin Valley, as shown in Fig. 1. This region, as defined for this study, includes Cholame and the city of San Luis Obispo and encompasses an area of approximately 6,000 square miles.

Two accelerograph stations in this region have been classified in the literature as "rock" sites, that is, stations which are supported on or within a few feet of rock (Table 1). These stations are the Temblor Station of the Cholame-Shandon Array and the San Luis Obispo City Recreation Building. The location and instrumentation; along with the geological, seismological, and the subsurface information; for each of these stations are described and illustrated in this section of the report. Ground motion time histories and response spectra are presented in the appendix for selected earthquakes recorded at the stations.

Seismological and geotechnical data for the Cholame No. 2 accelerograph station, including a 221-foot boring and geophysical shear wave velocity determinations, are presented in SW-AA (1975). The Cholame No. 2 station is located about 7 miles northwest of the Temblor site. Where applicable, the discussions of geology and seismicity in that report have been integrated into the present study.

3.2 STATION DESCRIPTIONS

3.2.1 Cholame-Shandon Array, Temblor

3.2.1.1 Location and housing structure. The Temblor strong motion accelerograph station (U.S.G.S. No. 1438) was originally located approximately 7 miles east of Cholame, California near the Antelope Pumping Station at the western end of Antelope Valley. The instrument was removed from this location in August 1969 and re-established approximately 7 miles to the northwest (Fig. 3-1) at the Temblor II site (U.S.G.S. No. 1097).

The Temblor station was originally located on a moderately sloping hillside, directly above the California Department of Water Resources Coastal Aqueduct tunnel through the Temblor Range. The original station was jointly established by the California Department of Water Resources and the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey on December 10, 1964. In August 1969, the station was moved to its present location, indicated as Temblor II in Fig. 3-1. At both sites the instrument was housed in a sheet metal, prefabricated shed on a 6-inch thick, concrete slab foundation. The slab dimension is unknown for the former Temblor station. Photographs of the instrument shed at Temblor II and of the geographic setting at the former Temblor site are presented in Fig. 3-2.

3.2.1.2 Instrumentation. The recording instrument at the Temblor station was an AR-240 triaxial accelerograph, Serial No. 139, manufactured by Teledyne-Geotech. This instrument remained in place until the station was relocated in 1969. According to Hudson, et al. (1969-1975a) the accelerograph had the following specifications at the time of the June 27, 1966, Parkfield earthquake:

Component Direction	Sensitivity (cm/g)	Period (sec)
N65W	7.64	.060
S24W	7.81	.058
Down	7.57	.060

The accelerograph was bolted to a cylindrical concrete pier that was poured simultaneously with the concrete floor slab of the housing structure. This pier was similar to the 1.2-foot high pier that can now be observed at the Temblor II station.

A photograph and plan view of the Temblor II station are presented in Fig. 3-3. No photograph of the former Temblor station is available.

3.2.2 San Luis Obispo City Recreation Building

3.2.2.1 Location and building. The San Luis Obispo strong motion station is in the basement of the City Recreation Building at 864 Santa Rosa Street. As shown in Fig. 3-4, this building is on the east corner of Santa Rosa and Mill Streets. It is a two-story, wood-frame structure with a partial basement which extends about 8 feet below grade. The building rests on a concrete slab-on-grade foundation.

The station (U.S.G.S. No. 1083) was established on October 26, 1948, under a cooperative effort by the U.S. Coast and Geodetic Survey and the city of San Luis Obispo. A photograph and plan view of the building are shown on Fig. 3-5.

3.2.2.2 Instrumentation. The recording instrument is a U.S. Coast and Geodetic Survey Standard triaxial accelerograph, Serial No. 2. The instrument records accelerations on 6-inch photograph paper. Hudson, et al. (1969-1975a) report the following specifications for the accelerograph at the time of the November 21, 1952, earthquake:

Component Direction	Sensitivity (cm/g)	Period (sec)
N36W	26.6	.098
S54W	31.8	.096
Up	26.3	.102

The accelerograph is located in a small room adjacent to the furnace room. The instrument is bolted to a 2-foot high, concrete pier; which is, in turn, cemented to the concrete floor slab of the building. A plan view of the room and a photograph of the instrument are shown on Fig. 3-6.

3.3 GEOLOGY AND SEISMICITY

3.3.1 Regional Geology

The San Luis Obispo region, as defined for this study and shown on Fig. 3-7, is located in coastal central California. Situated within the southern Coast Ranges province, the region is characterized by a wide belt of northwest-trending mountains and intermontane, alluvium-floored valleys. On the eastern edge of the region, the Coast Ranges merge with the flat-lying terrain of the San Joaquin Valley, and on the west they are bounded by a narrow coastal plain and the Pacific Ocean. This chain of mountains extends northward into Oregon, but ends abruptly to the south in Santa Barbara and Ventura Counties where it is terminated by the easterly topographic and structural trends of the Transverse Ranges.

Two types of basement rocks underlie the Coast Ranges at depth: a) a crystalline complex of lower (?) Cretaceous granitic and older metamorphic rocks (gr and m) (Fig. 3-7) and b) the Franciscan Assemblage, composed of a complex of Jurassic to Cretaceous sedimentary, volcanic, matamorphic, and associated ultramafic intrusive rocks (Mz) (Page, 1966). These two diverse basement complexes underlie three discrete tectonic blocks, separated by major faults. The crystalline complex, known as the "Salinian block", underlies a 25- to 30-mile wide belt between the San Andreas and Nacimiento-Sur faults, and Franciscan basement rocks underlie the crustal blocks to the west and east of these boundary structures.

Overlying both basement complexes and exposed in much of the region is a sequence of Cretaceous marine sedimentary rocks (K) and Tertiary shallow marine and continental sedimentary and volcanic strata (Ts and Tv). Plio-Pleistocene continental deposits (QP) unconformably mantle the older rocks throughout much of the region, as does Holocene stream alluvium (Qal) in many of the valleys and lowland areas.

The northwest-trending San Andreas and Nacimiento fault zones dominate the structural pattern of the San Luis Obispo region. Unlike the active strike-slip displacement on the San Andreas fault, movements on the Nacimiento fault appear to have been primarily vertical, and to have occurred prior to Quaternary time (Oakeshott, 1966).

The northwesterly topographic trend of the Coast Ranges is structurally controlled. Episodic folding, faulting, and uplift; probably beginning in late Jurassic time and culminating in the middle Pleistocene; has resulted in many northwest-trending faults and folds (Oakeshott, 1966). Several of the faults; including the Rinconada-San Marcos, San Juan-Red Hill, Huerhuero, and Chimeneas faults show evidence of Quaternary displacement but have no recorded historic activity (Jennings, 1975). On the other hand, the San Andreas fault zone has been very active in historic time.

3.3.2 Seismicity

The San Luis Obispo region has a moderately high degree of continuing seismicity. Historically, the region has been subjected to frequent earthquakes of moderate intensity. Five earthquakes have been accompanied by ground rupture along the segment of the San Andreas fault zone within the region (Jennings, 1975; and Greensfelder, 1972). The largest of these earthquakes, the 1857 Fort Tejon earthquake, was located about 75 miles south of the San Luis Obispo region and had an intensity of X-XI (MM). Other temblors occurred in 1901, 1922, 1934, and 1966. The June 27, 1966, Parkfield earthquake had a magnitude of 5.6. It was accompanied by surface rupture along the San Andreas fault extending about 20 miles northward from the town of Cholame (Jennings, 1975). The epicenter of this event is shown on Fig. 3-7.

The San Luis Obispo region was also shaken by the 1952 Arvin-Tehachapi earthquake. This shock had a Richter magnitude of 7.7 and resulted from movement on the White Wolf fault about 70 miles southeast of the region.

3.3.3 Local Geology

3.3.3.1 Cholame-Shandon Array, Temblor. The Temblor accelerograph station site is located in the Temblor Range approximately 5 miles northeast of the San Andreas fault zone. The local geology of the site is depicted on the Geologic Cross-Section C-C', Fig. 3-8.

The site vicinity is underlain at depth by the Franciscan Assemblage and associated ultramafic intrusives, primarily serpentinite and serpentinized peridotite. Overlying this basement complex is a thick sequence of Cretaceous marine sandstone and shale, comprising the Gravelly Flat and Panoche Formations. These rocks are, in turn, unconformably overlain by Tertiary marine sandstones and shales that locally include the Temblor Formation and the Monterey Shale.

Plio-Pleistocene non-marine deposits mantle both the Tertiary strata and Franciscan rocks a few miles west of the site. These deposits, known as the Paso Robles Formation, are relatively flat lying in this area but have been disturbed by faulting and minor warping. Quaternary alluvium and fan deposits cover the floor of Antelope Valley to the north and east of the site (Jennings, 1958).

The accelerograph station site is located on a northwest-trending faulted anticline. This anticline is breached by Mesozoic ultramafic intrusives, mostly highly sheared serpentinite (Jennings, 1958). The ultramafic rocks are juxtaposed by faulting against younger strata on all sides. The younger rocks, Cretaceous to Miocene in age, dip eastward and westward away from the fault contact with the ultramafics, displaying a piercement structure geometry characteristic of parts of the Diablo Range to the north.

3.3.3.2 San Luis Obispo City Recreation Building. San Luis Obispo is located in Los Osos Valley in San Luis Obispo, County, approximately 20 miles east of the Pacific Ocean. This valley lies between the Santa Lucia Range to the northeast and the San Luis Range to the southwest, all part of the northwest-trending Coast Ranges. The local geology of the San Luis Obispo area is depicted on the Geologic Cross-Section D-D' (Fig. 3-9).

Los Osos Valley is underlain by Holocene alluvial deposits consisting primarily of gravel, sand, and silt. Franciscan basement rocks, widely distributed and exposed in the surrounding hills and mountainous areas, are mantled by the alluvium in this lowland area. They consist of a complex of graywacke sandstone, shale, chert, greenstone, and basalt. These Jurassic to Cretaceous rocks are commonly highly sheared and are intruded by bodies of serpentinite and associated ultramafic rocks.

The Franciscan Assemblage is unconformably overlain in some areas by Cretaceous and Tertiary marine strata. The Cretaceous strata include an unnamed sequence composed mostly of sandstone, shale, and pebble conglomerate that is exposed in the San Lucia Ranges (Dibblee, 1974). The Tertiary rocks include the Vaqueros (?) Sandstone, the Monterey Shale, the Santa Margarita Formation, and dacite porphyry intrusives, all of Oligocene to Miocene age. These Tertiary strata, composed mostly of sandstone and shale, are exposed in the Santa Lucia and the San Luis Ranges, where they unconformably overlie both the unnamed Cretaceous strata and the Franciscan Assemblage.

Crystalline basement rocks underlie the area to the northeast of the Nacimiento fault, although they are not exposed west of the Rinconada fault. These crystalline rocks are composed mostly of granodiorite and quartz monzonite (Dibblee, 1974).

The structural features of the San Luis Obispo area conform to the overall structure of the southern Coast Ranges; the city lies within a belt of northwest-trending folded and faulted mountains and intermontane valleys. The San Andreas fault zone, which is the most prominent structural feature in the region, is located about 35 miles northeast of San Luis Obispo. This major crustal break has undergone surface displacement several times in the last 200 years (Jennings, 1975). Numerous other strike-slip faults associated with the San Andreas system, including the Rinconanda fault, are present nearby. Faulting related to this system, which probably had its beginnings at least 12 million years ago in Miocene time (Crowell, 1975), is locally expressed in the displacement of Quaternary deposits along the Rinconada fault (Jennings, 1975).

The Nacimiento fault zone is situated immediately east of San Luis Obispo; at its closest approach, it is less than 2 miles from the accelerograph station. This fault zone extends northwesterly to Monterey Bay in a complex pattern of slices. The Nacimiento fault zone separates the Franciscan basement complex on the west from the crystalline basement rocks on the east. Although it is known to be a boundary between major crustal blocks underlain by these distinct and incompatible basement rocks, the fault zone's structural characteristics are not fully understood. Jennings (1975) has indicated that some of the individual faults within the Nacimiento fault zone are part of the Coast Range thrust fault, which he describes as a "long-inactive, late Mesozoic subduction zone". Whatever the structural characteristics of the fault zone, there has been no known displacement on it since before Quaternary time (Jennings, 1975).

3.4 CATALOG OF SEISMIC EVENTS

The San Luis Obispo region is an area of moderately strong and frequent seismicity, dominated by the seismically active San Andreas fault zone in the eastern part of the region (Fig. 3-7). Movements along this fault have produced numerous earthquakes in historic time, some of which are discussed in Section 3.3.1.

The Temblor and San Luis Obispo accelerograph stations have obtained only a limited number of earthquake records, owing in part to the relatively short period of time they have been in existence. The San Luis Obispo station was established in 1948 and the Temblor station in 1964. During that period of time, four separate events were recorded in the region, the most significant of which was the magnitude 5.6 Parkfield earthquake of June 27, 1966. The largest event recorded was the Arvin-Tehachapi earthquake of July 21, 1952, which had a Richter magnitude of 7.7, although locally the recorded accelerations were less than those of the Parkfield event.

A list of selected earthquakes recorded at the two stations is presented in the appendix (Table A3-1). Selected ground motion time histories and their corresponding response spectra are presented in Fig. A3-1 through Fig. A3-18 of the appendix.

3.5 FIELD EXPLORATIONS

The San Luis Obispo region accelerograph station sites discussed in this chapter were visited to verify published information and gather additional details about the instrumentation, housing units, and site conditions. At each of the sites, the instrumentation and housing structure were photographed and details were gathered on the housing structure and instrumentation history. Also, a brief geologic reconnaissance was made in the vicinity of each site to verify the presence of rock and other units shown on published geologic maps. A 45-foot boring was advanced in the vicinity of the San Luis Obispo City Recreation Building to provide more detailed information on the subsurface conditions. Subsurface conditions at the Temblor sites were adequately verified with the geologic site reconnaissance and borings were not required at these locations.

3.6 SITE SUBSURFACE CONDITIONS

3.6.1 Cholame-Shandon Array, Temblor

The original Temblor accelerograph station was situated on a hillside underlain by serpentinite and serpentinized peridotite. At this location, these ultramafic rocks occur either as an injected sill-like body or in depositional contact within the shales of the Gravelly Flat Formation (Dibblee, 1973). The serpentinite and serpentized periodotite are moderately weathered at the surface and are highly sheared and brecciated throughout. These ultramafic rocks vary from moderately hard to hard below a thin zone of weathering.

The Temblor II accelerograph station (the present instrument location) is situated several miles from the original Temblor site, on a slope underlain by sandstone, siltstone, and shale of the Miocene Monterey Shale. These sedimentary strata are medium to moderately hard in an adjacent road-cut exposure and are overlain by a few feet of residual soil cover at the station.

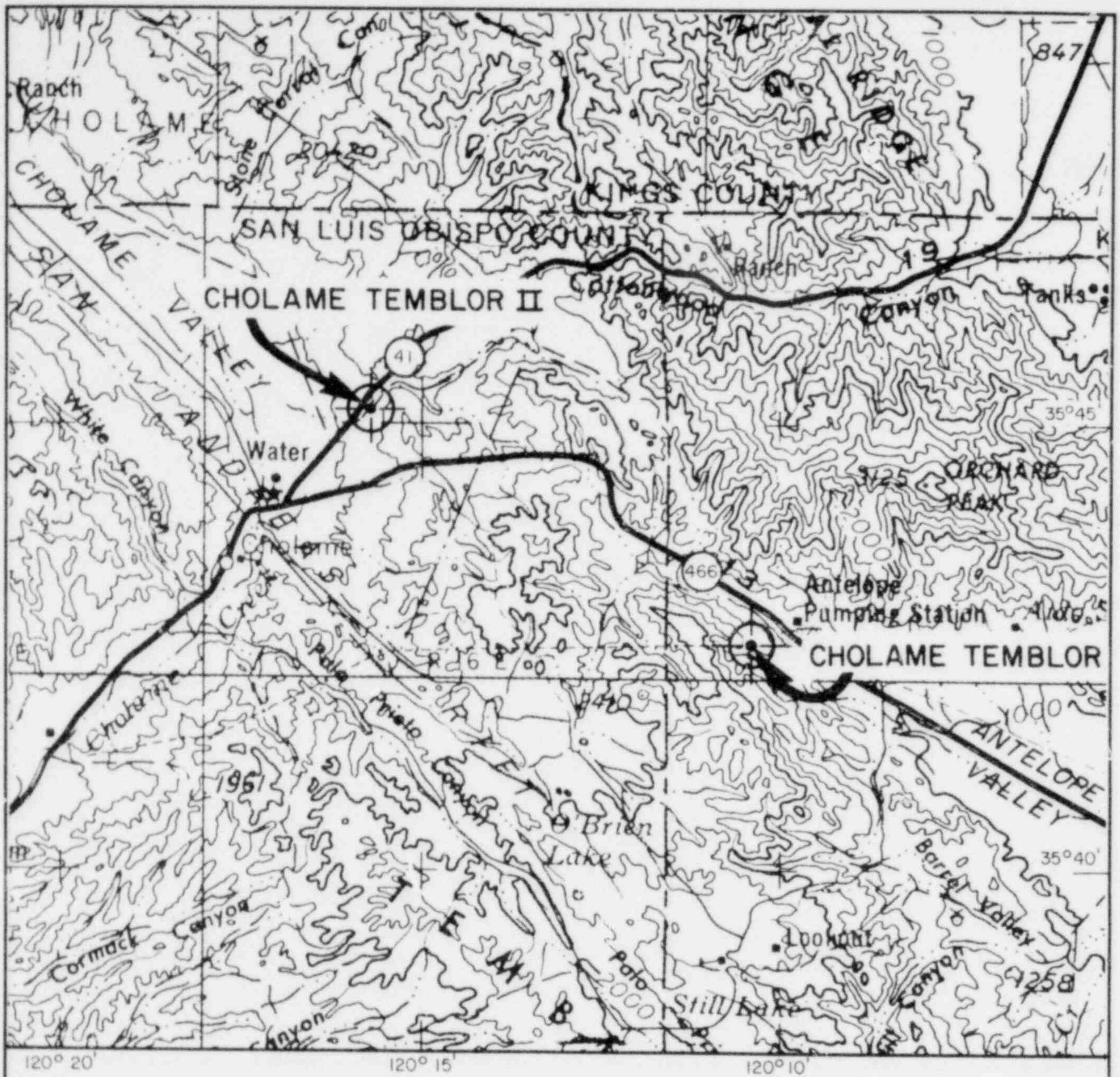
3.6.2 San Luis Obispo City Recreation Building

Subsurface conditions at the site were generalized from a 45-foot boring advanced adjacent to the northeast corner of the City Recreation Building. The materials encountered in this boring (Fig. 3-10) were 17.5 feet of alluvium overlying bedrock of the Franciscan Assembledge. A stiff to very stiff (?) silty clay with scattered fine gravel was encountered in the upper 17.5 feet of the boring. Below this depth, soft shale with some lenses of sandstone was encountered. It was inferred through drilling action that the shales became medium hard below a depth of about 40 feet.

Duke and Leeds (1972) report the following shear wave velocities for the materials at the City Recreation Building (site 62):

Depth (ft.)	Shear Wave Velocity (ft./sec.)
0- 5	1,024
5-21	1,727
21-80	2,599
more than 80	7,949

Shear wave velocities to a depth of about 20 feet correspond to surface refraction measurements. Velocities below this depth were estimated from the site geology. These velocities seem reasonable and in general agreement with the materials encountered in the boring B-4 (Fig. 3-10).



CHOLAME TEMBLOR (discontinued)

USGS Topographic Quadrangle:	Orchard Peak, California
Coordinates:	35° 42' 36" N. 120°10' 12" W.
Location:	South side of Highway 466 across from Antelope Pumping Station.
Structure:	Metal prefabricated instrument shelter.

CHOLAME TEMBLOR II

USGS Topographic Quadrangle:	Cholame Valley, California
Coordinates:	35° 45' 07" N. 120°15' 52" W.
Location:	South side of Highway 41, 4 miles east of Cholame.
Structure:	Metal prefabricated instrument shelter.

STATION LOCATION PLAN
CHOLAME-SHANDON ARRAY
TEMBLOR AND TEMBLOR II
CHOLAME, CALIFORNIA

FIG. 3-1

Former Instrument Shelter Location
Temblor, U.S.G.S. Station 1438
View to the Southwest from Hwy. 466

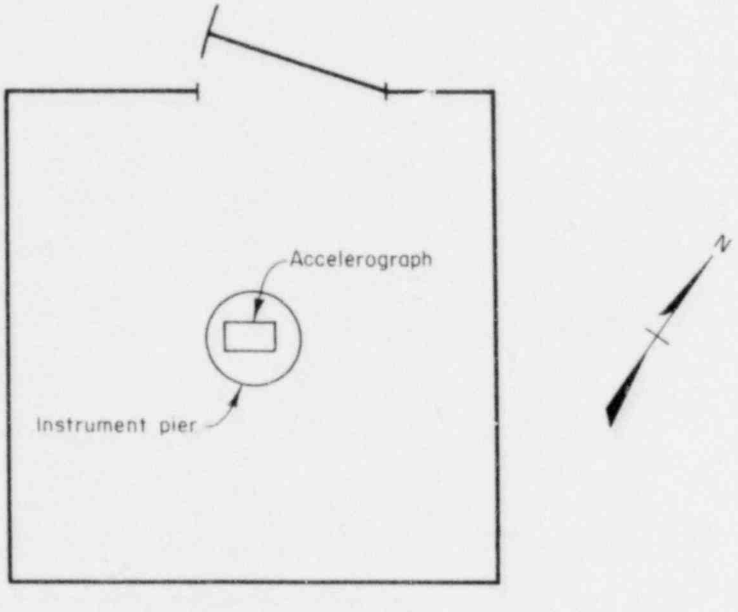
Instrument Shelter Location
Temblor II, U.S.G.S. Station 1097
View to the Southwest

Note: Instrument shelter plan for Temblor II
is shown on Fig. 3-3.

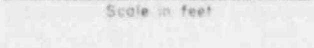
ACCELEROGRAPH STATION
CHOLAME-SHANDON ARRAY
TEMBLOR AND TEMBLOR II
CHOLAME, CALIFORNIA

FIG. 3-2

SMA-1 Accelerograph
U.S.G.S. Station 1097



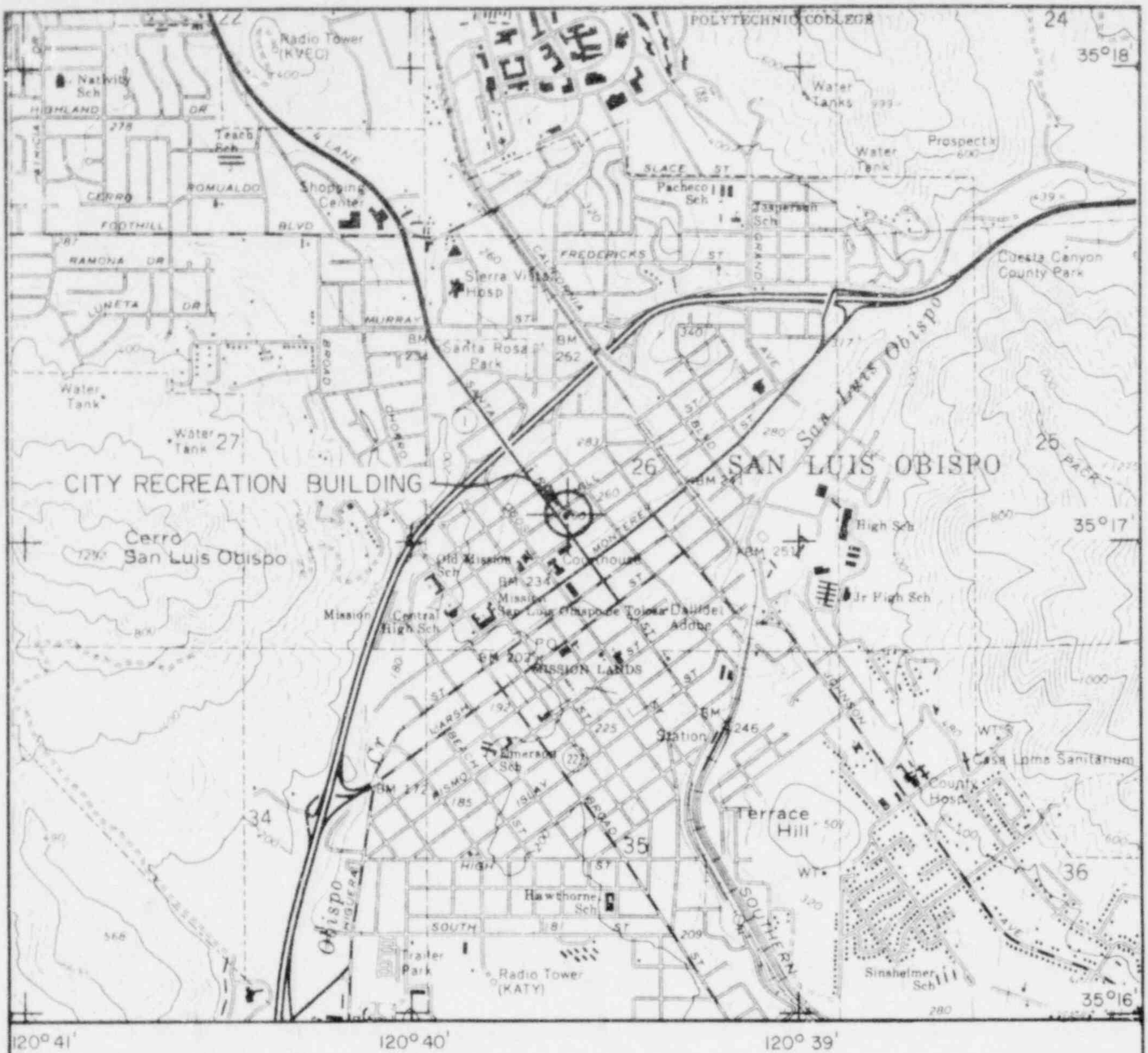
Instrument Shelter Floor Plan



Notes:
1) Temblor II station is similar to discontinued Temblor station except for instrumentation.
2) Location of instrument shelter is shown on Fig. 3-2.

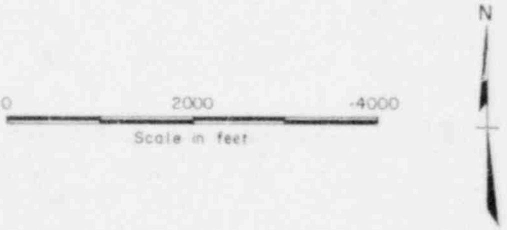
STATION INSTRUMENTATION
CHOLAME-SHANDON ARRAY
TEMBLOR II
CHOLAME, CALIFORNIA

FIG. 3-3



CITY RECREATION BUILDING

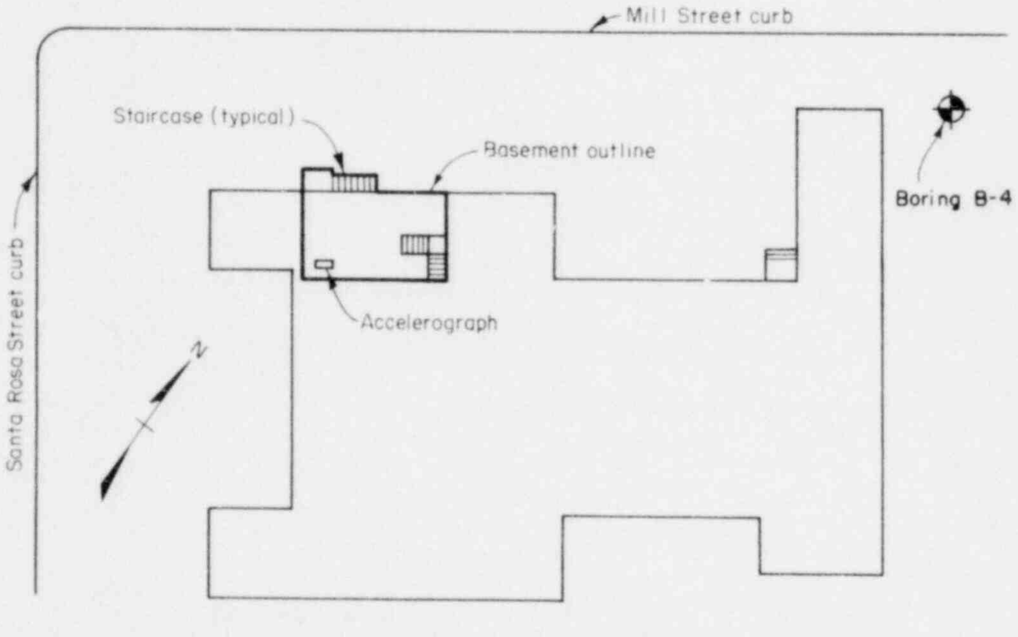
USGS Topographic Quadrangle:	San Luis Obispo, California.
Coordinates:	35° 17' 04" N. 120°39'36" W.
Location:	Southeast corner of Santa Rosa and and Mill Streets.
Structure:	Two-story wooden frame building with partial basement.



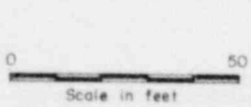
STATION LOCATION PLAN
CITY RECREATION BUILDING
SAN LUIS OBISPO, CALIFORNIA

FIG. 3-4

City Recreation Building
View to the East from
Santa Rosa and Mill Streets



Building Floor Plan

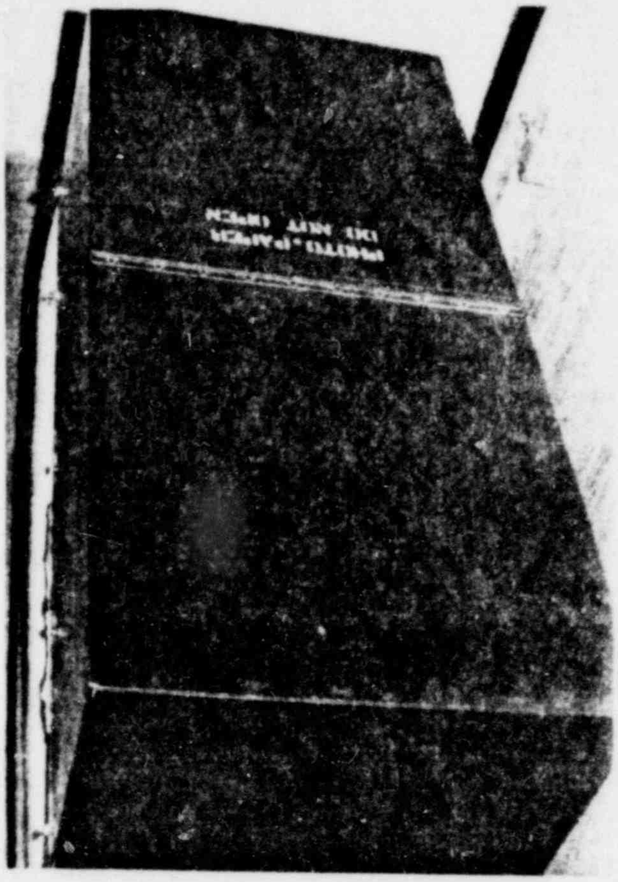


Notes: 1) Basement floor plan is shown on Fig. 3-6.

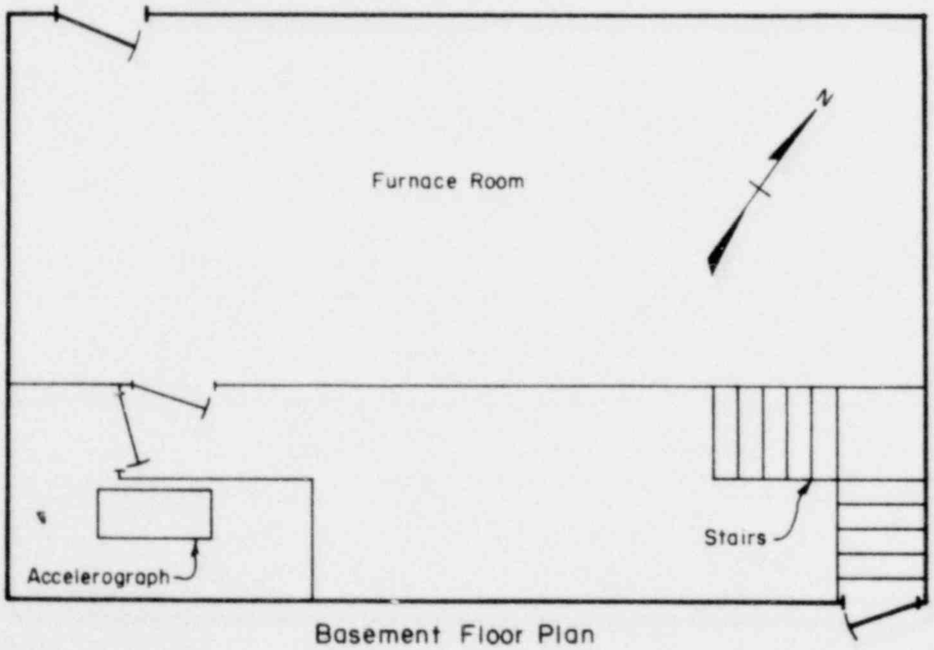
2) See Fig. 3-10 for Log of Boring B-4

ACCELEROGRAPH STATION
CITY RECREATION BUILDING
SAN LUIS OBISPO, CALIFORNIA

FIG. 3-5



U.S. Coast and Geodetic Survey
Standard Accelerograph, U.S.G.S. Station 1083

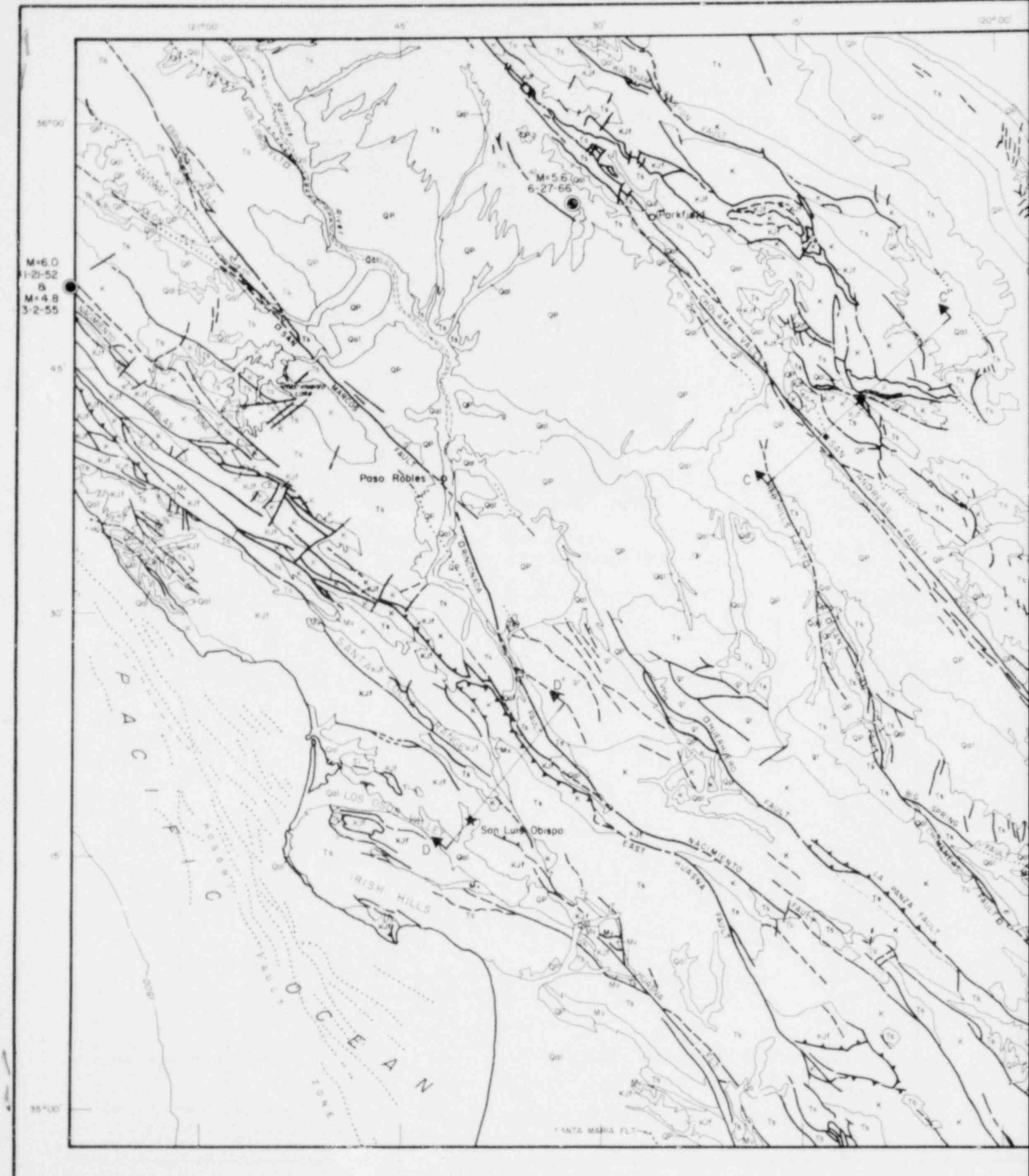


Basement Floor Plan

Note: Location of basement within the structure is shown on Fig. 3-5

STATION INSTRUMENTATION
CITY RECREATION BUILDING
SAN LUIS OBISPO, CALIFORNIA

FIG. 3-6


121°00'
45'
30'
15'
120°00'
36°00'
45'
30'
15'
35°00'
M=6.0
11-21-52
&
M=4.8
3-2-55
M=5.6
6-27-66
Parkfield
Paso Robles
San Luis Obispo
C
C'
D
D'
SAN MARCOS FAULT
RINCONADA FAULT
CHOLAME VALLEY
SAN ANDREAS FAULT ZONE
RED HILLS FAULT
SANTA LUCIA RANGE
LOS OSOS VALLEY
IRISH HILLS
EAST HUASNA FAULT
NACIMIENTO FAULT
LA PANZA FAULT
BIG SPRING
PACIFIC OCEAN
HOSGRI FAULT ZONE
SANTA MARIA FLT
Qal
QP
Ts
K
KJf
Mv

EXPLANATION

Qal	Alluvium, Quaternary in age (Includes terrace, alluvial fan, lake, and dune deposits)
QP	Paso Robles Formation, Plio-Pleistocene in age
Ts	Sedimentary rocks, Tertiary in age
Mv	Volcanic rocks, Miocene in age
Ti	Igneous intrusive rocks, Tertiary in age
K	Sedimentary rocks, Cretaceous in age
KJf	Franciscan Assemblage, Mesozoic in age (Includes associated serpentinite and ultramafic rocks)
gr	Granitic rocks, Mesozoic in age (Includes associated metamorphic rocks)
m	Metamorphic rocks, pre-Cretaceous in age

★	Accelerograph Station location
● M=5.6 6-27-66	Epicenter location, magnitude (Richter) and date of occurrence
□	Faults having moved during Quaternary time without historic record (approximately 2 million years)
■	Faults having moved during historic time, (approximately 200 years)
Contact	Dashed where approximately located
Fault	Dashed where approximately located, dotted where concealed
Thrust Fault	Barbs on upper plate, dashed where approximately located
Offshore Fault	Location approximate.

NOTES

1) Geology is simplified from Jennings (1958), Smith (1964), Matthews and Burnett (1965) and Strand (1958). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975).

2) Information on fault activity (Quaternary and historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. All faults with Quaternary activity have not been so indicated on this figure. (See Jennings, 1975, for details)

3) Individual faults within the San Andreas fault zone show evidence of Quaternary and historic activity. (See Jennings, 1975, for details)

4) Earthquake magnitude and epicentral location are from Hileman, Allen, and Norquist (1973).

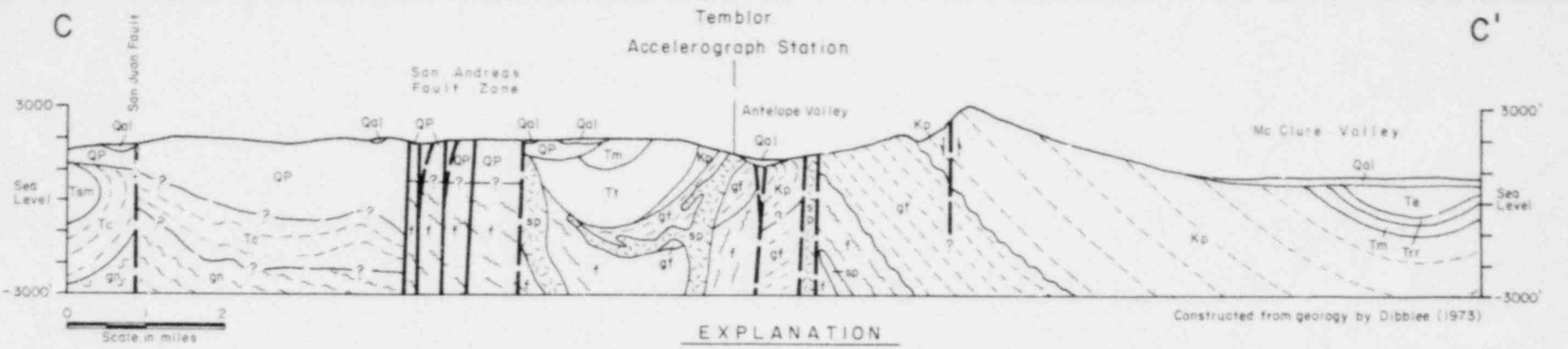
Location of Geologic Map

Submarine contour interval 1500 feet

STATION	CROSS SECTION & FIG. NO.
Cholame-Shandon Array, Temblor	C-C' 3-8
City Recreation Building	D-D' 3-9

GEOLOGIC MAP
SAN LUIS OBISPO REGION
CALIFORNIA

FIG. 3-7



Constructed from geology by Dibblee (1973)

EXPLANATION

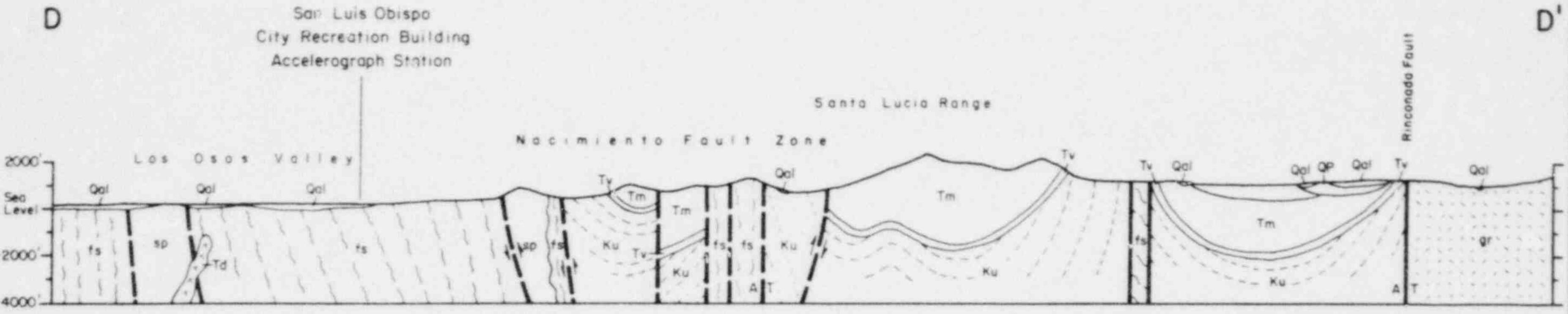
Holocene	Qal	Alluvium; gravel, sand, and silt (Qal)
Pliocene to Pleistocene	QP	Paso Robles Formation; non-marine gravel, sand, and thin-bedded lacustrine clays (QP)
Pliocene	Te	Etchegoin Formation; blue to gray sandstone and siltstone (Ts)
Miocene	Trr	Reef Ridge Shale (Ts)
	Tsm	Santa Margarita Formation; marine, friable sandstone, conglomerate and some shale (Ts)
	Tm	Monterey Shale; marine shale, siliceous shale, diatomite, and sandstone (Ts)
Oligocene(?), Miocene, and Pliocene	Tc	Caliente Formation; terrestrial soft mudstone, siltstone, sandstone, and conglomerate (Ts)
Oligocene and Miocene	Tt	Temblor Formation; marine sandstone and shale, known as the Vaqueros Formation southwest of the San Andreas fault zone (Ts)
upper Cretaceous	Kp	Panoche Formation; marine sandstone, shale, and claystone (K)
upper Jurassic(?) and lower Cretaceous	gf	Gravelly Flat Formation; mostly shale (K)
Jurassic or Cretaceous	sp	Serpentinite and serpentinized peridotite (KJf)
	f	Franciscan Assemblage; pervasively sheared graywacke sandstone and claystone, with lenses of chert, limestone, and glaucophane schist (KJf)
Mesozoic or Old.r	gn	Gneissic rocks; includes granitic and other crystalline basement rocks southwest of the San Andreas fault zone

Notes: 1) Abbreviations in parentheses refer to geologic symbols used on Fig. 3-7.

2) For plan view of cross-section see Fig. 3-7.

GEOLOGIC CROSS-SECTION C-C'
CHOLAME-SHANDON ARRAY, TEMBLOR
CHOLAME, CALIFORNIA

FIG. 3-8



Constructed from geology by Dibblee (1974)

EXPLANATION

Holocene	Qal	Surficial deposits, including Recent and older alluvium (Qal)
Pleistocene and Pliocene?	QP	Paso Robles Formation; non-marine sand and gravel (QP)
Miocene	Tsm	Santa Margarita Formation; marine white sandstone with some conglomerate (Ts)
	Tm	Monterey Shale; marine siliceous shale, silty shale, clayey shale with thin carbonate beds (Ts)
Oligocene or Miocene	Tv	Vaqueros(?) Sandstone; sandstone and conglomerate (Ts)
	Td	Dacite porphyry (intrusive)
Cretaceous	Ku	Marine sedimentary rocks; includes sandstone, shale, and pebble conglomerate (K)
Jurassic or Cretaceous	sp	Serpentinite (JKf)
	fs	Franciscan Assemblage includes graywacke sandstone, chert, greenstone or basalt and shale. Locally pervasively sheared (KJf)
Mesozoic	gr	Granitic rocks; granodiorite to quartz monzonite (gr)

Notes:

1) For plan view of cross-section see Fig. 3-7.

2 Abbreviations in parentheses refer to geologic symbols used on Fig. 3-7.

3) Structural interpretations by Dibblee (1974) vary from those presented by Jennings (1975).

GEOLOGIC CROSS-SECTION D-D'
CITY RECREATION BUILDING
SAN LUIS OBISPO, CALIFORNIA

FIG. 3-9

LOG OF BORING

BORING NO. B-4

STATION LOCATION: City Recreation Building, San Luis Obispo, CA

SHEET 1 OF 1

BORING LOCATION: Adjacent to N.E. corner of City Recreation Building (See Fig. 3-5)

SOURCE OF DATA: Shannon & Wilson (1977b)

EQUIPMENT USED: Truck mounted, Mobile B-40 solid stem auger (4"dia. continuous flight)

ELEVATION: Approx. 260' MSL

TOTAL DEPTH: 45'

DATE DRILLED: 30 September 1976

DEPTH IN FEET	LOG	USC	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	
10	▨		Stiff (?) to very stiff (?), gray and brown, silty CLAY with scattered fine gravel.	13	113	
20 30 40	▦		SHALE: Soft, gray to dark gray, with lenses of medium to hard sandstone. (Firmer drilling and drier material below [illegible] feet). Becoming medium hard below 40 feet (difficult drilling).	7 4	135 150	
50			Bottom of Exploration.			

NOTES: 1) **Grab samples were taken from the auger flights at selected depth intervals for material identification. No laboratory tests were performed on the samples.**

2) **Moisture contents and dry densities from Duke and Leeds (1972).**

FIG. 3-10

Section 4
Santa Barbara Region

SECTION 4
SANTA BARBARA REGION

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 4
SANTA BARBARA REGION

4.1 INTRODUCTION

The Santa Barbara region is defined for this report as an area on the southern California coast within about 40 miles of the city of Santa Barbara (Fig. 1). It lies mostly within Santa Barbara and Ventura Counties and includes parts of the east-trending Santa Ynez and San Rafael Mountains and southern-most Coast Ranges. The Santa Barbara Channel and Channel Islands are encompassed in the southern part of the region.

One accelerograph station in the Santa Barbara region has been classified in the literature as a "rock" site; that is, a station which is supported on, or within a few feet of rock (see Table 1). This station is at the University of California, Santa Barbara campus at Goleta. The location and instrumentation along with geological, seismological, and subsurface information for this station are discussed and illustrated in this section of the report. Ground motion time histories and corresponding calculated response spectra recorded at the station during the February 9, 1971, San Fernando earthquake are presented in the appendix.

The Santa Barbara County Courthouse strong motion station was previously studied in SW-AA (1976b). Where applicable, the discussions of geology and seismicity in that report have been integrated into the present study.

4.2 STATION DESCRIPTION

4.2.1 Fluid Mechanics Lab, U.C. Santa Barbara, Goleta

4.2.1.1 Location and building. The accelerograph station at U.C. Santa Barbara was in the Arts Building on the southwest side of the campus. This location, shown on Fig. 4-1, has an elevation of approximately 30 feet (MSL), and is about 2,000 feet from the ocean shoreline.

The Arts Building is a two-story, reinforced-concrete and concrete block building with a partial basement. It rests on spread footings and a concrete floor slab. The strong motion instrument was located in the basement in an area designated as the Fluid Mechanics Laboratory. This area of the basement is about 15 feet below grade. A photograph and plan view of the building are shown on Fig. 4-2.

The strong motion station (U.S.G.S. No. 282) was established prior to February 1971 by a joint effort of the California Institute of Technology and the former Seismological Field Survey unit of the National Oceanic and Atmospheric Administration (NOAA). The station was abandoned on April 13, 1976, when the instrument was removed for remodeling of the building. The U.S. Geological Survey currently has no plans to re-establish the station.

4.2.1.2 Instrumentation. The recording instrument originally installed in the Fluid Mechanics Laboratory at U.C. Santa Barbara was an RFT-250 triaxial accelerograph, Serial No. 183, manufactured by Teledyne-Geotech. It remained at the station until February 7, 1973, when it was replaced by an SMA-1 triaxial accelerograph, Serial No. 475. This instrument, which was manufactured by Kinemetrics, Inc., was removed on October 4, 1973. At that time, another RFT-250 accelerograph, Serial No. 201, was installed in the same location as the other instruments. This last instrument remained in place until the station was abandoned on April 13, 1976. Each of the accelerographs used at the station was bolted to the 4-inch thick concrete floor slab of the basement (Fig. 4-3).

The RFT-250, Serial No. 183, that recorded the February 9, 1971, San Fernando earthquake had the following characteristics (Hudson, et al., 1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
N42E	1.9	.045
S48E	1.9	.045
Up	1.9	.046

4.3 GEOLOGY AND SEISMICITY

4.3.1 Regional Geology

The Santa Barbara region includes parts of Santa Barbara, Ventura, and Kern Counties in coastal southern California, as depicted on the Geologic Map, Fig. 4-4. The region lies principally within the western Transverse Ranges province, a belt of east-trending mountain ranges and valleys, so named because its features are transverse to the general northwestward trend of California's landscape. The Transverse Ranges merge with the Coast Ranges province about 20 miles north of Santa Barbara. They include the Santa Barbara Channel and Channel Islands to the south, which are oceanward extensions of the Ventura basin, and the Santa Monica Mountains, respectively. The Transverse Ranges extend as far as Riverside County to the east and westward to the Pacific Ocean. Northeast of the Transverse Ranges, and also included within the Santa Barbara region, are the southernmost Great Valley and Sierra Nevada provinces.

East of the region, the Transverse Ranges are underlain by Precambrian to Mesozoic crystalline basement rocks (Bailey and Jahns, 1954). A wide variety of complexly related lithologies are present in this core complex, but granitic and gneissic rocks are predominant (P€ g and gr on Fig. 4-4). Further west, the Jurassic to Cretaceous Franciscan Assemblage (Mz); which consists of a highly sheared complex of graywacke, shale, chert, greenstone, and ultramafic intrusives; is apparently the prevalent basement rock (Jennings and Strand, 1969; and Dibblee, 1966b).

The Franciscan rocks are exposed in very few locations in the Santa Barbara region. They are mostly buried under a thick sequence of Cretaceous to Plio-Pleistocene sedimentary rocks of marine and non-marine origins (K, Ts, and QP), (Dibblee, 1966a). These strata, which locally exceed 30,000 feet in thickness, are interbedded with a small amount of Tertiary volcanic rocks (Tv) in parts of the region (Jennings and Strand, 1969). The marine sedimentary strata consist mostly of varieties of sandstone and shale, whereas the non-marine deposits include gravel and conglomerate as well.

The Quaternary Period is represented in lowland areas by upper Pleistocene conglomerates (Qf) and terrace deposits (Qt). Holocene alluvium (Qal) underlies the present floodplains of major streams, particularly on the coastal plain.

The Santa Barbara region is intensely faulted and folded along an easterly trend, the result of tremendous north-south compressive forces active during Pliocene and Quaternary time (Dibblee, 1966b). Many faults have been active during Quaternary time as a result of these crustal stresses; among them are the Santa Ynez, Pine Mountain, Mission Ridge, and Little Pine faults. Historic displacement (within the last 200 years) has been detected on a few faults in the region, including the Mesa and Big Pine faults in the Transverse Ranges and in the northeastern part of the region, the White Wolf fault and the highly active San Andreas fault zone (Jennings, 1975).

4.3.2 Seismicity

The Santa Barbara region is in an area of moderately high continuing seismicity. A magnitude 6.25 earthquake severely damaged Santa Barbara on June 29, 1925, and a magnitude 5.9 earthquake occurred in an area just east of the city on June 30, 1941. These earthquakes may have been caused by movement along the Mesa fault or its seaward projection. On July 21, 1952; high-angle, oblique displacement along the White Wolf fault caused one of the most severe earthquakes recorded in southern California, registering a magnitude of 7.7 on the Richter scale. The San Fernando earthquake of February 9, 1971, with a Richter magnitude of 6.4, was also recorded in this area. It resulted from displacement along the San Fernando fault located beyond the Santa Barbara region to the east.

4.3.3 Local Geology

The University of California Santa Barbara campus is located on Goleta Point along a narrow coastal plain between the Santa Barbara Channel and the Santa Ynez Mountains. The geology of this area is depicted on the Geologic Cross-Section, E-E', Fig. 4-5.

The coastal plain is approximately 5 miles wide near the campus. It is underlain by a generally southward-dipping sequence of Oligocene to Pliocene sedimentary strata that overlie the older rocks or the Santa Ynez Mountains. These strata are unconformably overlain by Pleistocene alluvial deposits that, in turn, are overlain by Holocene alluvium.

The strong motion station is underlain by an undetermined thickness of the Pliocene Sisquoc Formation. This formation is composed of soft, laminated, diatomaceous siltstone and shale. The Sisquoc Formation rests disconformably on the Miocene Monterey Shale, which consists primarily of hard siliceous shale with lesser amounts of bentonite clay and punky shale. The Monterey Shale, in turn, overlies a thick sequence of Tertiary strata including the Rincon Shale, Vaqueros Sandstone, Sespe Formation, and the Coldwater Sandstone, as shown on Fig. 4-5.

Quaternary alluvial deposits of three types occur in the vicinity of the station: a) as much as 2,000 feet of sands, actually Plio-Pleistocene in age, are exposed about 1 mile to the north; b) an older alluvium in the immediate vicinity of the station consisting of a dissected fanglomerate of probable Pleistocene age; and c) Holocene alluvial stream deposits (Dibblee, 1966a).

The Tertiary strata exposed near Goleta have been deformed by numerous east-trending folds and faults, as depicted on Fig. 4-5. The station is situated on a small syncline expressed in the Tertiary bedrock. The northern flank of this downwarp is truncated by the east-trending More Ranch fault about 1 mile north of the station. The More Ranch fault is a high-angle fault that has had at least 2,000 feet of offset in Quaternary time (Dibblee, 1966a). According to Jennings (1975), this fault may show evidence of active creep and apparently merges a few miles to the east with the historically active Mesa fault.

4.4 CATALOG OF SEISMIC EVENTS

The Santa Barbara region is an area of continuing moderately strong seismicity. Major faults such as the San Andreas, Big Pine, and White Wolf faults have produced major earthquakes in the region and are capable of future activity. The Mesa fault, although of lesser proportion than those faults mentioned above, is also considered active and may have caused the moderately strong earthquakes near Santa Barbara in 1925 and 1941.

Other major historic earthquakes felt in the region include the July 21, 1952, Arvin-Tehachapi earthquake and the February 9, 1971, San Fernando earthquake. High ground accelerations were recorded at the Santa Barbara County Courthouse for both the June 30, 1941, Santa Barbara earthquake and the Arvin-Tehachapi earthquake (SW-AA, 1976b).

The accelerograph at the University of California Santa Barbara campus recorded only the February 9, 1971, San Fernando earthquake. Specific data from this recording, including ground motion time histories and response spectra are presented in Table A4-1 and Figs. A4-1 through A4-6 of the appendix.

4.5 FIELD EXPLORATIONS

The accelerograph station at U.C. Santa Barbara was visited to verify published information and gather additional details about the instrumentation, housing structure, and the site conditions. Although this station has been discontinued by the U.S.G.S., the building and instrument room were examined and photographed. Also, a brief geological reconnaissance was made in the vicinity of the site to verify the presence of rock and other units shown on published geologic maps. Detailed subsurface information at the site was compiled from available boring logs and geological studies of the U.C. Santa Barbara campus. No borings were made for this investigation.

4.6 SITE SUBSURFACE CONDITIONS

Subsurface boring data in the vicinity of the Fluid Mechanics Lab (Figs. 4-6 and 4-7) indicate that siltstone of the Sisquoc Formation underlies the site at a depth of about 14 feet. The overburden materials primarily consist of fine sands and silts. The siltstone of the Sisquoc Formation that was observed in the geologic reconnaissance of this investigation appeared weathered and medium to moderately hard. Shear strengths of 3.2 and 2.8 ksf were determined from direct shear tests of the siltstone (LeRoy Crandall, 1962). These strengths are relatively low for rock and are more typical of that of a hard clay or silt. Therefore, it is concluded that the near-surface siltstone of the Sisquoc Formation has engineering properties more similar to that of soil.

Some seismic refraction profiles were run in the vicinity of the Fluid Mechanics Lab by Dames and Moore in 1962. The results from these profiles indicate that the overburden material at the site has a compressional wave velocity of about 1,600 fps. Velocity measurements for depths in excess of 15 feet probably reflect the conditions of the water table and hence are not representative of the siltstone of the Sisquoc Formation. Consequently velocities for depths in excess of 15 feet are not cited in this report.

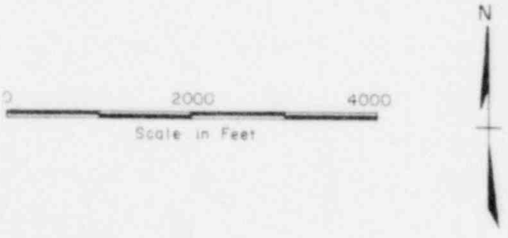
ARTS BUILDING 534

USGS Topographic Quadrangle:
Goleta, California.

Coordinates: 34° 24' 45" N.
119° 50' 54" W.

Location: Arts Building 534, U.C.S.B. campus.

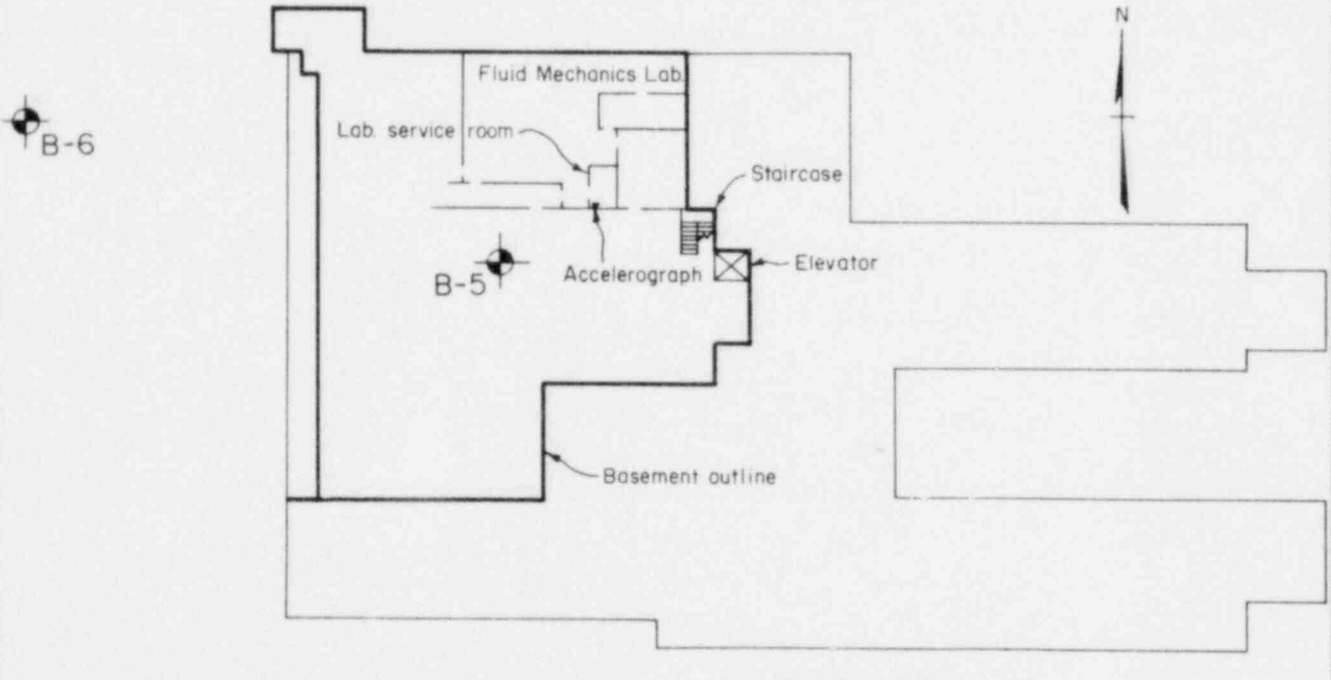
Structure: Two-story building with partial basement.



STATION LOCATION PLAN
FLUID MECHANICS LABORATORY
U.C. SANTA BARBARA
GOLETA, CALIFORNIA

FIG. 4-1

Arts Building 534, Basement and First Floor
View to Northeast

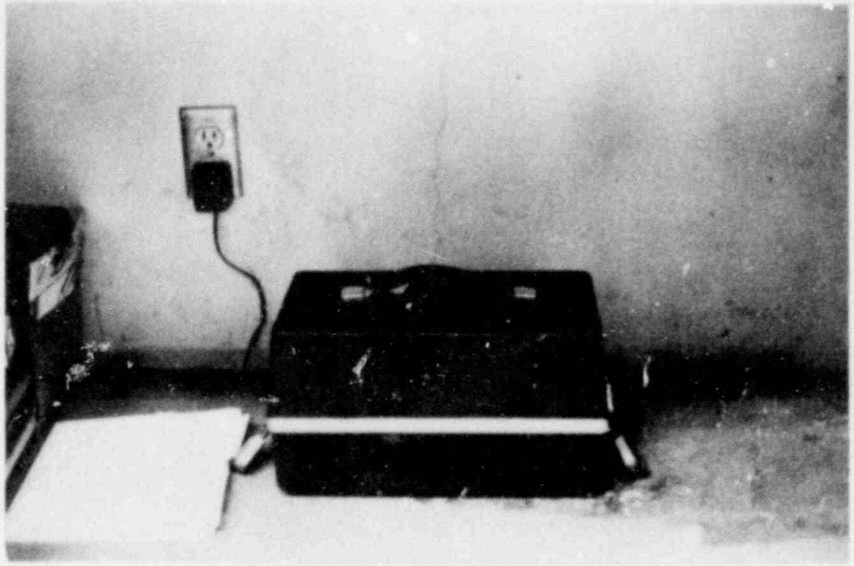


Arts Building 534
Basement Floor Plan

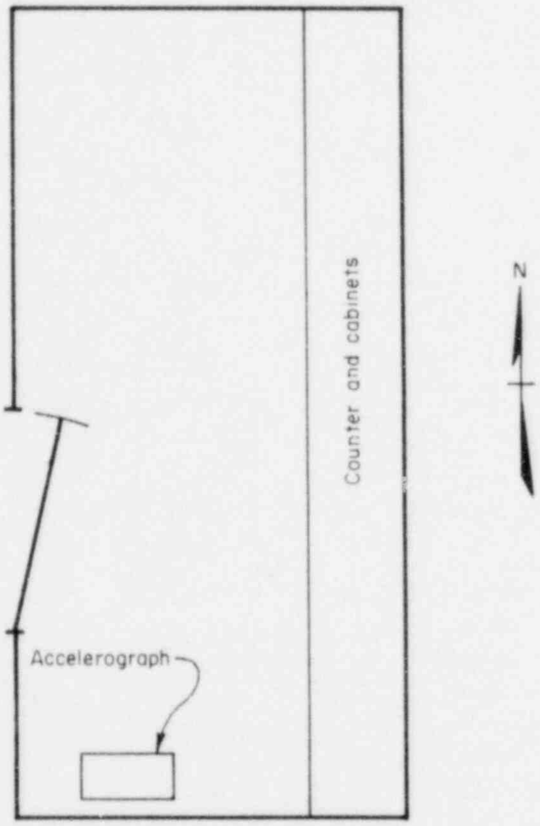
Notes: 1) Lab. service room plan is shown on Fig. 4-3.
2) Log of Boring B-5 and B-6 are shown on Fig. 4-6 and 4-7, respectively.

ACCELEROGRAPH STATION
FLUID MECHANICS LABORATORY
U.C. SANTA BARBARA
GOLETA, CALIFORNIA

FIG. 4-2



Former SMA-1 Accelerograph
U.S.G.S. Station 282



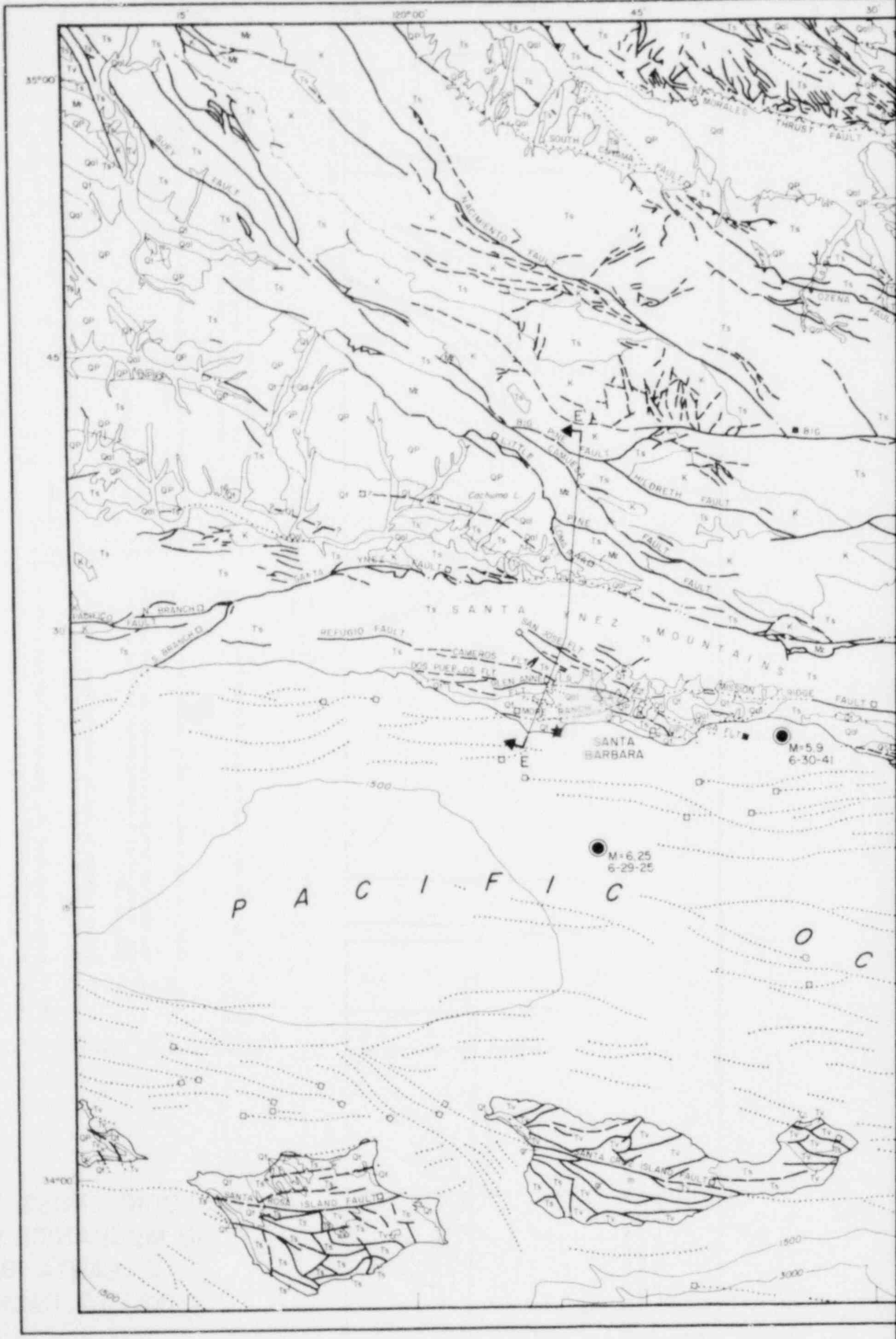
Fluid Mechanics Laboratory
Service Room Plan, Basement

0 5
Scale in Feet

Note: Location of Laboratory Service Room within the structure is shown on Fig. 4-2.

STATION INSTRUMENTATION
FLUID MECHANICS LABORATORY
U.C. SANTA BARBARA
GOLETA, CALIFORNIA

FIG. 4-3


15'
120°00'
45'
30'
35°00'
45
30
15
34°00'
SUEY FAULT
NACIMIENTO FAULT
SOUTH CUYAMA FAULT
MORALES THRUST FAULT
OZENA FAULT
BIG PINE FAULT
LITTLE PINE FAULT
HILDRETH FAULT
BIG
Cachuma L.
SANTA YNEZ FAULT
PACIFICO FAULT
N. BRANCH
S. BRANCH
REFUGIO FAULT
SANTA YNEZ MOUNTAINS
SAN JOSE FLT.
CAMEROS FLT.
DOS PUEBLOS FLT.
GLEN ANNIE FLT.
MORE RANCH FLT.
MISSION RIDGE FAULT
E
E
SANTA BARBARA
M=5.9
6-30-41
M=6.25
6-29-25
PACIFIC
OC
SANTA CRUZ ISLAND FAULT
SANTA ROSA ISLAND FAULT
1500
3000
Ts
Tv
K
Mt
QP
Qal
Qt

EXPLANATION

Qal	Alluvium, **Holocene in age;** includes dune deposits	K	Sedimentary rocks, Cretaceous in age
Qf	Stream channel, fan, and basin deposits, **Holocene in age**	Mz	Mesozoic sedimentary rocks, also includes metamorphic rocks
Ql	Lake deposits, Quaternary in age	gr	Mesozoic granitic rocks, also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks
Qt	Marine deposits, marine and nonmarine terrace deposits, Quaternary in age, includes upper Pliocene marine deposits	m	Metamorphic and metasedimentary rocks, pre-Cretaceous in age
QP	Nonmarine sedimentary deposits, Plio-Pleistocene in age	P	Sedimentary and volcanic rocks, Paleozoic in age
Tv	Volcanic rocks and igneo - intrusive rocks, Tertiary in age	pЄg	Precambrian igneous and metamorphic rocks, includes crystalline rocks which may be as young as Mesozoic
Ts	Sedimentary rocks, Tertiary in age		

★	Accelerograph Station location	Contact	Dashed where approximately located
● M=5.9 6-30-41	Epicenter location, Richter magnitude, and date of occurrence	Fault	Dashed where approximately located, dotted where concealed, queried where existence is uncertain
□	Faults that have moved during Quaternary time without historic record (approx. past 2 million years)	Thrust Fault	Barbs on upper plate, dashed where approximately located, dotted where concealed
■	Faults that have moved during historic time (approx. 200 years)	Offshore Fault	Location approximate

NOTES

1) Geology is simplified from Jennings and Strand (1969), Jennings (1959), Jennings (1962), Smith (1964), and Jennings (1958). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975) and Ziony, et al. (1974).

2) Information on fault activity (Quaternary activity, historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1975, for details)

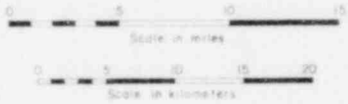
3) Individual faults within the San Andreas fault zone show evidence of Quaternary and historic activity. (See Jennings, 1975, for details)

4) Heavy border on boxes indicates units that appear on this figure.

5) Earthquake magnitudes and epicentral locations are from Coffman and Von Hake (1973).

6) Cross-section E-E' is shown on Fig. 4-5.

Location of Geologic Map

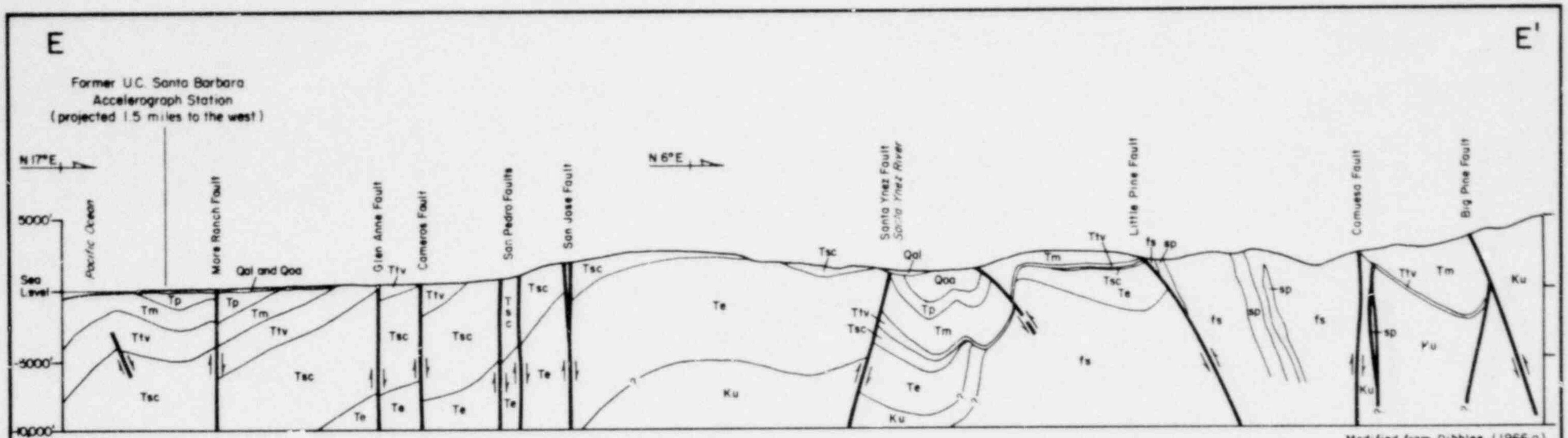


Submarine contour interval 500 feet

N

GEOLOGIC MAP
SANTA BARBARA REGION
CALIFORNIA

FIG. 4-4



Modified from Dibblee (1966 a)

EXPLANATION

Holocene	Qal	Undisected alluvium; clay, silt, sand, and gravel (Qal)
Pleistocene	Qoa	Disected alluvial gravel, sand, and silt deposits (Qt)
	Qsp	Paso Robles and Santa Barbara Formations, non-marine and marine clay, silt, sand, and poorly indurated siltstone, sandstone, and conglomerate (Qt)
Pliocene	Tp	Careaga Sandstone, Tequepis Sandstone, and Sisquoc Formation; marine sandstone, siltstone, and diatomaceous shale (Ts)
Miocene	Tm	Monterey Shale; hard platy siliceous shale, soft organic shale, chert, limestone, and tuff (Ts)
	Ttv	"Temblor" Sandstone, Rincon Shale, and Vaqueros Sandstone, marine sandstone, clay, and shale (Ts)
Oligocene	Tsc	Sespe Formation; non-marine arkosic sandstone, siltstone, and conglomerate (Ts)
Eocene	Te	"Coldwater" Sandstone, Cozy Dell Shale, Matilija Sandstone, Juncal Formation and Sierra Blanca Limestone; marine sequence of sandstone, siltstone, and clay shale (Ts)
Cretaceous	Ku	Undifferentiated marine sandstones and shales, including the Jalama Formation
	sp	Serpentinite
Cretaceous or Jurassic	fs	Franciscan Assemblage; graywacke and shale

Notes:

1) For plan view of cross-section see Fig. 4-4.

2) Abbreviations in parentheses refer to geologic symbols used on Fig. 4-4.

0 10,000 20,000
Scale in feet

GEOLOGIC CROSS-SECTION E-E'
FLUID MECHANICS LABORATORY
U.C. SANTA BARBARA
GOLETA, CALIFORNIA

FIG. 4-5

LOG OF BORING

BORING NO. B-5

STATION LOCATION	Fluid Mechanics Lab, UCSB, Goleta, CA
SHEET	1 **OF** 1
BORING LOCATION	See Fig. 4-2
SOURCE OF DATA[1]	L.T. Evans, Inc. 1956 Foundation Investigation for Arts Bldg. (Boring 2)
EQUIPMENT USED	18" diameter Bucket Auger
ELEVATION	44.7 ft.
TOTAL DEPTH	18 ft.
DATE DRILLED	8 October 1956

DEPTH IN FEET	LOG[2]	USC[2]	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	
	▥		Brownish gray, silty, fine SAND.	NA	NA	
5	░		Dark grayish brown, medium SAND.			
	░		Light grayish tan, very fine SAND.			
10	░		Light tanish gray, fine to medium SAND.			
	░		Brown, medium SAND.			
	░		Light tannish gray, fine to medium SAND.			
	▨		Light brown, silty CLAY.			
15 ∇	▩		SILTSTONE: tannish gray			
20			Bottom of Exploration.			

NOTES: 1) Original foundation engineering data has been modified for use in this report, including rewording of descriptions, omission of data, and format changes.

2) See Fig. 4-8 for explanations.

FIG. 4-6

LOG OF BORING

BORING NO. B-6

STATION LOCATION: Fluid Mechanics Lab, UCSB, Goleta, CA
SHEET 1 OF 1
BORING LOCATION: See Fig. 4-2
SOURCE OF DATA[1]: LeRoy Crandall & Assoc. 1962 Foundation Investigation for Speech and Drama Bldg. (Boring 120-7)
EQUIPMENT USED: 18" Dia. Rotary Bucket
ELEVATION: 30.0'
TOTAL DEPTH: 20.0'
DATE DRILLED: 27 September 1962

DEPTH IN FEET	LOG[2]	USC[2]	CLASSIFICATION OF MATERIALS (DESCRIPTION)	MOISTURE CONTENT %	DRY DENSITY pcf	SHEAR STRENGTH Ksf
	▥		Brown sandy SILT. (Fill)			
	▩		SHALE: (siltstone) Mottled brown and light gray, fractured, highly weathered	55	65	3.2
5	▩			51	68	
	▩			50	69	
	▩		Mottled dark brown and gray-brown.			
10	▩			43	72	2.8
	▩		Highly fractured.			
	▩		Less fractured dark brownish gray.			
15	▩			39	77	
20	▩			33	87	
			Bottom of Exploration			

NOTES: 1) Original foundation engineering data has been modified for use in this report, including rewording of descriptions, omission of data, and format changes.

2) See Fig. 4-8 for explanations.

FIG. 4-7

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 50% of material is LARGER than No. 200 sieve size)	GRAVELS (More than 50% of coarse fraction is LARGER than the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	GW	Well graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH FINES (Appreciable amt. of fines)	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS (More than 50% of coarse fraction is SMALLER than the No. 4 sieve size)	CLEAN SANDS (Little or no fines)	SW	Well graded sands, gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH FINES (Appreciable amt. of fines)	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE GRAINED SOILS (More than 50% of material is SMALLER than No. 200 sieve size)	SILTS AND CLAYS (Liquid limit LESS than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS AND CLAYS (Liquid limit GREATER than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils
ROCK 1)				Sandstone, siltstone, and shale
				Conglomerate

BOUNDARY CLASSIFICATION: Soils possessing characteristics of two groups are designated by combinations of group symbols.

1) Rock in the geologic sense (as shown in the logs of borings) often has physical engineering properties of stiff to hard soils.

Reference:
The Unified Soil Classification System, Corps of Engineers (1953).

LOG OF BORING EXPLANATION

FIG. 4-8

Section 5
Lake Hughes Region

SECTION 5

LAKE HUGHES REGION

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SECTION 5

LAKE HUGHES REGION

LIST OF FIGURES

SECTION 5
LAKE HUGHES REGION

5.1 INTRODUCTION

The Lake Hughes region is centered in the Transverse Ranges of California as shown in Fig. 1. As defined for this report, the region encompasses an area of about 6,000 square miles, including the westernmost parts of the Tehachapi Mountains and Mojave Desert. To the south, it also includes the northernmost Los Angeles basin and the San Gabriel Valley.

Four accelerograph stations in the Lake Hughes region were studied: the Outlet Works at Santa Felicia Dam, the Old Ridge Route Station near Castaic, and the Lake Hughes Array Stations Nos. 12 and 4. Each of these stations was previously classified by one or more researchers as a "rock" site (Table 1), that is, a site which is founded on or within a few feet of rock.

The location and instrumentation, along with geological, seismological, and subsurface information for each of the accelerograph stations are discussed and illustrated in this section. Ground motion time histories and response spectra for selected earthquakes recorded at the stations are presented in the appendix.

Volume 1, Section 2 of this series of reports (SW-AA, 1976a) also discusses several accelerograph stations that fall within the Lake Hughes region. In that reference, those stations are considered to lie within a larger area loosely defined as the Northern Mountains District. Geological and seismological studies for that report are integrated with the new data presented in the following discussion.

5.2 STATION DESCRIPTIONS

5.2.1 Santa Felicia Dam Outlet Works, Piru

5.2.1.1 Location and building. Santa Felicia Dam is 3.5 miles north of Piru in eastern Ventura County, California, as shown in Fig. 5-1. It is a large earthfill dam, constructed in 1955 by the United Water Conservation District to provide irrigation and groundwater recharge supply.

The Outlet Works Control House, which served as the housing structure for the accelerograph, is located at the right toe of the dam. It is a one-story, reinforced-concrete structure on a concrete foundation that contains a concrete-lined stilling well extending 10 feet below grade. The building adjoins a 60-inch I.D. outlet pipe which passes through the dam embankment. A photograph and plan view of the vicinity of the Outlet Works is shown in Fig. 5-2.

The strong motion station (U.S.G.S. No. 284) was installed in the Outlet Works Control House on June 20, 1967, by the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey. The station was discontinued on November 8, 1973, and relocated to a barn on the west abutment of the dam. The U.S.G.S. relocated the instrument since it was felt that at the former location, recorded ground motions may have been influenced by the large-diameter outlet pipes beneath the station.

5.2.1.2 Instrumentation. The recording instrument that was installed at the Outlet Works Control House was an AR-240, triaxial accelerograph, Serial No. 242, manufactured by Teledyne-Geotech. At the time of the February 9, 1971, San Fernando earthquake, the instrument had the following characteristics (Hudson, et al., 1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
S08E	7.6	0.054
S82W	7.6	0.055
Down	7.6	0.055

The accelerograph was bolted to a 4-inch high concrete pier cemented to the concrete floor slab of the building. A photograph of the former instrument location and a plan view of the Outlet Works Control House are included in Fig. 5-3.

The former Outlet Works station has been relocated to a garage on the west abutment of the dam. In addition, another accelerograph station is located on the crest, and four seismoscopes are positioned at various locations around the dam. The U.S.G.S. has consolidated the station numbers of all instruments located at the Santa Felicia Dam, and collectively refers to all instruments at the site as station number 285.

5.2.2 Old Ridge Route, Castaic

5.2.2.1 Location and housing structure. The former Castaic strong motion station was located approximately 4.5 miles north of the junction of Lake Hughes Road and the Old Ridge Route near Castaic, California. The station location, as shown in Fig. 5-4, was several hundred feet east of the Old Ridge Route on a ridge crest separating Grasshopper Canyon and Violin Canyon.

The Old Ridge Route station (U.S.G.S. No. 110) was established on January 28, 1965, by joint effort of the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey and the California State Department of Water Resources. The accelerograph was installed in a small instrument shelter to record free-field motions (Fig. 5-5). The station was discontinued on May 14, 1975, when the instrument was moved to a site near Castaic Dam.

5.2.2.2 Instrumentation. The strong motion instrument originally installed at the Old Ridge Route station was an AR-240 triaxial accelerograph, Serial No. 124, manufactured by Teledyne-Geotech. U.S. Geological Survey files (unpub.) indicate the instrument was initially installed with the longitudinal trace oriented due south. The accelerograph was reoriented to N21°E (longitudinal trace) on November 30, 1967, to correspond to instruments in the Lake Hughes Array.

The AR-240 instrument was temporarily removed for short periods of time during 1969 and 1971 and was replaced by a SMA-1 triaxial accelerograph, Serial No. 587, between July 28, 1972, and October 29, 1973. This SMA-1 accelerograph manufactured by Kinemetrics, Inc., was installed in an orientation corresponding to that of the AR-240. The AR-240 accelerograph was operative at the station during the February 9, 1971, San Fernando earthquake and had the following characteristics at that time (Hudson, et al., 1969 to 1975a):

Component Direction	Sensitivity (cm/g)	Period (sec)
N21E	8.1	.053
N69W	7.6	.051
Down	7.9	.052

A seismoscope, Serial No. 2874, was also operational at the station. A plan view of the instrument shelter and a photograph of the instrument location are shown on Fig. 5-6.

5.2.3 Lake Hughes Array No. 12

5.2.3.1 Location and housing structure. The Lake Hughes Array No. 12 strong motion station is located at the U.S. Forest Service Red Mountain Guard Station (previously known as the Elizabeth Lake Guard Station). This facility is about 9 miles southwest of Lake Hughes and 4 miles north of Castaic Dam along Elizabeth Lake Canyon Road, as shown in Fig. 5-7.

The instrument is housed in a small shed attached to the south side of the fire truck garage. Both the shed and the garage are wood-frame structures supported on concrete slab-on-grade foundations. The garage was built in the mid-1930's, but the instrument shed was probably not added until many years later.

The Lake Hughes Array is a planned network of accelerographs and seismoscopes that were installed cooperatively by the California Department of

Water Resources and the U.S. Coast and Geodetic Survey. The array extends between Lake Hughes and Castaic, nearly perpendicular to San Andreas fault. It was established to determine the impact of earthquakes upon nearby structures of the California Aqueduct and to record earthquake ground motion attenuation away from the fault.

Lake Hughes Array No. 12 (U.S.G.S. Station No. 128) was established on June 30, 1966, and is the southernmost of the stations in the Lake Hughes Array. A photograph of the station along with a plan view of the immediate vicinity are shown on Fig. 5-8.

5.2.3.2 Instrumentation. An AR-240, triaxial accelerograph, Serial No. 217, manufactured by Teledyne-Geotech, and a seismoscope, Serial No. 2893, were originally installed in the Lake Hughes Array Station No. 12 in 1966. At that time the accelerograph was oriented with the camera pointing N37^{o}E, but was realigned on November 30, 1967, to record accelerations parallel and perpendicular to the San Andreas fault. Hudson, et al. (1969 to 1975a) report the following characteristics for the instrument at the time of the February 9, 1971, San Fernando earthquake:

Component Direction	Sensitivity (cm/g)	Period (sec)
N21E	7.6	.054
N69W	7.6	.054
Down	7.6	.056

The California Division of Mines and Geology replaced the AR-240 instrument at Lake Hughes Array Station No. 12 with a SMA-1 accelerograph in late 1976. This instrument records standardized time form a remote radio transmitter in Colorado, utilizing an integral WWVB receiver.

The accelerograph and seismoscope are bolted to the 4-inch thick concrete floor of the shed. A photograph of the instrument and a plan view of the shelter are shown on Fig. 5-9.

5.2.4 Lake Hughes Array No. 4

5.2.4.1 Location and housing structure. The Lake Hughes Array No. 4 strong motion station is located at the Los Angeles County William Mendenhall Probation Camp, about 2.5 miles southwest of Lake Hughes, California (Fig. 5-10). The instrument is housed in a prefabricated metal instrument shelter on the hillside overlooking the southeast side of the camp. The shelter is a 5.4-foot square structure supported on a 4- to 8-inch thick concrete slab foundation. It is about 30 to 40 feet south of a large water tank, and is on the headwall of an encroaching landslide scarp on the west. A photograph of the station and a plan view of the immediate vicinity are shown on Fig. 5-11.

The Lake Hughes Array No. 4 Station (U.S.G.S. No. 126) was established on June 23, 1966, by the cooperative efforts of the California Department of Water Resources and the former Seismological Field Survey unit of the U.S. Coast and Geodetic Survey. It is one station in a network of accelerographs and seismoscopes known collectively as the Lake Hughes Array, which extends nearly transverse to the San Andreas fault between Lake Hughes and Castaic. This array was established to determine the impact of earthquake ground motions away from the San Andreas fault.

5.2.4.2 Instrumentation. An AR-240 triaxial accelerograph, Serial No. 187, manufactured by Teledyne-Geotech and a seismoscope, Serial No. 2891, were originally installed at the Lake Hughes Array Station No. 4 on June 23, 1966. The instrument was originally installed with its camera pointing N45°E, but was realigned to N21°E on December 30, 1967, to record accelerations parallel and perpendicular to the trace of the San Andreas fault.

In August 1969, the AR-240 instrument was replaced by an RFT-250 triaxial accelerograph, Serial No. 164, also manufactured by Teledyne-Geotech. At least three different RFT-250 instruments occupied the station at various times until March 1975, when a SMA-1 accelerograph, Serial No. 1491, equipped with a WWVB receiver was installed.

At the time of the February 9, 1971, San Fernando earthquake, the RFT-250 accelerograph, Serial No. 164, was operative at the station. According to Hudson, et al. (1969 to 1975a), the instrument had the following characteristics:

Component Direction	Sensitivity (cm/g)	Period (sec)
S69E	1.9	.048
S21W	1.9	.046
Down	1.9	.046

Each of the accelerographs located at the Lake Hughes Array No. 4 have been bolted to a 1-foot high, 2-foot diameter concrete pier which was poured simultaneously with the floor slab of the shelter. A photograph of the present instrument and a plan view of the shelter are presented in Fig. 5-12.

5.3 GEOLOGY AND SEISMICITY

5.3.1 Regional Geology

The Lake Hughes region is located in southern California, approximately 30 miles northwest of Los Angeles, as shown on the geologic map, Fig. 5-13. This region, centered around the town of Castaic, lies mostly within the Transverse Ranges province, a wide belt of east-trending mountain ranges interspersed with narrow to moderately broad intermontane valleys. Within the region, the Transverse Ranges extend southward across the Santa Monica Mountains, where they are truncated against the northwest-trending Peninsular Ranges across the Santa Monica-Raymond Hill fault system. The western Mojave Desert bounds the Transverse Ranges to the north, locally across the San Andreas fault zone. The Transverse Ranges trend westward to the Pacific Ocean and eastward as far as Riverside County.

Precambrian to Mesozoic intrusive and metamorphic rocks (gr, p€g, and m) underlie the Transverse Ranges. This crystalline basement complex is well exposed in the mountainous areas in the eastern half of the region, but plunges under a thick cover of Cretaceous and Cenozoic strata (K, Ts, and Tv) to the west and in the San Fernando Valley.

The western Mojave Desert province is located about 15 miles north of the center of the Lake Hughes region. It is an alluviated desert plain underlain by a thick sequence of Tertiary sedimentary and volcanic strata that in turn rest unconformably on a pre-Tertiary crystalline basement. The western Mojave Desert is a distinct tectonic block, separated from the Tehachapi Mountains to the northwest and the Transverse Ranges to the southwest by the Garlock and San Andreas fault zones, respectively (Dibblee, 1967). These fault zones are vertical crustal breaks with major strike-slip displacements. At their juncture at the western end of the Mojave Desert, numerous major faults converge or cross one another, resulting in an area of extreme tectonic complexity.

The northeast-trending Tehachapi Mountains occupy the northernmost part of the region. They consist of a pre-Tertiary crystalline basement complex that was uplifted during Cenozoic time along a system of boundary faults (Buwalda, 1954).

The structural geology of the Lake Hughes region is dominated by an extensive system of major strike-slip faults and associated thrust faults and folds. The region is tectonically active, as witnessed by historic movement on the San Andreas, Big Pine, and San Fernando faults, as well as the White Wolf fault immediately north of the region (Jennings, 1975). Many other faults have been active in Quaternary time including the Garlock, San Gabriel, Frazier, Santa Ynez, Pine Mountain, San Cayetano, and Clearwater faults. The juncture of the San Andreas, Garlock, San Gabriel, and associated smaller faults, many of which are active or potentially active, makes the Lake Hughes region one of the most tectonically complex and seismically active areas in California.

5.3.2 Seismicity

The Lake Hughes region is characterized by continuing high seismic activity, the result of tectonic stresses acting along the San Andreas and associated fault zones. Several major earthquakes have shaken the region in historic time. The most severe temblor (Intensity X-XI, MM) occurred along the San Andreas fault near Fort Tejon in 1857 (VanderHoof, 1955). An Intensity VII (MM) also occurred on the San Andreas fault north of Gorman in 1916 (Coffman and von Hake, 1973). Other major historic earthquakes in the region include the magnitude 7.7, 1952 Arvin-Tehachapi earthquake on the White Wolf fault north of the region, and the magnitude 6.4, February 9, 1971, San Fernando earthquake on the San Fernando fault.

5.3.3 Local Geology

5.3.3.1 Santa Felicia Dam Outlet Works, Piru. Santa Felicia Dam is located in the Piru Mountains in the northeastern part of the Ventura basin, approximately 19 miles southwest of the San Andreas fault zone. The local geology of this area is depicted on the Geologic Cross-Section F-F', Fig. 5-14.

The area is underlain by a thick sequence of Cenozoic clastic sedimentary rocks ranging in age from Eocene to Pleistocene. Holocene stream alluvium underlies the Santa Clara River and Piru Creek floodplains, and Quaternary terrace deposits occur locally along the valley margins. Basement rock is not exposed near the station but presumably is similar to the granitic and metamorphic complex exposed in the Transverse Ranges to the east. In the station vicinity, the basement rocks are buried below several thousand feet of Tertiary strata (Cordova, 1956).

The San Felicia Dam site is underlain by shales and sandstones of the Miocene Modelo Formation. These beds dip approximately 70° to the south and strike nearly due east. They are situated on the south flank of a sharp anticline, the axis of which is located about 1,000 feet north of the site (Rhoades, 1954). Sandstone is the predominant lithology and is generally medium grained and loosely cemented. The interbedded shales are hard and fissile to moderately soft.

The Modelo Formation in the station vicinity contains siliceous and diatomaceous shales and conglomerate interbedded with massive sandstone and laminated shale. These rocks constitute the core of the anticline discussed above and are flanked to the north and south by strata of the Pliocene Pico and Saugus Formations. The Pliocene strata are composed of marine and non-marine sandstone and conglomerate with lesser amounts of shale.

The Piru Creek channel lies immediately east of the Outlet Works. In earlier time, the stream had cut its valley about 75 feet below its present level (Rhoades, 1954). Subsequently, this former gorge has been filled with Quaternary sands and gravels to the present elevation of the streambed.

The Piru Mountains are essentially a fault block system, bordered by major faults and internally deformed by east-trending faults and folds. This deformation resulted from north-south compressional forces, mainly during Pleistocene time (Cordova, 1956). Piru Dam is approximately 2.5 miles north of the San Cayetano fault, a major thrust fault associated with the nearby Santa Susana thrust. These structures are known to have been active in Quaternary time but not during the last 200 years (Jennings, 1975). They are, however, along the same trend as the San Fernando fault, a similar, but active fault about 20 miles southeast of Piru Dam that caused the February 9, 1971, San Fernando earthquake.

The dam is approximately 7 miles southwest of the San Gabriel fault, which has had Quaternary displacement, and 20 miles south of the highly active San Andreas fault zone. Numerous other faults known to have been active in Quaternary time within 10 or 15 miles of Piru Dam include the Oak Ridge, Northridge Hills, Simi, Pine Mountain, and Santa Ynez faults.

5.3.3.2 Old Ridge Route, Castaic. The Old Ridge Route strong motion station is located in the San Gabriel Mountains in an area known as the Ridge basin. The local geology of this area is depicted on the Geologic Cross-Section G-G', Fig. 5-15.

The Ridge basin is a northwest-trending structural depression lying between the San Andreas and San Gabriel fault zones. It is filled with 33,000 feet or more of Tertiary marine and non-marine clastic sediments which are underlain at a depth by a basement complex of gneissic and granitic rocks of Mesozoic age or older (Crowell, 1954).

The Tertiary strata in the Ridge basin have been deformed into a series of broad folds. They unconformably overlie or are faulted against the crystalline basement complex on the north and east flanks of the basin. To the southwest, the Tertiary strata are truncated by the San Gabriel fault zone, except locally where upper Pliocene strata overlap the fault. The Violin Breccia is interstratified with the upper Miocene Castaic Formation adjacent to the fault zone. This breccia, containing rubble up to 6 feet in diameter, accumulated as talus and alluvial deposits at the base of the San Gabriel fault scarp, testifying to movement on the fault as early as upper Miocene time (Crowell, 1954).

The Old Ridge Route station was founded on bedrock of the upper Miocene Castaic Formation. This formation is composed of buff to brown marine sandstone, siltstone, and shale beds, ranging from a few inches to several feet thick. These strata dip southwestward approximately 20 degrees toward a major synclinal axis less than a mile to the west (Dehlinger, 1952).

The Old Ridge Route station was located within 3 miles of the San Gabriel fault and about 14 miles south of the San Andreas fault zone. Other large faults in the area include the Clearwater, San Francisquito, and the Bee Canyon fault to the east of the station and the Pine Mountain, Santa Ynez, and Agua Blanca faults to the west. The Holser, Santa Susana, and San Fernando are a few of many nearby faults south of the Old Ridge Route station. As discussed in Section 5.3.2.1, several of these faults have had Quaternary displacement, and the San Andreas fault zone and San Fernando fault have historic records of offset.

5.3.3.3 Lake Hughes Array Station No. 12. The Lake Hughes Array Station No. 12 is situated in Elizabeth Lake Canyon in the western San Gabriel Mountains. The geology of this area is depicted on the Geologic Cross-Section H-H', Fig. 5-16.

The station area is in the eastern part of the Ridge basin, a structural depression filled with a thick accumulation of Tertiary clastic marine sedimentary strata overlying crystalline basement rock. This basement rock consists of a complex of igneous and metamorphic rock identified by Szatai (1961) as the pre-Cretaceous Sawtooth Gneiss. It is exposed extensively north of the Clearwater fault and occurs in a small triangular-shaped area south of the fault. South of the San Francisquito fault, the basement consist of strongly foliated rocks of probable Precambrian age known as the Pelona Schist (Jennings and Strand, 1969).

Locally, the crystalline basement in the Ridge basin is overlain by as much as 9,000 feet of Tertiary sedimentary strata. These strata have been relatively downdropped and juxtaposed against crystalline basement rocks by the Clearwater and San Francisquito faults (Jennings and Strand, 1969). The lowermost of the Tertiary sedimentary rocks consist of marine sandstone, conglomerate, and shale of the Paleocene to Eocene San Francisquito Formation. These strata dip generally southward from the Clearwater fault and are thrust over the younger sandstones, shales, conglomerates, and breccias of the Sespe Formation across the east-trending Bee Canyon fault. The Sespe Formation is of non-marine origin and is mostly Oligocene in age, but may include Eocene and Miocene deposits (Jennings and Strand, 1969). It is overlain to the south by Miocene marine and non-marine sandstone, shale, and conglomerate of the Castaic and Mint Canyon Formations.

The Tertiary strata in the immediate vicinity of the station are deformed by a series of small east-trending folds. Numerous faults are present in the area, the most important of which are the San Andreas fault zone about 9 miles to the north, and the San Gabriel fault zone approximately 7 miles to the southwest. The Clearwater fault, 2.5 miles to the north, is the closest fault with known Quaternary displacement, and the San Andreas is the closest fault with a record of rupture during the last 200 years (Jennings, 1975). The San Fernando fault, which produced the February 9, 1971, San Fernando earthquake, is about 20 miles south of the station.

5.3.3.4 Lake Hughes Array Station No. 4. Station No. 4 of the Lake Hughes Array is situated on the south slope of Elizabeth Lake Canyon, approximately 2.5 miles southwest of the town of Lake Hughes and the San Andreas fault zone. The geology of this area is depicted in the Geologic Cross-Section I-I', Fig. 5-17.

The bedrock in the station area consists predominantly of a complex of gneiss and granitic rocks with an average composition of granodiorite (Dibblee, 1961). These crystalline rocks are of Mesozoic age or older and typically have a northeast-trending foliation. They are in sharp contact with a Jurassic-Cretaceous (?) quartz monzonite approximately 1.5 miles north of the station, although this contact is more commonly gradational (Dibblee, 1961). South of the San Francisquito fault and about 6 miles south of the station, the Pelona Schist basement complex comprises the bedrock. It is a strongly foliated rock of probable Precambrian age.

Four miles south of the station a block of Tertiary strata is downdropped, relative to the crystalline basement rocks, between the east-trending Clearwater and San Francisquito faults. These strata, locally consisting of Paleocene to Oligocene sandstones, siltstones, and shales, unconformably overlie the gneissic and granite basement complex and dip steeply to the south.

Quaternary alluvium of both Pleistocene and Holocene age mantle the bedrock in low-lying areas near the station. In particular, the San Andreas rift zone and Elizabeth Lake Canyon have fairly thick accumulations of Quaternary deposits. Landslides are fairly common, particularly in areas underlain by the Pelona Schist (Dibblee, 1961).

The prominent structural features in the station area are the major east-trending faults characteristic of the Transverse Ranges such as the Clearwater and San Francisquito faults and the San Andreas fault zone, located only 2.5 miles to the north. The San Andreas is the only known active fault in the immediate vicinity of the station; the San Fernando fault, which ruptured in 1971, is 25 miles to the south. There are, however, several faults that have been active in Quaternary time, including the Clearwater fault located 4 miles south of the station, and the San Gabriel, Pelona, and Mint Canyon faults somewhat further removed.

5.4 CATALOG OF SEISMIC EVENTS

The Lake Hughes region is situated in one of the most seismically active areas in California. Numerous major earthquakes have shaken the region in historic time, including the January 9, 1857, Fort Tejon earthquake which had a modified Mercalli Intensity of X-XI, probably the largest historic earthquake to have occurred in California. The magnitude 7.7; Arvin-Tehachapi earthquake of July 21, 1952, and the magnitude 6.4; February 9, 1971, San Fernando earthquake also had epicenters in the Lake Hughes region. Epicentral locations are shown on Fig. 5-13 for some of the events. These and other earthquakes are also discussed in Section 5.3.2.

The Lake Hughes region accelerograph stations were established between 1965 and 1967, and therefore have recorded only a few of the many historic earthquakes that have shaken the region. Five separate events have been recorded, ranging from 4.0 to 6.4 in Richter magnitude. A list of specific information on these earthquakes and the instrumental records are provided in the appendix (Table A5-1). Selected ground motion time histories and their corresponding response spectra are also provided in Figs. A5-1 through Fig. A5-30 in that appendix.

5.5 FIELD EXPLORATIONS

The Lake Hughes region accelerograph station sites were visited to verify published information and gather additional details about the station instrumentation, housing units, and site conditions. At each of the sites, the instrumentation and housing structure were photographed and details were gathered on the housing structure and instrumentation history. Also, a brief geologic reconnaissance was made in the vicinity of each site to verify the presence of rock and other units shown on published geologic maps. Detailed subsurface information at the sites was compiled from available data, including boring logs and geophysical surface refraction measurements, and the findings of the geologic reconnaissance of this investigation. At the Lake Hughes Array Station No. 12 site, a hand-auger boring was attempted to investigate the depth to rock. Other than this site, borings were not made for this investigation.

5.6 SITE SUBSURFACE CONDITIONS

5.6.1 Santa Felicia Dam Outlet Works, Piru

The Outlet Works Control House that contained the accelerograph station at Santa Felicia Dam is situated at the downstream face of the dam. It is adjacent to a 150-foot high rock cliff that serves as the west abutment of the dam (Fig. 5-1). The Piru Creek floodplain lies immediately east of the building and consists of about 80 feet of streambed sand, gravel, cobbles, and boulders as determined from borings by the United Water Conservation District (U.W.C.D.).

Subsurface conditions at the site were generalized from a 17-foot, U.W.C.D. boring advanced at a location about 60 feet southwest of the outlet works accelerograph station. The materials encountered in this boring (Fig. 5-18) were 7 feet of undifferentiated overburden overlying sandstone and shale of the Modelo Formation. The overburden is probably a part of the streambed sands, gravels, cobbles, and boulders that comprise the Pine Creek floodplain. From rock outcrops observed in the geologic reconnaissance of the site, the sandstone of the Modelo Formation is medium to moderately hard and it is interbedded with layers of hard shale.

5.6.2 Old Ridge Route, Castaic

The Old Ridge Route accelerograph station site was located on the crest of a moderately steep ridge which is directly underlain by sandstone, siltstone, and shale of the Miocene Castaic Formation. From rock outcrops observed in the geologic reconnaissance of the site, the sandstone at the surface is weathered and medium to moderately hard.

Geophysical surface refraction measurements have been made in the vicinity of the site by Shannon & Wilson, Inc., (1973) and Duke, et al. (1971). Two refraction lines, perpendicular to each other, were run in the Shannon & Wilson, Inc., investigation. These lines intersected at the southeast corner of the accelerograph station. The refraction line of the investigation by Duke was located about 700 feet northwest and about 100 feet lower than the accelerograph station. The results from both of these investigations are summarized below.

Shannon & Wilson (1973)

Depth (ft.)	Shear Wave Velocity (fps)
0 - 20	530
20 - 68	1,150
more than 68	2,150

Duke, et al. (1971)

Depth (ft.)	Shear Wave Velocity (fps)
0 - 12	640
12 - 50	1,230
50 - 90	2,160
90 - 200	2,590

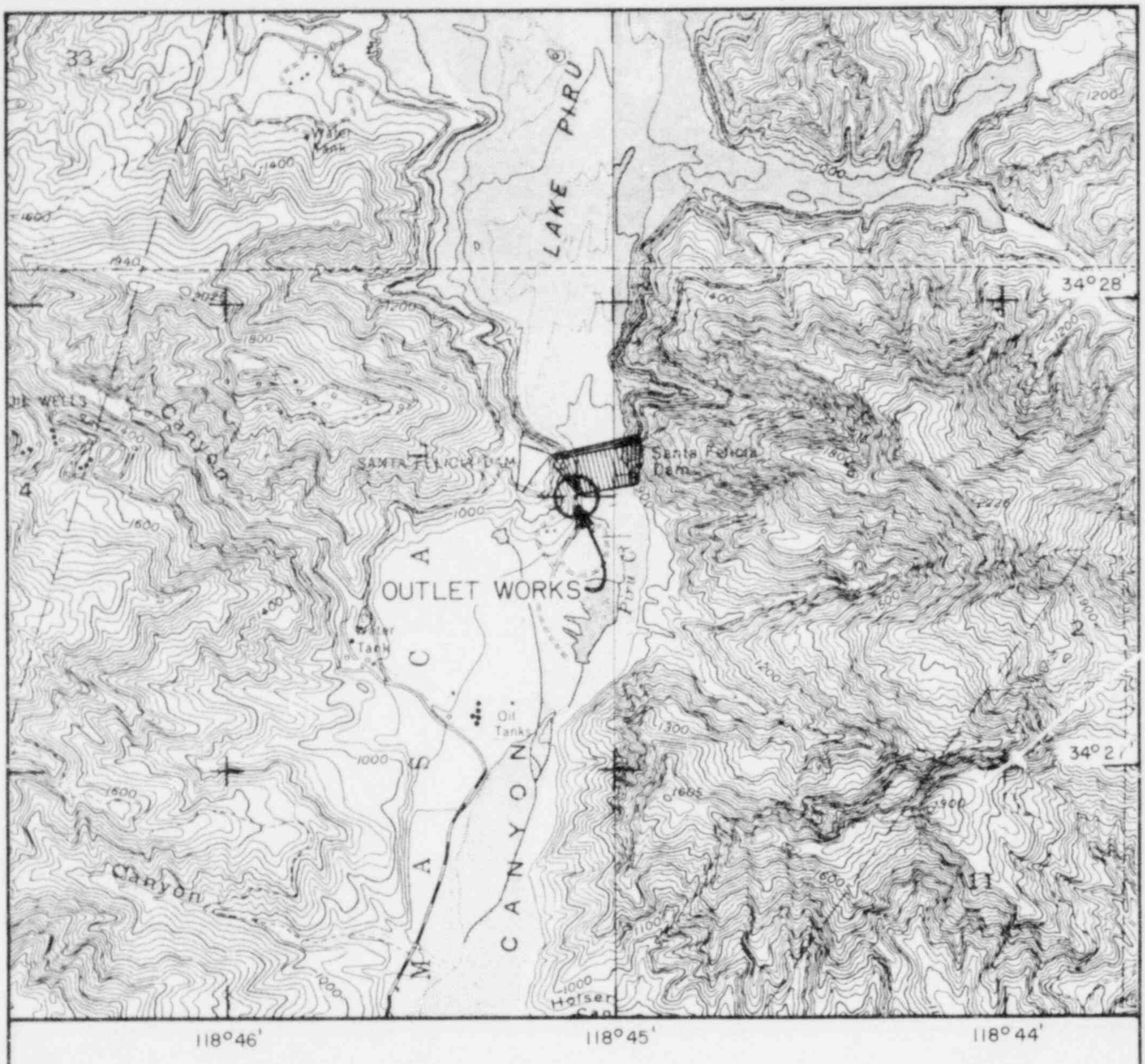
The velocities shown for the Shannon & Wilson, Inc., studies represent the average values for the two refraction lines. In the investigation by Duke, velocities were measured to a depth of about 50 feet. Below this level, velocities were estimated based on site geology.

5.6.3 Lake Hughes Array No. 12

Subsurface conditions at the Lake Hughes No. 12 accelerograph station consist of several feet of landslide debris overlying sandstone, conglomerate, and shale of the Elizabeth Canyon Formation (Eocene). The landslide debris beneath the station is probably no thicker than 5 to 10 feet, based upon observations during the geologic reconnaissance. Several hand-auger borings were attempted to define the thickness of the debris material during the geologic reconnaissance. However, obstructions were encountered in each of these borings and the maximum depth of penetration was only 3 or 4 feet.From rock outcrops observed nearby, the sandstone of the Elizabeth Canyon Formation is moderately hard.

5.6.4 Lake Hughes Array No. 4

Based on the geologic reconnaissance of the Lake Hughes Array No. 4 site, the station is founded on moderately weathered, granitic bedrock. The station is located in a bench cut into the steep slope along the south side of Elizabeth Lake Canyon. Nearby exposures indicate this rock is moderately to strongly decomposed to depths of about 15 feet with fresher rock below this depth. There is a small landslide in this weathered rock which is encroaching upon the station.

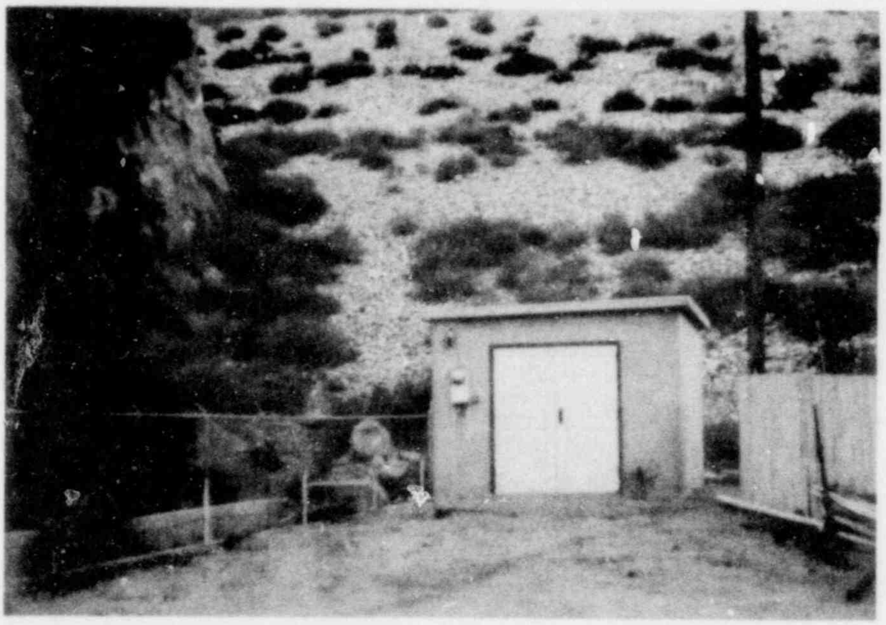


OUTLET WORKS

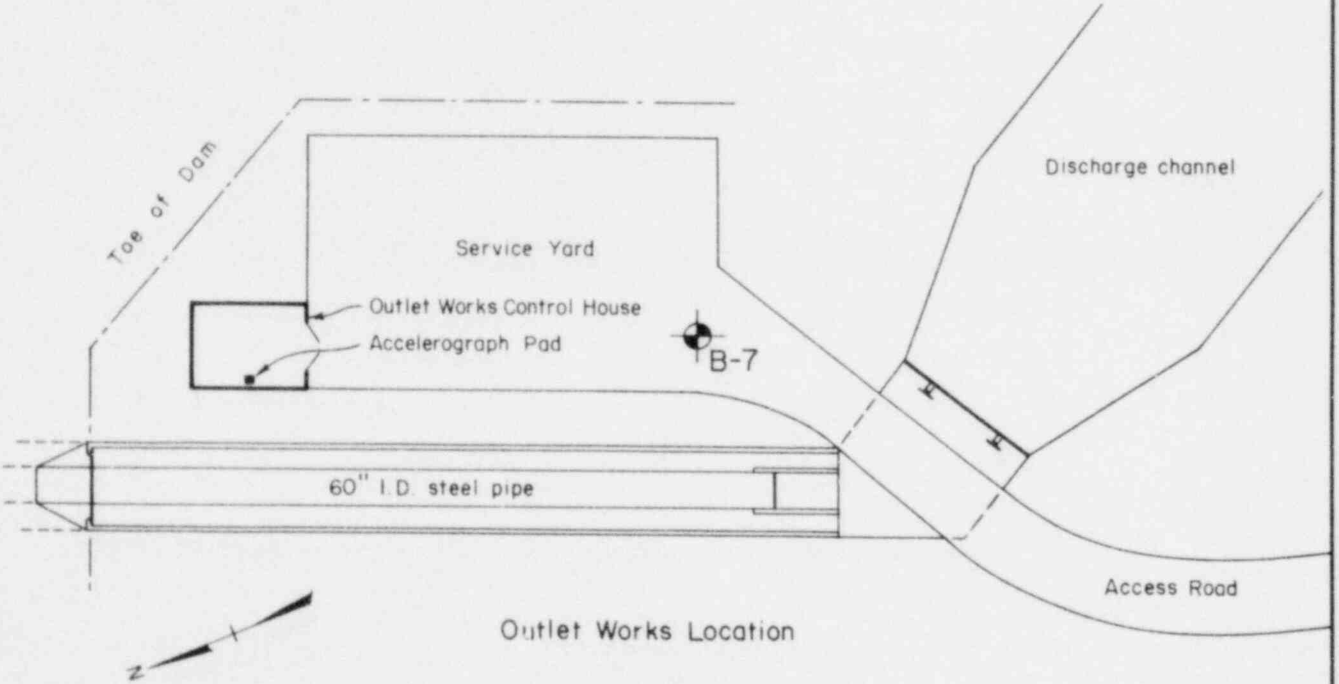
USGS Topographic Quadrangles:	Piru and Val Verde, California.
Coordinates:	34° 27' 35" N. 118° 45' 06" W.
Location:	Outlet works at base of Santa Felicia Dam.
Structure:	Concrete housing with deep concrete foundation.

STATION LOCATION PLAN
SANTA FELICIA DAM
OUTLET WORKS
PIRU, CALIFORNIA

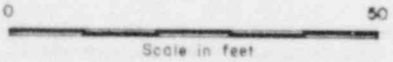
FIG. 5-1



Outlet Works Control House
View to the North Toward Toe of Dam



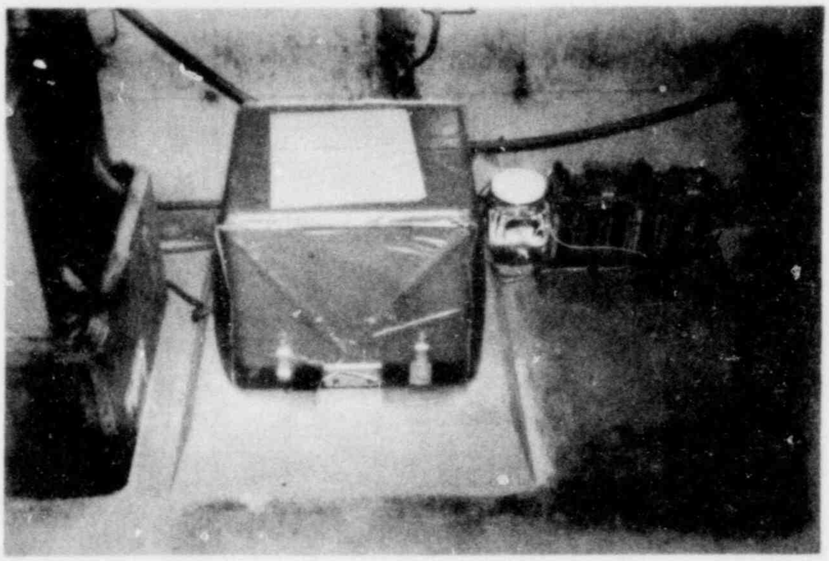
Outlet Works Location



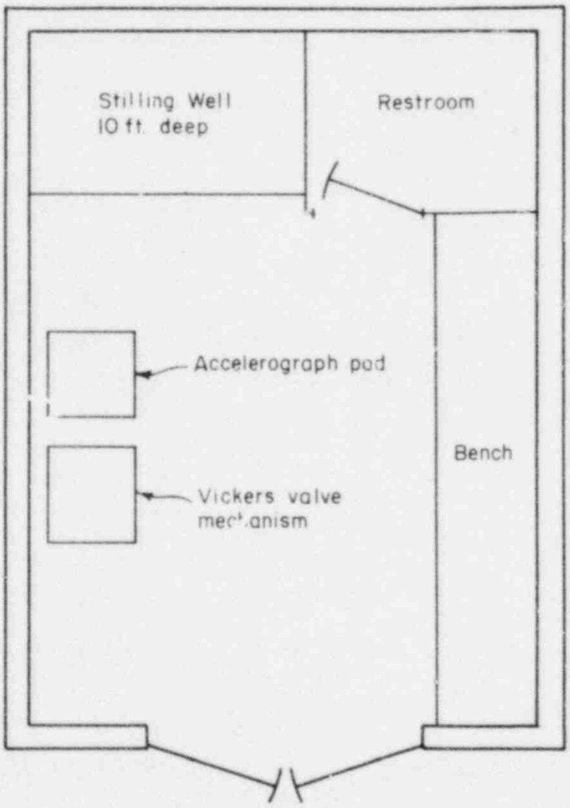
ACCELEROGRAPH STATION
SANTA FELICIA DAM
OUTLET WORKS
PIRU, CALIFORNIA

Notes: 1) Outlet Works Control House plan is shown on Fig. 5-3.
2) Log of Boring for B-7 is shown on Fig. 5-18.

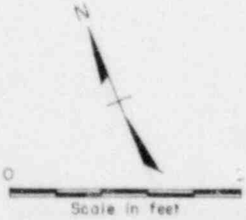
FIG. 5-2



AR-240 Accelerograph
U.S.G.S. Station 284 (discontinued)



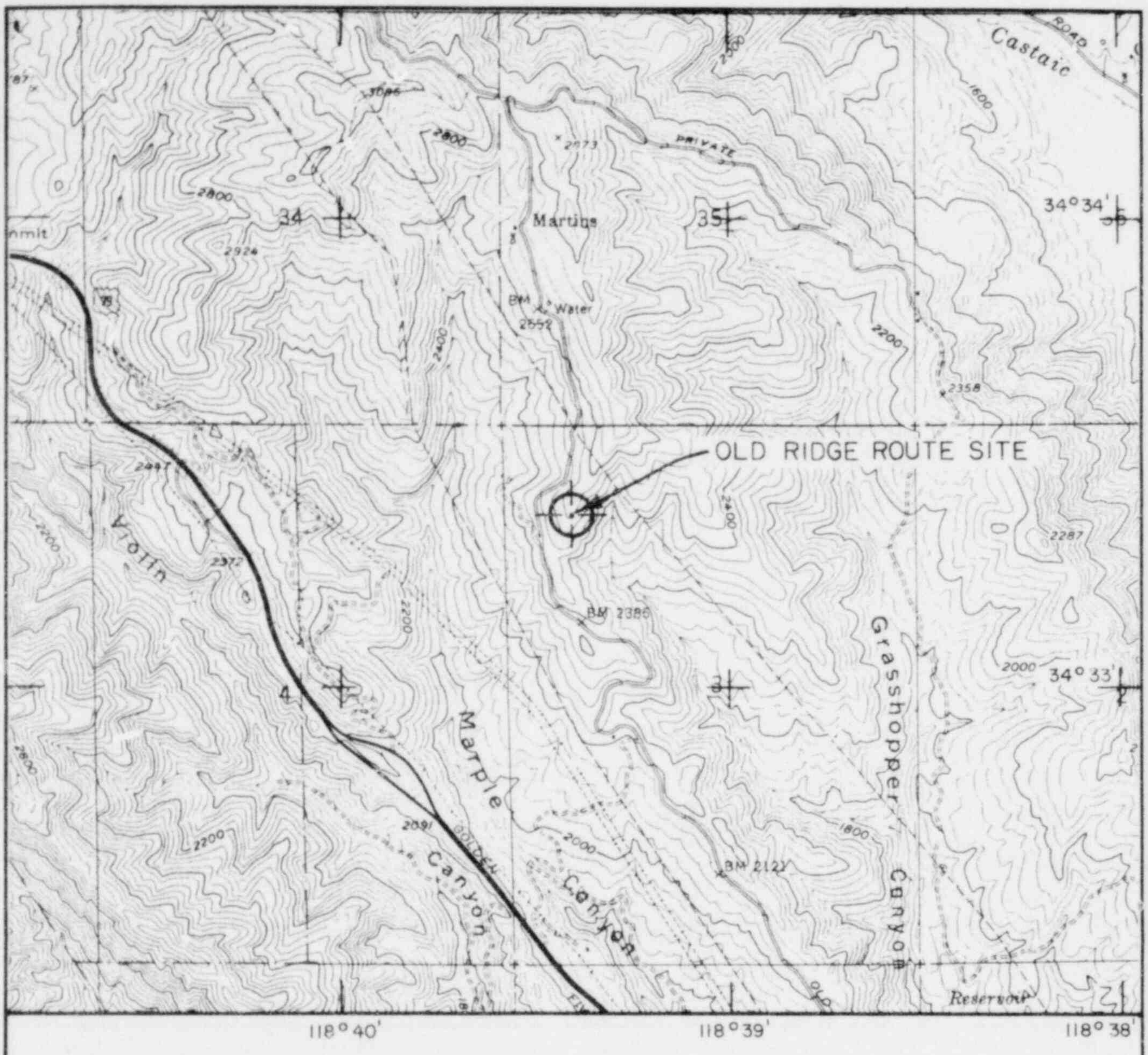
Outlet Works Control House Plan



Note: Location of Outlet Works Control House is shown on Fig. 5-2.

STATION INSTRUMENTATION
SANTA FELICIA DAM
OUTLET WORKS
PIRU, CALIFORNIA

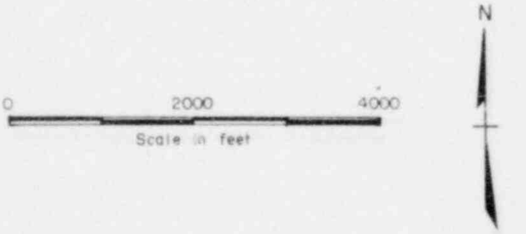
FIG. 5-3



OLD RIDGE ROUTE SITE

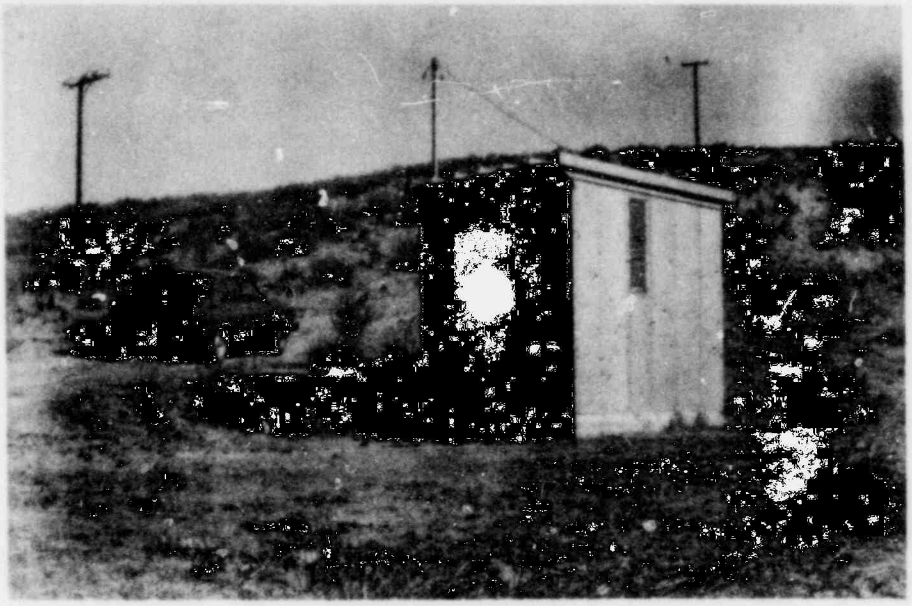
OLD RIDGE ROUTE SITE

USGS Topographic Quadrangle:	Whitaker Peak, California.
Coordinates:	34° 33' 22" N. 118° 39' 24" W.
Location:	4.5 miles north of the junction of Lake Hughes Road and the Old Ridge Route.
Structure:	Sheet-metal prefabricated instrument shelter.

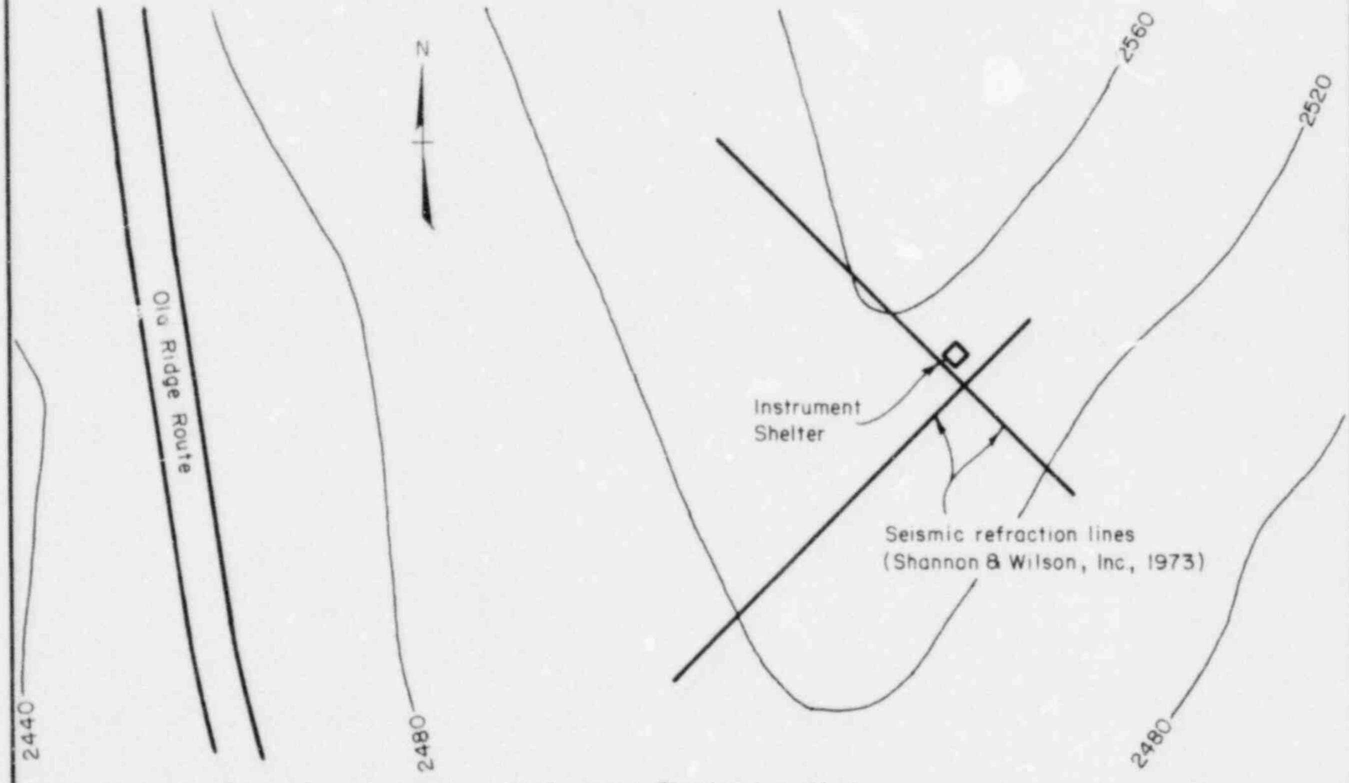


STATION LOCATION PLAN
OLD RIDGE ROUTE
CASTAIC, CALIFORNIA

FIG. 5-4



Instrument Shelter
View to the North



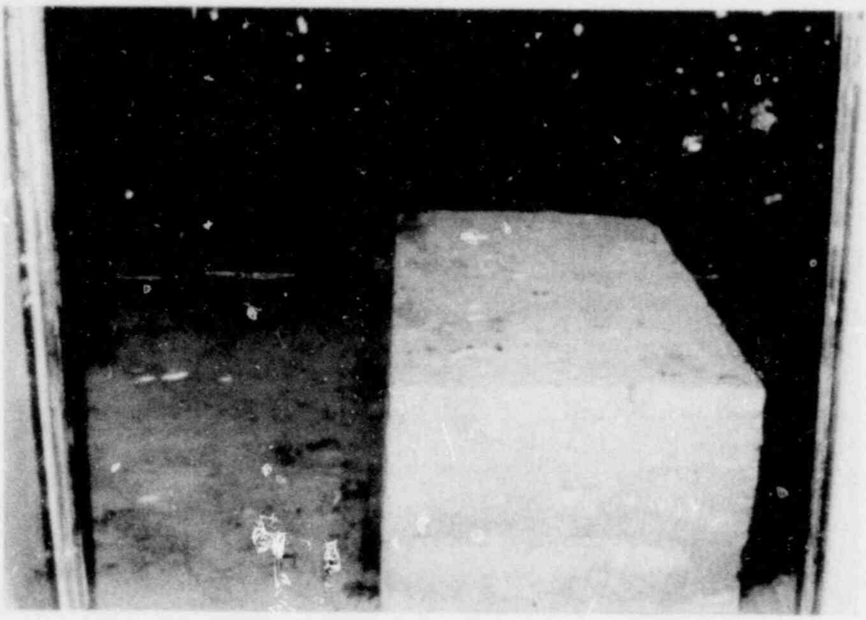
Instrument Shelter Location

0 50 100 150
Scale in feet

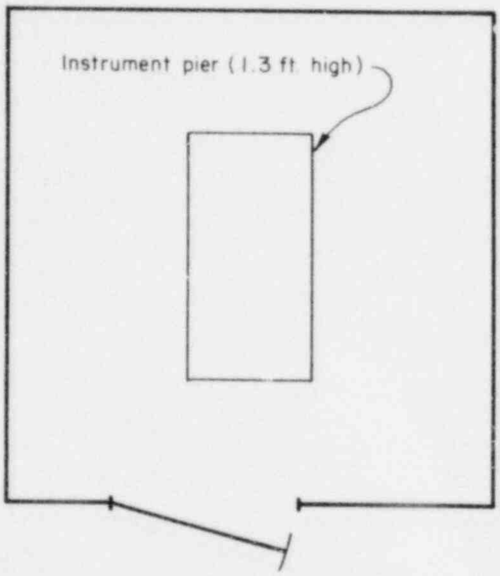
Note: Instrument shelter plan shown on Fig. 5-6.

ACCELEROGRAPH STATION
OLD RIDGE ROUTE
CASTAIC, CALIFORNIA

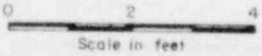
FIG. 5-5

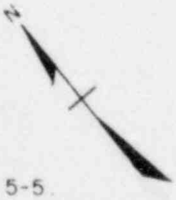


Instrument Pier
U.S.G.S. Station 110 (discontinued)



Instrument Shelter Plan

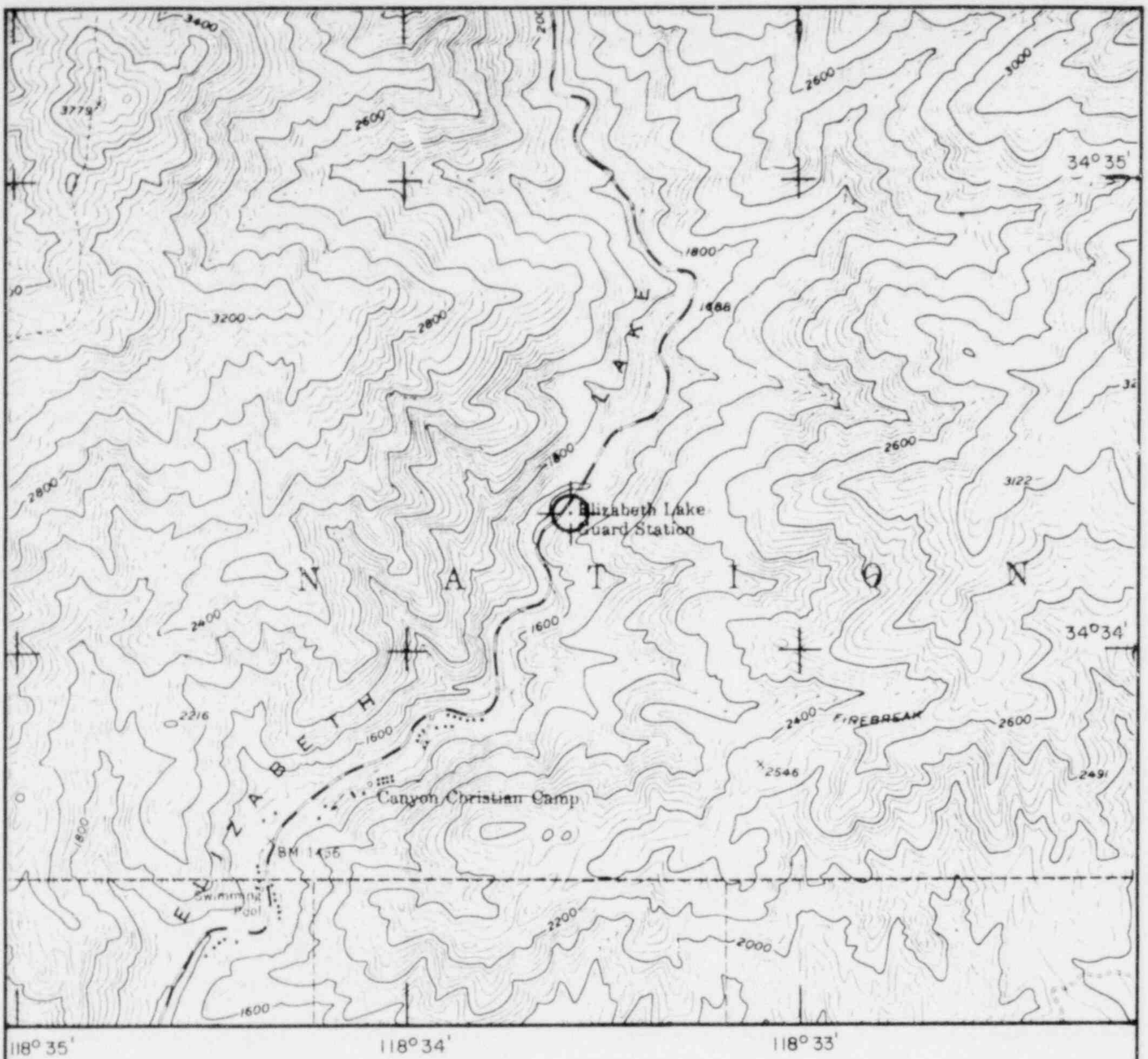




Note: Location of instrument
shelter is shown on Fig. 5-5.

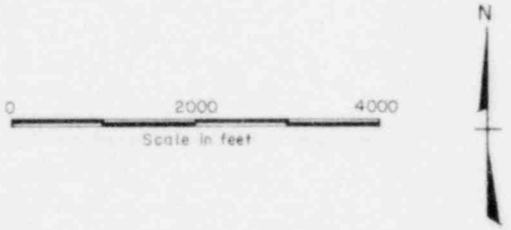
STATION INSTRUMENTATION
OLD RIDGE ROUTE
CASTAIC, CALIFORNIA

FIG. 5-6



ELIZABETH LAKE GUARD STATION*

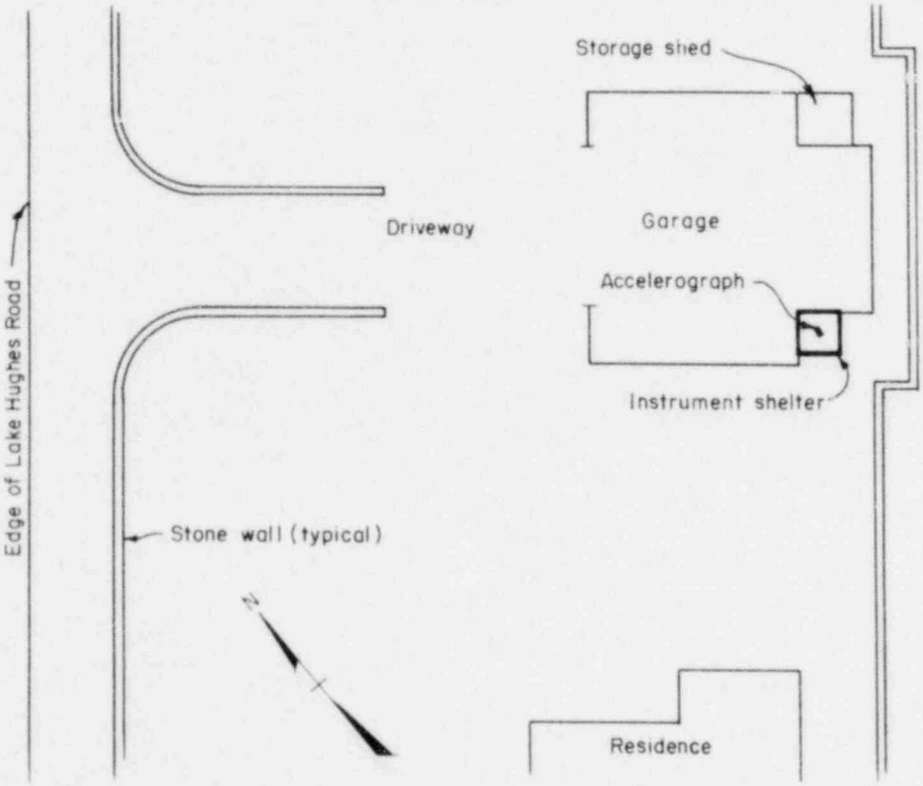
USGS Topographic Quadrangle:	Warm Springs Mountain, California
Coordinates:	34° 34' 17" N. 118° 33' 35" W.
Location:	Elizabeth Lake Canyon Road, approximately 4 miles north of Castaic Dam
Structure:	Small wooden housing attached to wooden truck garage.
Note:*	Recently renamed Red Mountain Guard Station



STATION LOCATION PLAN
LAKE HUGHES ARRAY STATION 12
LOS ANGELES COUNTY, CALIFORNIA

FIG. 5-7

Elizabeth Lake Guard Station
View to the South

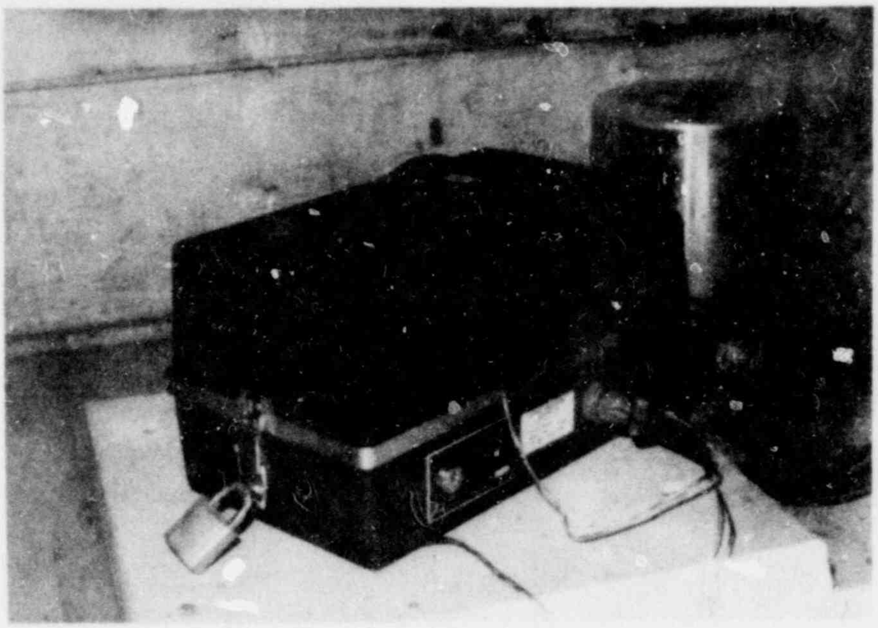


Ground Floor Plan

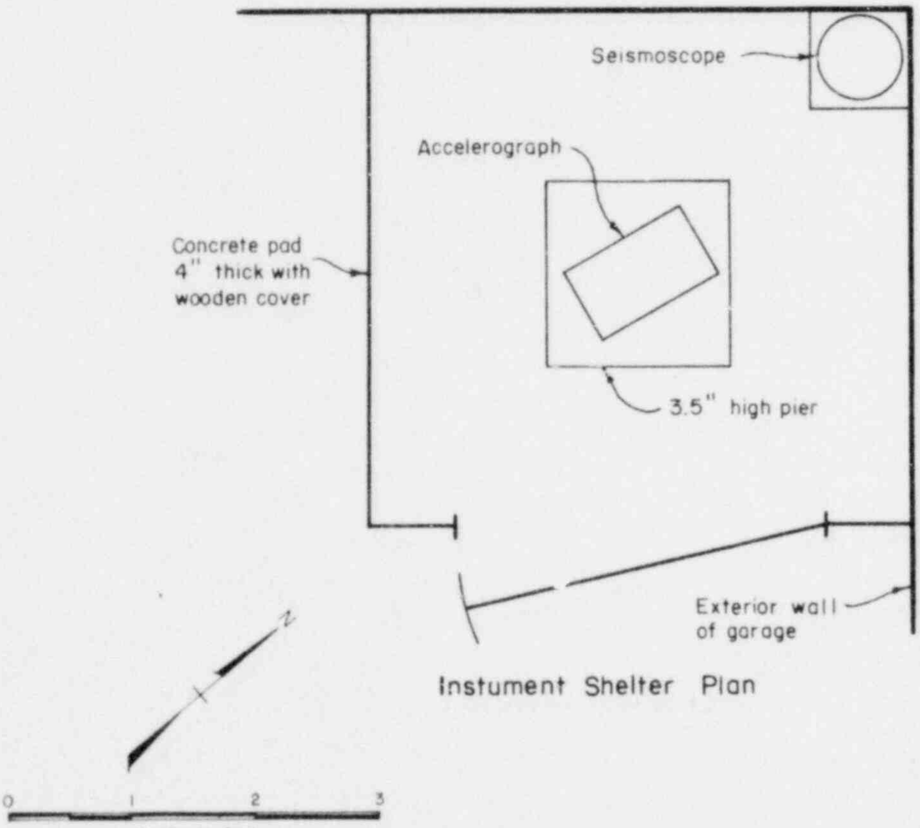
Note: Instrument shelter floor plan is
shown on Fig. 5-9

ACCELEROGRAPH STATION
LAKE HUGHES ARRAY STATION 12
LOS ANGELES COUNTY, CALIFORNIA

FIG. 5-8



SMA-1 Accelerograph
U.S.G.S. Station 128
Elizabeth Lake Guard Station

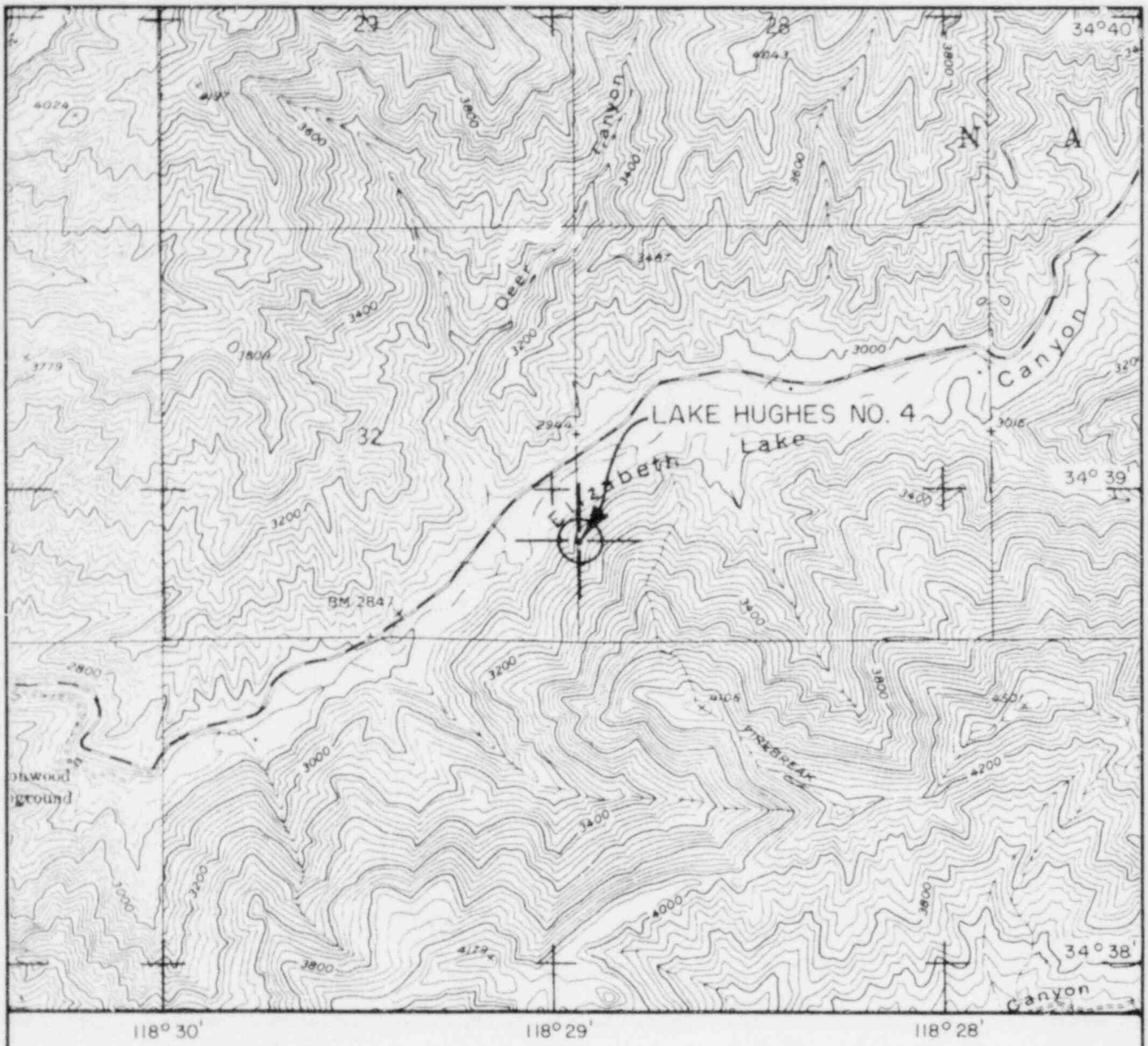


Instument Shelter Plan

STATION INSTRUMENTATION
LAKE HUGHES ARRAY STATION 12
LOS ANGELES COUNTY, CALIFORNIA

Note: Location of instrument shelter relative to Guard Station is shown on Fig. 5-8.

FIG. 5-9



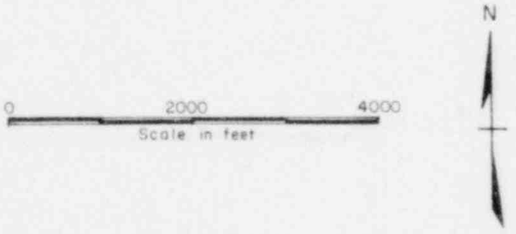
LAKE HUGHES NO. 4

USGS Topographic Quadrangles:
Lake Hughes and Burnt Peak, California.

Coordinates: 34° 38' 53" N.
118° 28' 56" W.

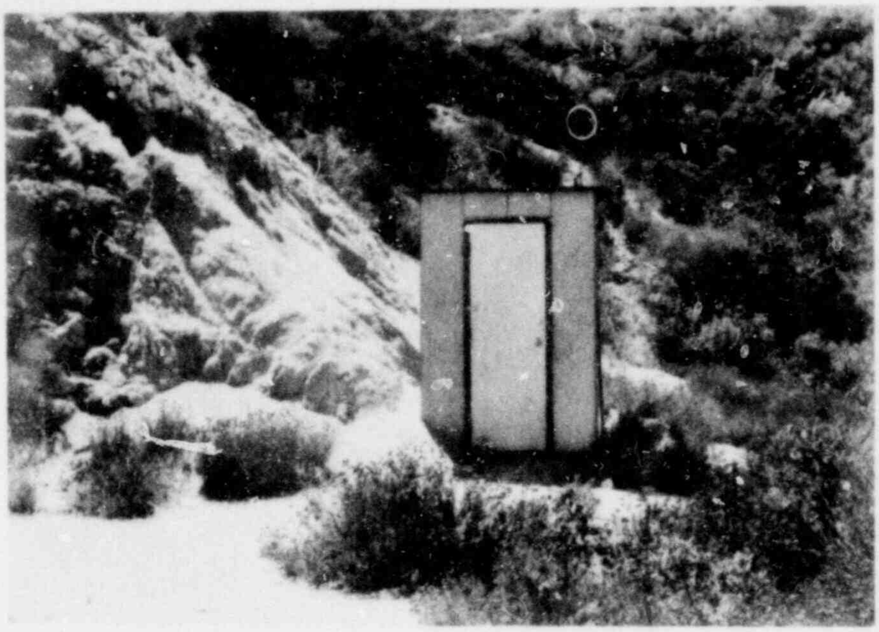
Location: William Mendenhall Probation Camp
2.5 miles southwest of Lake Hughes.

Structure: Prefabricated metal instrument shelter.

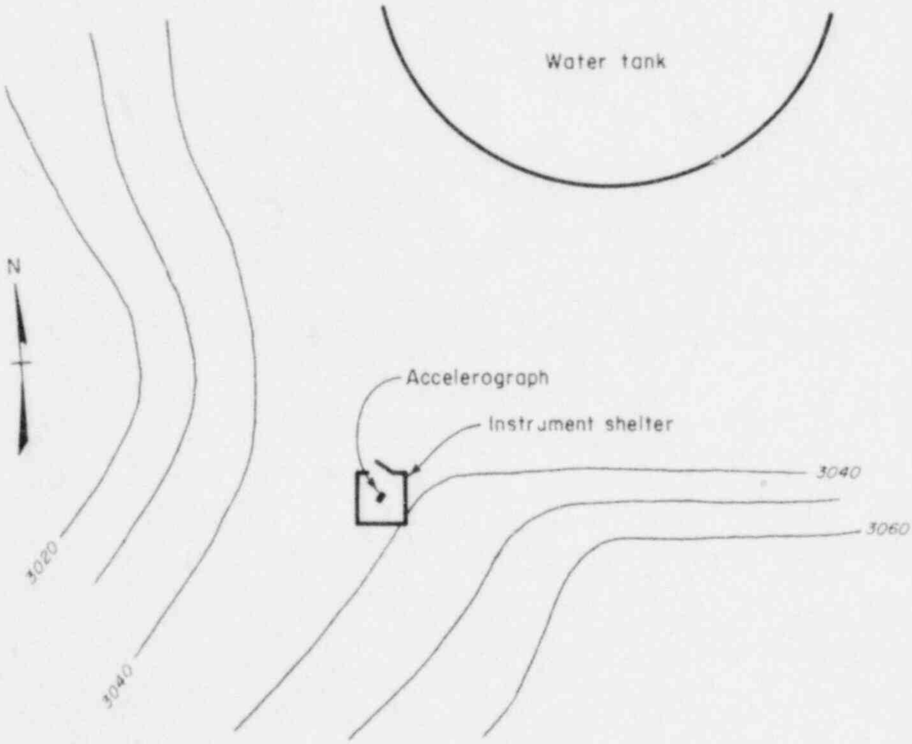


STATION LOCATION PLAN
LAKE HUGHES ARRAY
STATION NO. 4
LOS ANGELES COUNTY, CALIFORNIA

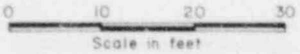
FIG. 5-10



Instrument Shelter
View to the South



Instrument Shelter Location

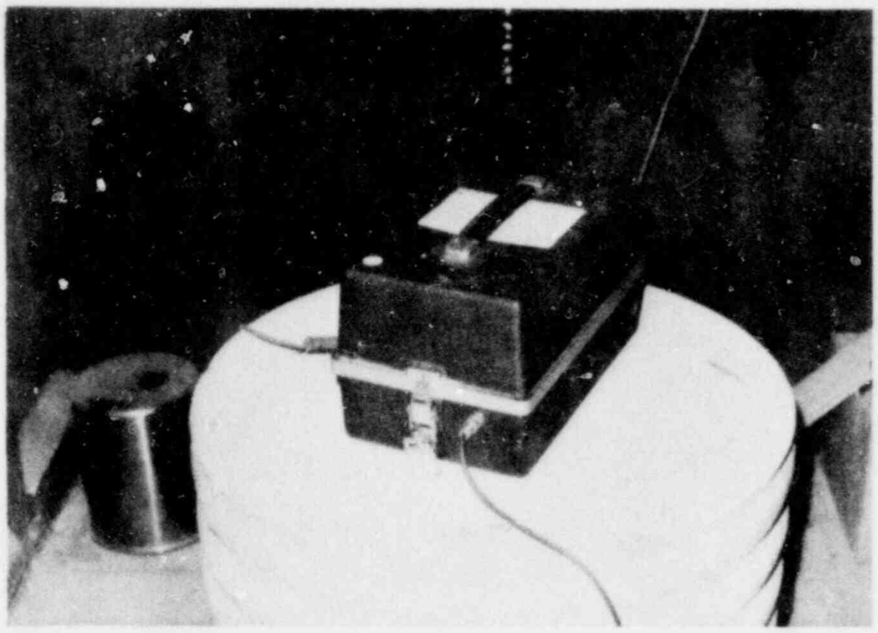


Notes: 1) Instrument Shelter plan shown on Fig. 5-12.

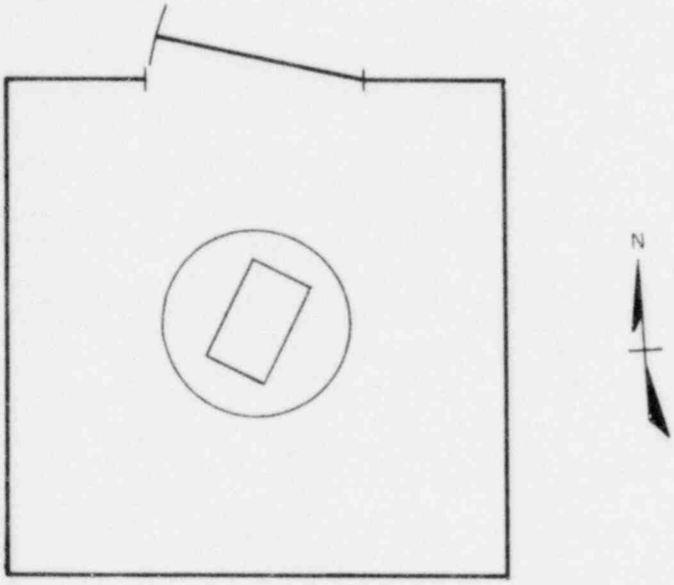
2) Elevations and contours are approximate.

ACCELEROGRAPH STATION
LAKE HUGHES ARRAY
STATION NO. 4
LOS ANGELES COUNTY, CALIFORNIA

FIG. 5-11



SMA-1 Accelerograph
U.S.G.S. Station 126



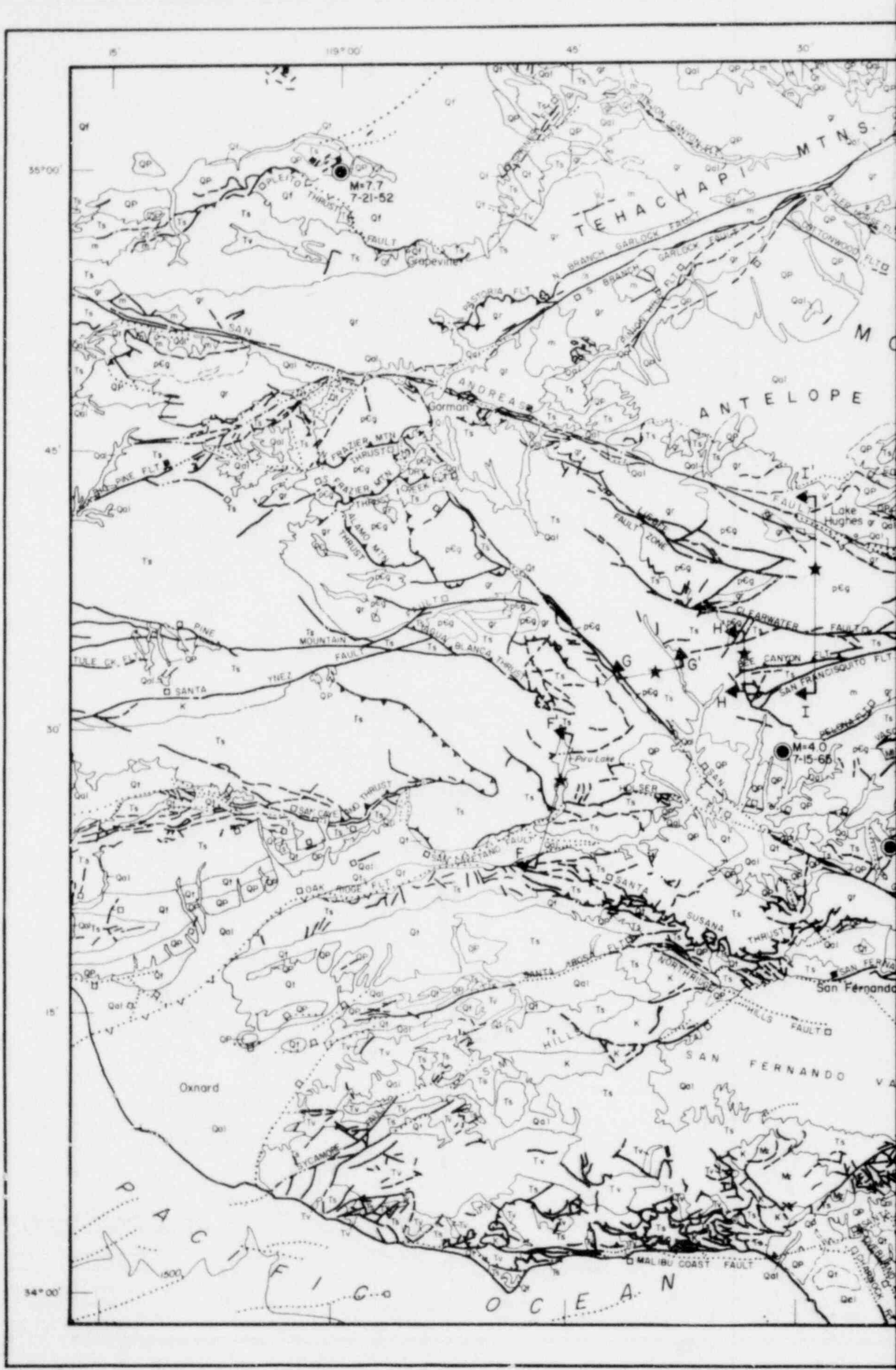
Instrument Shelter Floor Plan

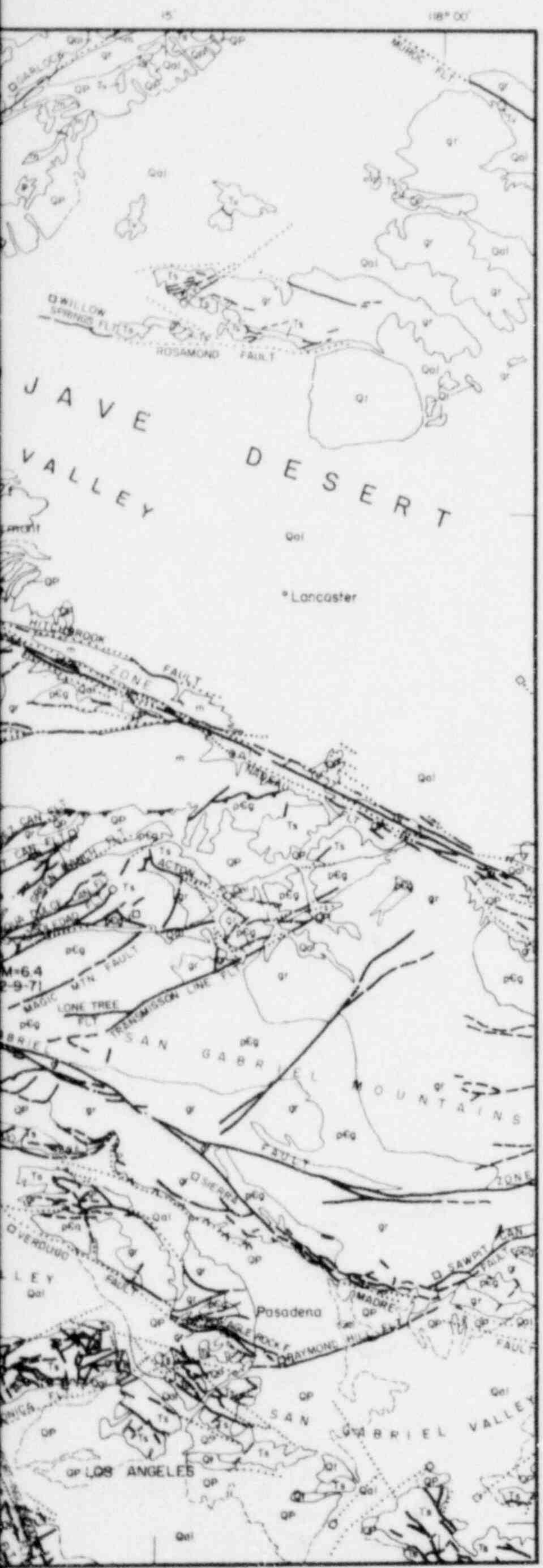
0 3
Scale in feet

Note: Location of instrument shelter is shown on Fig. 5-11.

STATION INSTRUMENTATION
LAKE HUGHES ARRAY
STATION NO. 4
LOS ANGELES COUNTY, CALIFORNIA

FIG. 5-12


15'
119°00'
45'
30'
35°00'
45'
30'
15'
34°00'
M=7.7
7-21-52
PLEITO THRUST
FAULT
Grapevine
TEHACHAPI MTNS.
N. BRANCH GARLOCK FAULT
S. BRANCH GARLOCK FAULT
PASTORIA FLT
COTTONWOOD FLT
SAN
ANDREAS
Gorman
ANTELOPE
M O
PINE FLT
FRAZIER MTN THRUST
S. FRAZIER MTN THRUST
ALAMO MTN THRUST
CREEK FLT
FAULT ZONE
Lake Hughes
I'
PINE MOUNTAIN FAULT
TULE CK. FLT
SANTA YNEZ
AGUA BLANCA THRUST
CLEARWATER FAULT
H'
G
G'
H
I
F'
SAN FRANCISQUITO FLT
CANYON FLT
M=4.0
7-15-65
Piru Lake
HOLSER
SAN GABRIEL FLT
SAN CAYETANO THRUST
SAN CAYETANO FAULT
F
OAK RIDGE FLT
SANTA SUSANA THRUST
SANTA ROSA FLT
NORTHRIDGE HILLS FAULT
San Fernando
SIMI HILLS
SAN FERNANDO VA
Oxnard
SYCAMORE
PACIFIC OCEAN
MALIBU COAST FAULT
1500
Qal
Qt
QP
Ts
Tv
K
gr
pЄg
m

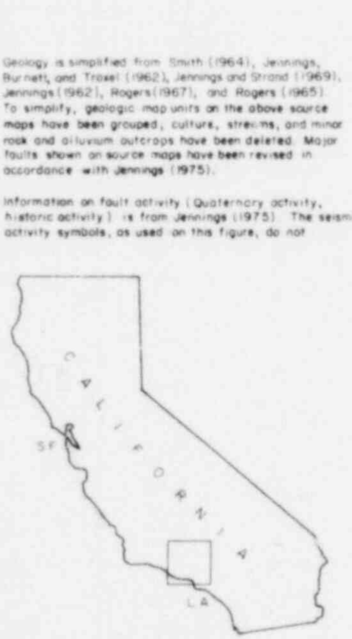


EXPLANATION

Qal	Alluvium, **Holocene in age**, includes dune deposits
Qf	Stream channel, fan, and basin deposits, **Holocene in age.**
Ql	Lake deposits, Quaternary in age
Qt	Marine deposits, marine and nonmarine terrace deposits, Quaternary in age; includes upper Pliocene marine deposits
QP	Nonmarine sedimentary deposits, Plio-Pleistocene in age
Tv	Volcanic rocks and igneous intrusive rocks, Tertiary in age
Ts	Sedimentary rocks, Tertiary in age
K	Sedimentary rocks, Cretaceous in age
Mz	Mesozoic sedimentary rocks; also includes metamorphic rocks
gr	Mesozoic granitic rocks; also includes pre-Cenozoic metamorphic, volcanic, and ultramafic rocks
m	Metamorphic and metasedimentary rocks, pre-Cretaceous in age
P	Sedimentary and volcanic rocks, Paleozoic in age
pЄg	Precambrian igneous and metamorphic rocks; includes crystalline rocks which may be as young as Mesozoic

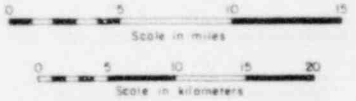
★	Accelerograph Station location
● M=7.7 7-21-52	Epicenter location, Richter magnitude, and date of occurrence
□	Faults that have moved during Quaternary time without historic record (approx. past 2 million years)
■	Faults that have moved during historic time (approx. 200 years)
Contact	Dashed where approximately located
Fault	Dashed where approximately located, dotted where concealed, queried where existence is uncertain
Thrust Fault	Barbs on upper plate, dashed where approximately located, dotted where concealed
Offshore Fault	Location approximate.

NOTES:
1) Geology is simplified from Smith (1964), Jennings, Burnett, and Troxel (1962), Jennings and Strand (1969), Jennings (1962), Rogers (1967), and Rogers (1965). To simplify, geologic map units on the above source maps have been grouped; culture, streams, and minor rock and alluvium outcrops have been deleted. Major faults shown on source maps have been revised in accordance with Jennings (1975).
2) Information on fault activity (Quaternary activity, historic activity) is from Jennings (1975). The seismic activity symbols, as used on this figure, do not necessarily mean that the entire length of the fault shows evidence of the respective activity. (See Jennings, 1975, for details).
3) Individual faults within the San Andreas fault zone show evidence of Quaternary and historic activity. (See Jennings, 1975, for details).
4) Heavy border on boxes indicates units that appear on this figure.
5) Earthquake magnitudes and epicentral locations are from Hudson, et al. (1969-1975a and b) and Hileman, et al. (1973).



Location of Geologic Map

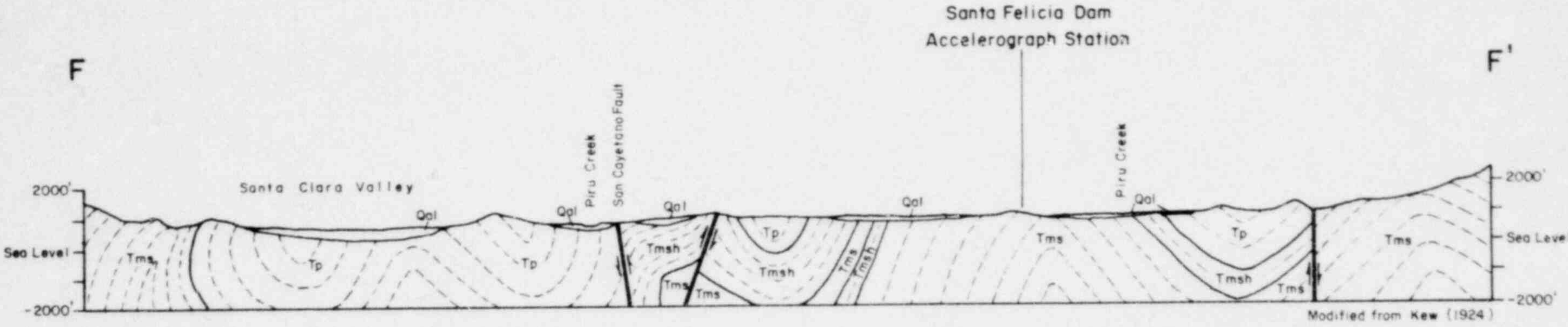
STATION	CROSS-SECTION & FIG. NO.	
Santa Felicia Dam	F-F'	5-14
Old Ridge Route	G-G'	5-15
Lake Hughes Array Station 12	H-H'	5-16
Lake Hughes Array Station 4	I-I'	5-17



Submarine contour interval 1500 feet

GEOLOGIC MAP
LAKE HUGHES REGION
CALIFORNIA

FIG. 5-13



Modified from Kew (1924)

EXPLANATION

Holocene

Qal Alluvium (Qal)

Pliocene

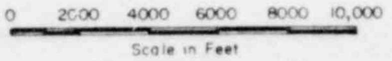
Tp Pico Formation; marine, fine to coarse-grained sandstone and conglomerate (Ts)

Miocene

Tmsh Modelo Formation; siliceous, diatomaceous, and clay shales (Ts)

Tms Modelo Formation; coarse sandstone (Ts)

Tm Modelo Formation; massive sandstone with interbedded shale and conglomerate (Ts)



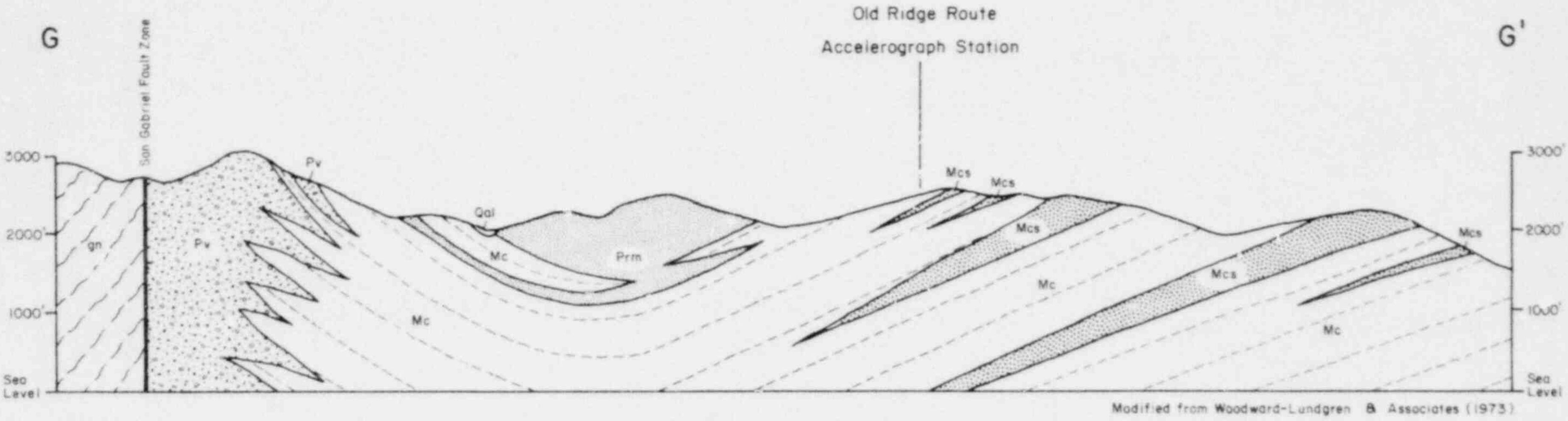
Notes:

1) Abbreviations in parentheses refer to geologic symbols used on Fig. 5-13.

2) For plan view of cross-section see Fig. 5-13.

GEOLOGIC CROSS-SECTION F-F'
SANTA FELICIA DAM
OUTLET WORKS
PIRU, CALIFORNIA

FIG. 5-14



Modified from Woodward-Lundgren & Associates (1973)

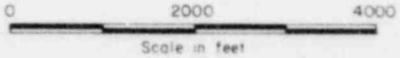
EXPLANATION

Holocene	Qal	Alluvium; gravel, sand, and clay (Qal)
Pliocene	Prm	Marple Canyon Tongue of Ridge Route Formation; predominantly sandstone (Ts)
Miocene or Pliocene to Pleistocene	Pv	Violin Breccia; rubble of gneiss blocks to six-foot diameter in muddy matrix (Ts)
Miocene	Mc Mcs	Castaic Formation (Ts); Mc – Predominantly shale Mcs – Predominantly shale with sandstone lenses
Pre-Tertiary	gn	Gneiss (p€g)

Notes:

1) Abbreviations in parentheses refer to geologic symbols used on Fig. 5-13.

2) For plan view of cross-section see Fig.5-13.



GEOLOGIC CROSS-SECTION G-G'
OLD RIDGE ROUTE
CASTAIC, CALIFORNIA

FIG. 5-15