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Geotechnical and Strong Motion Earthquake Data from U.S. Accelerograph Stations

Anchorage, AK (AMU Gould Hall)
Seattle, WA (Federal Office Building)
Olympia, WA (Highway Test Lab)
Portland, OR (State Office Building and PSU Cramer Hall)

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ABSTRACT

This is the fourth in a series of reports presenting geotechnical and seismic data for selected accelerograph stations. This volume discusses the findings at five stations, one each in the cities of Anchorage, Alaska; Seattle, Washington; Olympia, Washington; and two in Portland, Oregon. This report contains information for each site describing the station building and instrumentation, geology and seismicity of the area, and site conditions. Deep borings, downhole geophysical measurements, and laboratory tests were conducted at each station, except Olympia, to evaluate the subsurface conditions. Since subsurface data was already available for Olympia, field and laboratory testing was not conducted for this study.

SUMMARY

The accelerograph stations discussed in this report include the Alaska Methodist University (AMU) Gould Hall in Anchorage, the Federal Office Building in Seattle, the Highway Test Lab in Olympia, and the State Office Building and Portland State University (PSU) Cramer Hall in Portland. Subsurface conditions that were encountered in the borings at each of the sites are summarized below.

Subsurface conditions at AMU Gould Hall in Anchorage consist of at least 300 feet of glacial sediments. These sediments are primarily very dense sands and gravels except for some till-like, hard, clayey silts and silty clays encountered between depths of 42 and 125 feet. Shear wave velocities in the upper sands and gravels and till-like silts and clays were generally above 1600 fps. Velocities in the underlying sands and gravels, below 125 feet, increased from 2450 fps at the top of the stratum to 4400 fps below 245 feet.

Subsurface conditions adjacent to the Federal Office Building in Seattle consist of 23 feet of fill overlying glacial sediments that extend to a depth of at least 400 feet. The glacial sediments primarily consist of very dense sands and gravels except for a hard, silty clay layer encountered between depths of 77 and 153 feet. Shear wave velocities generally ranged between values of 1350 and 2000 fps in the glacial sediments above a depth of 216 feet. Below this depth, the velocities were at least 2500 fps.

Subsurface conditions at the Highway Test Lab in Olympia consist of 10 feet of fill overlying glacial sediments to a depth of at least 511 feet. The glacial sediments are primarily very dense sands. Interbedded very stiff to hard silts and clays and very dense sands were encountered between depths of 40 and 135 feet and again below 474 feet. Shear wave velocities in the glacial sediments gradually increased with depth from a value of approximately 700 fps near the ground surface to 1900 fps at a depth of 410 feet. Velocities greater than 3000 fps were obtained below a depth of 430 feet.

Subsurface conditions at both the State Office Building and PSU Cramer Hall consist of alluvium overlying a sequence of Tertiary strata. For this study, one deep boring was advanced in a central location between both sites. Borings of others that are located closer to each site were reviewed to study the depth of alluvium locally. From

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these sources, the alluvium consists of medium dense, silty sand and sandy silt. It is approximately 65 feet thick near the State Office Building and 100 feet thick near Cramer Hall. As determined from the boring for this study, the underlying Tertiary strata consist of about 140 feet of very dense gravel overlying breccia and basalt. Shear wave velocities in the alluvium and upper 25 feet of the weathered Tertiary stratum (gravel) ranged from 775 to 1800 fps. Shear wave velocities of 3600 fps and higher were obtained below a depth of 116 feet.

VOLUME 4

REPORT DIVISIONS

GEOTECHNICAL AND STRONG MOTION EARTHQUAKE DATA FROM U.S. ACCELEROGRAPH STATIONS

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INTRODUCTION

Purpose and Scope

Although many theoretical and analytical advancements have been made in the seismic design of major structures, they have far outstripped our understanding of the basic earthquake data base. This data base consists of earthquake ground motions that have been recorded at strong motion accelerograph stations located in various parts of the United States as well as other countries. Together, these earthquake records constitute a data base of maximum ground motion values, time histories of acceleration and response spectra, upon which seismic design recommendations are formulated. Effective use of this data, however, has been clouded by incomplete information and inconsistencies in reported subsurface conditions at many of the earthquake recording stations (Duke and Leeds, 1972; EERI and NOAA, 1971; Seed, et al., 1974, 1975; Trifunac and Brady, 1975; etc.). Thus, to make better use of the earthquake data base, it is necessary to have a more clear understanding of the subsurface characteristics at the various accelerograph stations.

The purpose of this report is to compile basic geotechnical and strong motion earthquake data for selected accelerograph stations in the United States. This report contains information on a total of five accelerograph stations, one each in Anchorage, Alaska; Seattle, Washington; Olympia, Washington; and two in Portland, Oregon. The scope of work included a reconnaissance of each site and an evaluation of subsurface conditions with a deep boring, geophysical surveys and laboratory tests. In addition, geological and seismological information was researched and is presented for each station. By providing this information for the more significant accelerograph stations, the earthquake data base may be used more effectively, leading to more refined seismic design practices.

Authorization

This study was performed under Contract No. AT (49-24)-200 between the U.S. Nuclear Regulatory Commission and the joint venture of Shannon & Wilson, Inc., and Agbabian Associates (SW-AA). This study is part of an overall research program to evaluate soil behavior under earthquake loading conditions.

Previous Reports

As part of the SW-AA joint venture work, over 70 accelerograph stations have been studied since the program began in 1975. This particular study represents the fourth in a series of reports on accelerograph stations that are generally regarded as being founded on "soil" deposits. Other studies have been conducted for stations located on "rock" and for selected stations in Los Angeles, California. Reports in the series are listed below:

a) "Soil" Site Studies:

Volume No.	Stations Studied
1 (SW-AA, 1975)	Ferndale, Parkfield (Cholame No. 2) and El Centro, California
2 (SW-AA, 1976a)	Pasadena, Santa Barbara, Taft, and Hollister, California
3 (SW-AA, 1977a)	Gilroy, California; Logan, Utah; Bozeman, Montana; Tacoma, Washington; and Helena, Montana
4 (this report)	Anchorage, Alaska; Seattle, Washington; Olympia, Washington; and Portland, Oregon

b) "Rock" Site Studies:

Volume No.	Stations Studied
1 (SW-AA, 1976b)	19 accelerograph stations in southern California
2 (SW-AA, 1977b)	29 accelerograph stations in both northern and southern California

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

Acknowledgements and Contributors

This study benefited from the efforts of numerous individuals. We especially acknowledge and 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 and contributions as project monitor.

We also acknowledge a number of other individuals and organizations for their assistance and cooperation in this work. For granting drilling access, we thank Mr. Ross Olds, Buildings and Grounds Director at Alaska Methodist University; Mrs. Peg Neuman of Fisher Properties, Inc. (manager of vacant lot adjacent to the Federal Office Building in Seattle); and Mr. W. Neland, Director of the Physical Plant at Portland State University. For assistance in expediting the field work and for contributing geotechnical data at the Portland State University site we thank Mr. E. Smith and D. Barkost of the Physical Plant Department. The staff of the Seismic Engineering Branch of the U.S. Geological Survey, including Messrs. F. Ellis, E. Etheridge and D. Johnson, has been particularly helpful in contributing geotechnical and seismic data relating to the strong motion stations.

The SW-AA joint venture efforts were directed by Dr. R. P. Miller, Project Manager. Project Engineer and principal investigator for this task was Mr. W. P. Grant. Mr. Grant coordinated most of the field and laboratory work and organized and prepared most of the materials in this report. The geological materials in this report were

collected and assembled by Mr. K. Marcus under the supervision of Messrs. D. Clayton and H. H. Waldron. The field work was monitored by Messrs. Grant and Marcus. Mr. J. M. Musser obtained the field geophysical data, and Mr. A. Azzam supervised laboratory testing.

REPORT ORGANIZATION

General

This report is organized into a main text and three appendices. Within the main text and each appendix are four sections (14-17), presenting information for the individual accelerograph stations. Figure 1 shows the locations of the accelerograph stations that were investigated and their corresponding section numbers. The two stations located in Portland are discussed in Section 17.

The main text, under the heading of Station Data, has station information organized into three main areas: Station Description, Geology and Seismicity, and Site Conditions. Details of particular items presented in the main text are included in the appendices. The structure and format of the data contained in the report are discussed below.

Station Data

Station Description

For each site, information is presented on the accelerograph station location and building as well as a discussion of the station instrumentation and a listing of earthquakes recorded at the site. This narrative is supplemented with drawings showing the location and layout of the building, and with photos of the building exterior and instrumentation. Information on the instrumentation at the station was primarily obtained from the equipment maintenance records kept at the station, and from records on file with the USGS Seismic Engineering Branch in Seattle, Washington, and Menlo Park, California.

Geology and Seismicity

The geology of each station is discussed on a regional and local level. This discussion is accompanied by a map displaying the regional geology and a subsurface cross-section through or adjacent to the site. Data sources used in compiling the geologic map are indicated on a separate geologic index map.

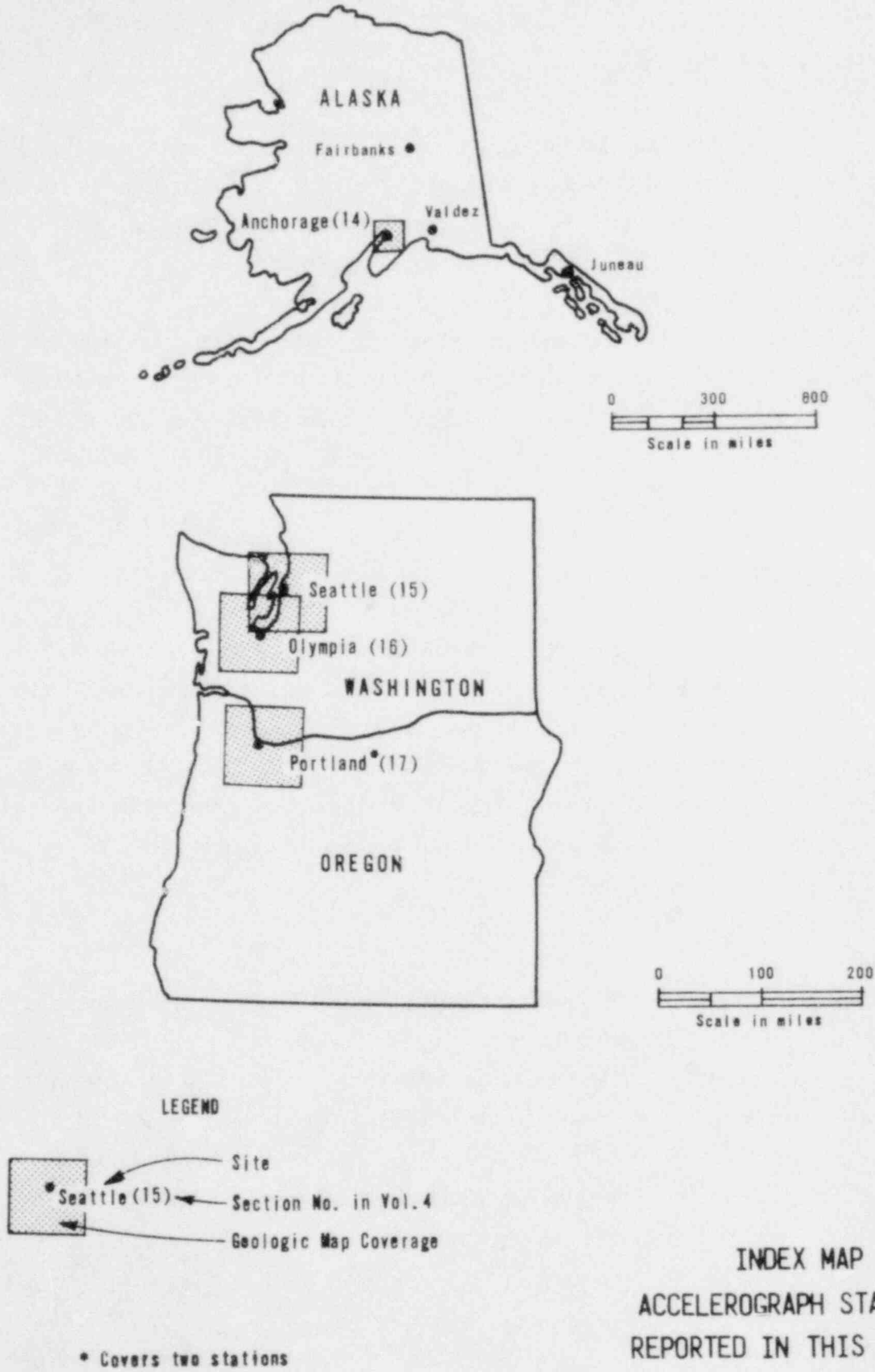
The geologic structure and seismicity of each region are also discussed. Significant faults and structural trends are indicated on the geologic map, as are the epicenters of some of the more significant historic earthquakes. The text also discusses any correlations that have been made between the structure in the area and historic events.

Site Conditions

The site conditions at each station are discussed in terms of surficial features, subsurface conditions and dynamic soil properties. The subsurface conditions at all sites, except Olympia, were evaluated based on a deep boring, geophysical measurements and laboratory tests performed for this study. The conditions at Olympia were previously studied by others. Findings of the field studies and results of the laboratory tests are all summarized on a single figure for each site.

Appendices

Following the main text are three appendices: A - Earthquake Records, B -Field Explorations, and C - Laboratory Testing. Appendix A presents a listing of earthquakes that have been recorded at each station. Time history plots of ground motion and response spectra are also presented for those records that have been digitized. Appendix B presents detailed findings of the field drilling and geophysical testing program. A description of the general laboratory testing procedures and the results of the individual tests are presented in Appendix C.



INDEX MAP
ACCELEROGRAPH STATIONS
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FIG. 1

STATION DATA

Section 14

AMU Gould Hall
Anchorage, Alaska

SECTION 14

AMU GOULD HALL, ANCHORAGE, ALASKA

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14.1 STATION DESCRIPTION

14.1.1 Location and Building

Anchorage is located in the southern portion of Alaska near the base of the Kenai peninsula. The city lies at the head of Cook Inlet, which is a large tidal estuary of the Gulf of Alaska. Anchorage, the largest city in the state, lies within the Greater Anchorage Area Borough.

Gould Hall is a student dormitory on the Alaska Methodist University (AMU) campus. The university is within the Anchorage city limits and is about 3 miles southeast of the downtown area. The location of Gould Hall is indicated on Fig. 14-1.

Gould Hall is a rectangular shaped, low-rise building (Fig. 14-2). Plan dimensions of the structure are about 35 by 225 feet. The building has two stories above grade and a daylight basement. The southeast wall of the basement is fully exposed, while the northwest wall is embedded about 5 feet below grade.

Gould Hall is a reinforced concrete block building with conventional footing foundations. Precast concrete panels are used on the northwest and southeast exterior walls of the building, while the other two walls are faced with brick. Interior partitions and shear walls at the ends of the building are constructed of reinforced concrete blocks. The basement floor is a concrete slab on grade. Structural loads are supported on both spread and continuous footings. Construction was completed in 1961.

14.1.2 Instrumentation and Earthquake Recordings

The Gould Hall accelerograph station is part of the USGS strong motion instrument network and is identified as station number 2702. Gould Hall was initially instrumented on May 8, 1964, shortly after the destructive, magnitude 8.3, Prince William Sound earthquake of March 27, 1964. The instrumentation installed at the station consisted of an AR-240 accelerograph and a seismoscope, serial numbers 209 and 178, respectively. On August 24, 1965, the original seismoscope was removed and a new one (S/N 2956) installed at the same location. The AR-240 accelerograph remained in place until May 21, 1975, at which time it was replaced with a SMA-1 recorder (S/N 312). The original AR-240 accelerograph and the SMA-1 replacement unit were installed at the following bearings (pendulum motion): Longitudinal - S 45 E; Vertical - Down; Transverse - N 45 E (USGS, unpub.). On May 18, 1977, the SMA-1 recorder was rotated 180° and refastened to the floor to provide better access for servicing.

All instruments at Gould Hall have been located in the basement in room 3 (Fig 14-2). Others may refer to the basement by different names, such as the "ground" floor or "first" floor. A plan of the accelerograph room and a photo of the current instrumentation are shown in Fig. 14-3. Both the SMA-1 accelerograph and the seismoscope at the station are bolted directly to the concrete floor slab. In this portion of the building, the basement is about 5 feet below the adjacent outside grade.

Five earthquakes have been recorded at the Gould Hall accelerograph station, all on the original AR-240 instrument. Details of these earthquakes are presented in Appendix A. Summary data is given below.

Date (Mo-Da-Yr)	Magnitude (Richter)	Maximum Intensity (MM)	Peak Acceleration (g)
5-11-65	5.5	IV	0.05
8-30-66	5.8	V	0.03
6-1-70	5.5	IV	≤ 0.05
12-29-74	5.6	V	0.03
12-31-74	5.9	V	0.09

Two of the station records are significant in earthquake engineering as they have peak accelerations of 0.05 g or greater. These are the May 11, 1965 and December 31, 1974 records. Currently, neither has been digitized and processed. However, the 1974 record may be processed by the USGS in the next year.

14.2 GEOLOGY AND SEISMICITY

14.2.1 Regional Geology

Surface geology of the Anchorage region is depicted on the Geologic Map of Fig. 14-4. For the purpose of this report, the Anchorage region is defined by the area within about 60 kilometers (37 miles) of Anchorage. The extent of this region, relative to the state of Alaska, is indicated on the map insert of Fig 14-4. The Geologic Map was prepared from the data sources shown in Fig. 14-5. Symbols shown in parentheses in the following discussion refer to geologic units on the map.

The major physiographic provinces in the Anchorage region are the Aleutian and Alaska Ranges on the extreme west and northwest, the Kenai - Chugach Mountains on the east and southeast, and between these two mountainous provinces, the Cook Inlet Lowlands (Wahrhaftig, 1965). The city of Anchorage is situated near the boundary between the Cook Inlet Lowlands and the Kenai - Chugach Mountains, at the head of Cook Inlet, a major marine re-entrant in the Lowlands.

The Kenai - Chugach Mountains, on the east, are primarily underlain by Mesozoic metasedimentary and metavolcanic rocks, including greenstone, metagraywacke, slate, and argillite (Magoon, et al., 1976; Clark, 1972). Two structurally distinct, but lithologically similar, groups of these Mesozoic strata are separated by the Eagle River fault. They are the Valdez Group (Msm) southeast of the fault and the McHugh Complex (Mvm), which has been thrust over it from the northwest. Mesozoic and/or Paleozoic ultramafic and gabbroic rocks (MzPzu) and some isolated outcrops of intrusive rocks (Mi) occur near Palmer on the northwest side of the Eagle River fault.

The Cook Inlet Lowlands occupy a northeast-trending structural trough which is thought to be underlain to a large degree by a thick accumulation of moderately consolidated Tertiary sedimentary rocks and unconsolidated Quaternary sediments (Miller and Dobrovolny, 1959). Tertiary bedrock (Ts), locally more than 16,000 feet thick, is exposed along the Matanuska Valley in the northeast part of the region. The rocks consist mostly of Paleocene to Oligocene non-marine sandstone, siltstone, shale, conglomerate, and minor lignite. In the Talkeetna Mountains north of the Matanuska Valley, the Tertiary section also includes in excess of 6,000 feet of Miocene to Oligocene volcanic rocks. Plutonic granitic rocks of Cretaceous and

Tertiary age (Tkgd) crop out north of the Eagle River fault near Palmer, and north of the Lake Clark-Castle Mountain fault system northwest of Anchorage.

Quaternary deposits in the Anchorage region represent several major glacial advances, ranging from pre-Wisconsin to Wisconsin in age. The oldest pre-Wisconsin glacial sediments include till, outwash, and lacustrine and eolian sediments deposited prior to and during the Eklutna Glacial Stade (Qpe; and Qe). These units crop out principally in the southern portion of the Anchorage region. The youngest pre-Wisconsin glaciation (Knik Glacial Stade) deposited advance outwash, lateral and ground morainal deposits, pitted outwash, glaciofluvial deposits, and ice-contact stratified drift (Qk). In Wisconsin time, the Naptowne Glaciation resulted in the development of extensive kame terraces and other glaciofluvial outwash deposits (Qn). In many areas these various Quaternary deposits have not been differentiated (Qs).

Holocene deposits, including alluvial, lacustrine, and eolian sediments (Qal), occupy the floors of abandoned meltwater channels and lakes created during the Wisconsin Glaciation. Many of the larger streams have built large deltas or alluvial fans at their mouths. Thick Holocene beach deposits and elevated tidal flats also are present along the shorelines. Other post-glacial sediments include landslide slump and flow deposits (Qls).

14.2.2 Local Geology

The local geology in the vicinity of Anchorage is depicted diagrammatically in Geologic Cross-Section N-N' of Fig 14-6. As indicated in this figure, Anchorage is situated near the margin of two distinctive physiographic and geologic provinces - the Cook Inlet Lowlands on the west and the Chugach Mountains on the east. The Gould Hall accelerograph station, located in the Lowlands in the southeastern part of Anchorage, is approximately 6 miles west of the mountain front.

The Chugach Mountains east of Anchorage are underlain by metamorphosed Mesozoic bedrock (Mvm and Msm) that has been intensely fractured. Rocks in the McHugh Complex (Mvm) are primarily metamorphosed sandstone while those of the Valdez Group (Msm) are predominantly metagraywacke and metasiltstone. As shown in cross-section N-N' (Fig 14-6), these strata plunge westward below a wedge of

Quaternary and Tertiary strata.

The Cook Inlet Lowlands in the vicinity of Anchorage are underlain by Tertiary bedrock and unconsolidated Quaternary sediments. The Tertiary strata include sedimentary rocks (Ts), primarily non-marine sandstone, siltstone, shale and conglomerate, and plutonic granitic rocks (Tkgd). The Quaternary sediments overlying the bedrock may be as thick as 900 feet in the western part of Anchorage (Schmoll and Dobrovolny, 1972). These sediments include till and drift deposits of the Naptowne (Qn), Knik (Qk), and Eklutna (Qe) Glacial Stades, and Holocene alluvium (Qal).

14.2.3 Structure and Seismicity

The Anchorage region has had a long history of tectonism dating back at least as far as Mesozoic time. The region is situated near the boundary of the North American and Pacific lithospheric plates, where subduction of the oceanic Pacific plate beneath the continental North American plate has resulted in crustal uplift and compression, producing an oceanic trench and a series of arcuate mountain ranges paralleling the subduction core. The present orogenic cycle, which probably began during the Pliocene, has resulted in regional compressive deformation in a general north-south direction around the margin of the Gulf of Alaska.

The Anchorage region encompasses parts of several orogenic belts, including the Talkeetna and Seldovia geanticlines and the Matanuska and Chugach Mountains geosynclines. These nearly parallel arcuate orogenic belts swing from a northeasterly orientation within the region to an easterly to northwesterly orientation just east of the map area (Payne, 1955). Several major arcuate fault zones also occur within the region, generally paralleling, but locally transecting, the trend of the major fold belts. The most prominent of these structures include the Eagle River, Castle Mountain, and Knik faults. The Eagle River fault is a major thrust fault, which, as shown on Fig. 14-6 and discussed in Section 14.2.1, separates two major blocks of Mesozoic strata in the Chugach Mountains east of Anchorage. It is paralleled on the northwest by the Knik fault. This fault, although buried beneath a thick accumulation of Quaternary sediments in the vicinity of Anchorage, is thought to offset the Tertiary strata, based on the presence of an apparent offset of Tertiary bedrock in the area and on geophysical evidence (Grantz, et al., 1963; and Barnes, 1966). The Castle Mountain fault northwest of the Matanuska Valley is the largest known structure with Quaternary displacement. Recent mapping has shown it to be active along part of its extent, with oblique-slip movement occurring between 225 and 1,860 years ago (Detterman, et al., 1974). This structure, although primarily a high-angle reverse fault, is also thought to have a large component of right-lateral displacement (Detterman, et al., 1976). The cumulative displacement on this fault is not known, but it is probably at least a few kilometers.

Southern Alaska and the adjoining Aleutian Island chain are in a region of extreme seismo-tectonic activity, occupying a part of the nearly continuous circum-Pacific seismic belt. This zone of seismo-tectonic activity in the southern part of Alaska is circumferential to the Gulf of Alaska and coincident with the arcuate mountain ranges and intervening lowlands that extend from the Alaskan Range on the north to the Aleutian Trench on the south.

Despite the high level of seismic activity in this region, the historical record of this activity is imperfectly known. Prior to the 20th century, the sparse population that existed throughout much of Alaska precluded obtaining more than a very fragmentary record of this activity. Only since the early 1900's, when instrumented records became available, can the record of even the larger events in Alaska be considered to be relatively complete.

Presented in Table 14-1 is a list of significant historic earthquakes that have occurred in the Anchorage region. Events selected for inclusion in this table generally have magnitudes of 6 or greater or maximum intensities (MM) of V or more. Epicenters of the earthquakes are all within about 60 kilometers (37 miles) of Anchorage, and all events are plotted on Fig. 14-4.

Only one of the 14 earthquakes in this listing had had a maximum intensity of VII or larger. This was the April 26, 1933 event which had a magnitude of 7.0 and Modified Mercalli intensity of VII. This event was centered about 32 miles west of Anchorage.

Several other major earthquakes, with epicenters beyond the limits of Figure 14-4 have also significantly affected Anchorage. The February 23, 1925 event produced Intensity VII effects at Anchorage, a distance of nearly 140 miles west-southwest of the epicentral area. The October 3, 1954, magnitude 6.75 shock produced Intensity VIII damage effects in Anchorage, some 60 miles northeast of the epicenter. The most recent earthquake to affect the Anchorage area was the Prince William Sound, March 27, 1964 event, which occurred about 80 miles southeast of Anchorage. This very severe earthquake had a magnitude of 8.3 and resulted in Intensity VII to VIII damage effects in Anchorage, largely from foundation failures occurring because of liquefaction and major landsliding.

14.3 SITE CONDITIONS

Site conditions at Gould Hall were studied with a site reconnaissance, deep boring, in situ geophysical measurements, and laboratory testing. A 300-foot deep boring was drilled at a location about 130 feet northwest of Gould Hall to study the subsurface conditions. A downhole geophysical survey was performed for the full depth of the boring to obtain shear wave velocities of the soils. Soil samples retrieved from the boring were tested in the laboratory to determine their index and engineering properties. Detailed results of the field drilling and geophysical testing are presented in Appendix B, and detailed results of the laboratory tests are presented in Appendix C. Summary findings from the field and laboratory studies are presented in Fig. 14-7 and discussed below.

14.3.1 Surface Features

Gould Hall lies within a series of low elongate hills and intervening valleys that are of glacial origin. Most of the buildings on the AMU campus are located on top of one of these small hills (Fig. 14-1). Gould Hall, at an elevation of about 210 feet MSL, is located on the southeast side of a hill. In the immediate vicinity of the building, the ground is relatively flat except to the south, where it slopes down quite steeply for a 30 foot differential in elevation.

14.3.2 Subsurface Conditions

The 300 foot deep boring at the Gould Hall site was drilled entirely within glacial till and outwash sand and gravel, and did not encounter rock. The soil strata encountered in the drilling are generalized in the boring log of Fig. 14-7 and briefly discussed below.

The surficial 42 feet of material consisted of very dense, silty sand and gravel. These sands and gravels had blow counts over 100 and an average water content of about 10 percent. Shear wave velocities within this zone increased from a value of 1000 fps at the ground surface to 1600 fps below a depth of 10 feet.

Between depths of 42 and 125 feet, a hard, till-like, gravelly, clayey silt and silty clay was encountered. Below 69 feet, however, the gravel content decreased, and only occasional seams of sand and gravel were encountered, including a 10-foot thick layer of gravel and cobbles between 97 and 107 feet. The clayey silts and silty clays had low plasticity values and an average water content of about 15 percent. Shear strengths of the clays (unconfined compression tests) ranged from 1.2 to 5.5 tsf. The higher strengths occurred with brittle failure and the lower with a more plastic failure. Shear wave velocities within this zone ranged from 1900 to 2300 fps.

Below a depth of 125 feet, the soils encountered were very dense gravels and cobbles with occasional layers of silty, clayey, fine sand and coal seams. These gravels were observed to the base of the boring at a depth of 300 feet. Within this zone, blow counts all were over 100 and water contents generally varied from 10 to 15 percent. Values of shear wave velocity increased from 2450 fps at the top of the layer to 4400 fps below 245 feet.

The water table was not measured in the boring because a heavy bentonite slurry was used to return drill cuttings to the ground surface.

14.3.3 Dynamic Soil Properties

The strain-dependent, dynamic soil properties of shear modulus attenuation and damping ratio are presented in Fig 14-7. These plots include data from laboratory resonant column and cyclic ial tests performed on the very hard clay encountered in the boring between depth 69 and 125 feet. For comparison purposes, these plots also contain the behaviorial relationsh..s for "clay" and "rock" that have been proposed by others (SW-AJA, 1972; Schnabei, et al., 1971). The laboratory shear modulus values presented in Fig. 14-7 have been normalized to the low-strain shear modulus of the soil. This low-strain shear modulus was computed from the shear wave velocity of the soil, determined from the field downhole geophysical survey measurements. This normalization permits direct comparison of the laboratory data with the modulus attenuation relationships proposed by others.

Review of the data in Fig. 14-7 indicate:

1) The laboratory moduli values should be adjusted to account for disturbances due to sampling, testing and other effects. The uncorrected laboratory moduli values fall fairly close to the "clay" curve. However, the hard, silty clays at the site are much stiffer than the soft to medium stiff soils that were used to develop the "clay" curve. Therefore, it is expected that the dynamic behavior of the site soils would fall somewhere between the "rock" and "clay" curves. Correction factors of 2 to 4 would bring the laboratory moduli within this range.

2) The laboratory damping data lie between the "clay" and "rock" curves in the low-strain range but follow the "clay" curve for higher strain levels. Again, the dynamic behavior of the hard, silty clays that were tested is expected to fall somewhere between that of the "rock" and "clay" curves.

TABLE 14-1

SIGNIFICANT EARTHQUAKES IN THE ANCHORAGE REGION[1]

Source[2]	Year	Date Mo. Day	Time (AST) Hr:Min	Latitude[3] North (°)	Longitude[3] West (°)	Magnitude[4] (Richter)	Max. Intensity (MM)	Depth (Miles)	Epicentral Distance From Accelerograph Station (miles)
A	1929	4 - 6	00:33	61.5	149	--	V	--	34 NE
A	1931	10 - 17	02:30	61	149	--	V	--	30 SE
C	1933	4 - 26	16:36	61.25	150.75	7.0 (P)	VII	16	32 W
C	1933	6 - 13	12:20	61	151	6.25 (P)	--	16	42 WSW
A	1934	4 - 19	08:52	61	150	--	V	--	15 SW
C	1934	6 - 17	23:14	60.5	151.0	6.75 (P)	V	50	45 NW
A	1935	8 - 23	12:09	61	150	--	V	--	15 SW
B	1936	10 - 22	20:24	61.4	149.7	--	VI	--	15 NNE
A	1940	7 - 19	04:47	61	150	--	VI	--	15 SW
C	1941	7 - 29	15:51	61	151	6.25 (P)	VI	--	42 WSW
C	1951	6 - 25	06:13	61.1	150.1	6.25 (P)	V	30	12 SW
B	1962	10 - 20	16:05	61.1	149.7	--	VI	50	7 SE
D	1965	5 - 11	07:38	61.4	149.6	5.5 (m_b)	IV	36	16 NNE
D	1974	12 - 29	08:25	61.597	150.511	5.6 (m_b)	V	42	37 NW

Notes:

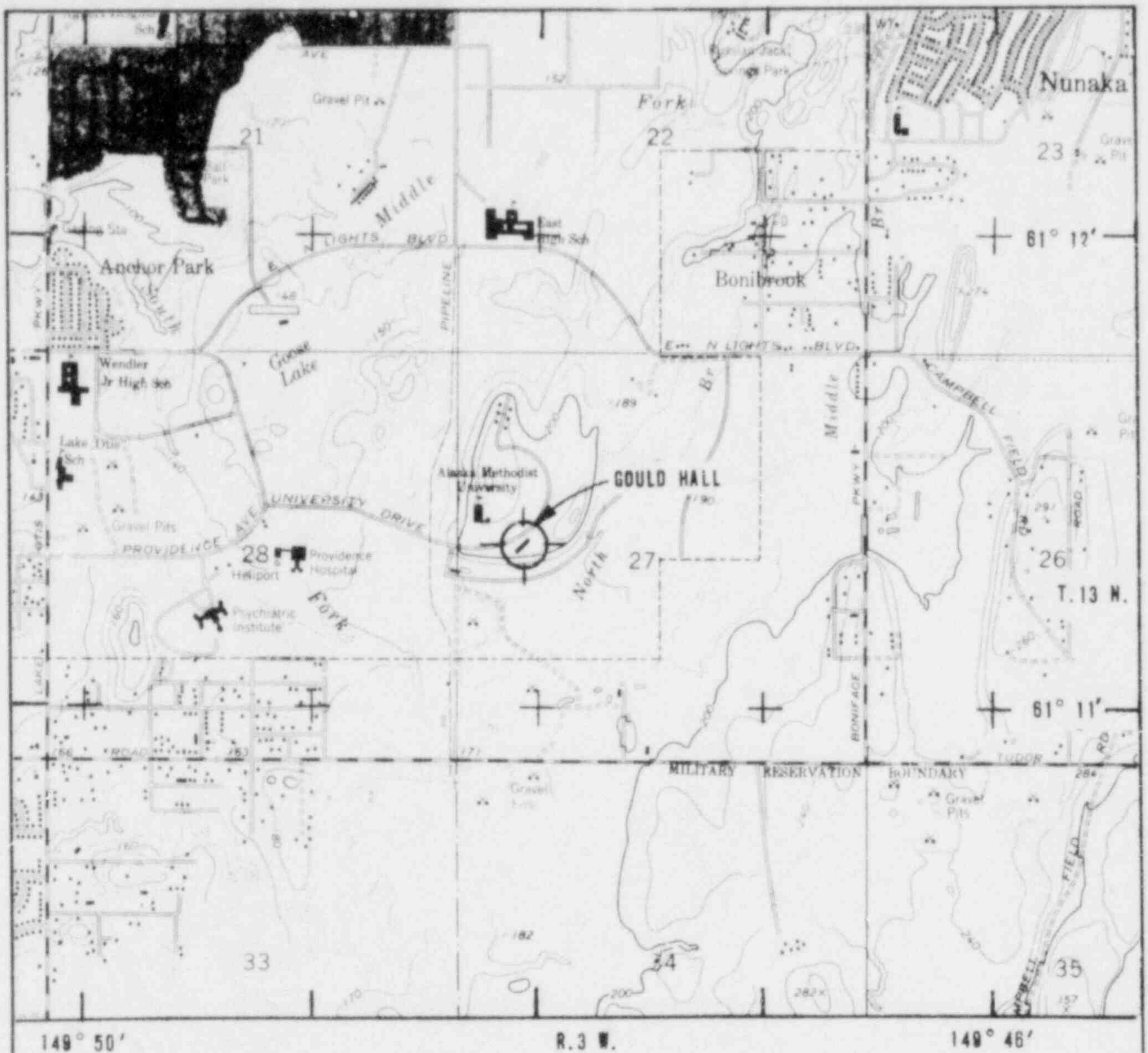
1. Earthquakes selected for this tabulation generally have maximum intensities of V or greater or magnitudes of 6.0 or greater. All events have epicenters within about 60 km (37 miles) of Anchorage. The intent of this table is to provide a general indication of seismicity in the region; it is not a complete list of all earthquakes.

2. The following sources were used in compiling the earthquake data:
   - A. Coffman and Von Hake (1973)
   - B. United States Earthquakes
   - C. Meyers (1976)
   - D. NOAA (1978)

3. The range of uncertainty for epicentral locations may be taken as about ± 0.5° for earthquakes prior to 1960 and as about ± 0.2° for those since 1960.

4. Magnitudes are as follows:
   - m_b - Computed from body waves on a seismogram
   - P - Computed by the California Institute of Technology, Pasadena

POOR ORIGINAL



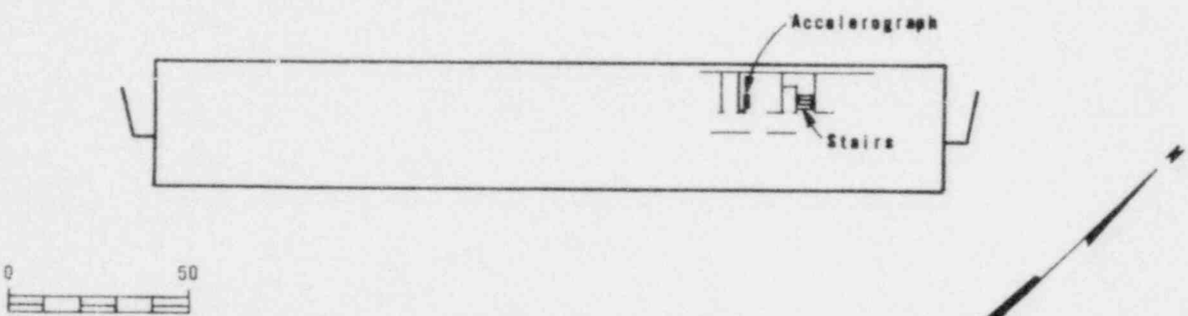
GOULD HALL

USGS Station No.:	2702
Borough:	Anchorage
USGS Topographic Quadrangle.	Anchorage and Vicinity, Alaska N6104-W14937.5/18x27.5 1962
Coordinates:	61° 11′ 20″ N. 149° 48′ 3″ W.
Location:	Southern portion of campus
Building:	2 stories with daylight basement. Reinforced concrete block construction.

STATION LOCATION
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-1

GOULD HALL
VIEW: SOUTHEAST

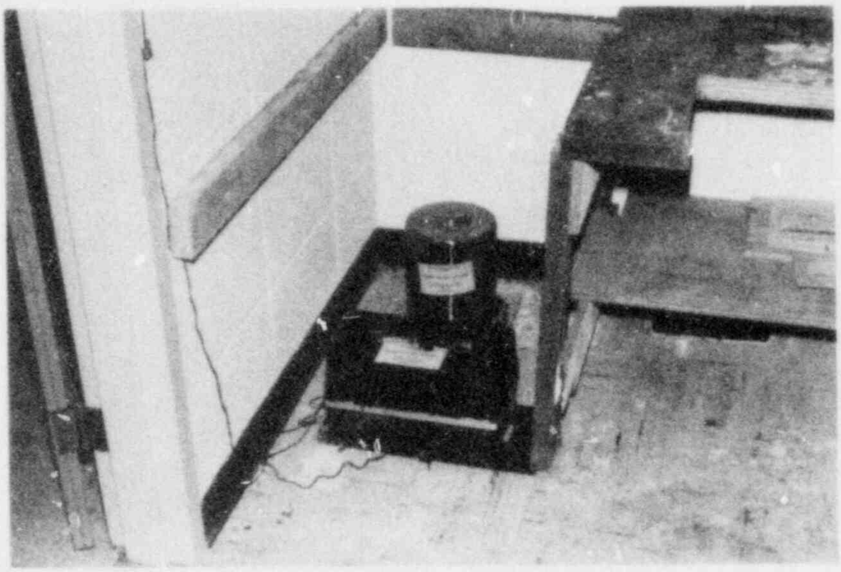


BASEMENT PLAN

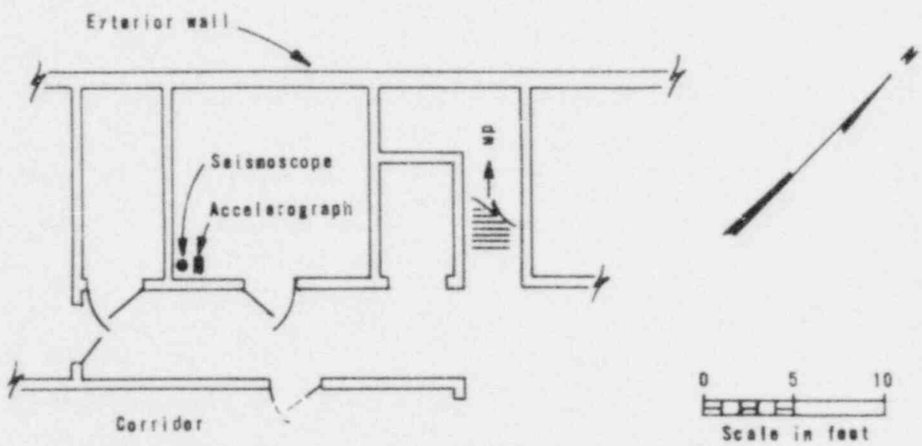
NOTES

1. Accelerograph room plan shown in Fig. 14-3
2. The basement may be called the "ground" or "first" floors by others.

BUILDING PLAN
AMU GOULD HALL
ANCHORAGE, ALASKA



SMA-1 ACCELEROGRAPH
GOULD HALL - BASEMENT
VIEW: SOUTHWEST



ACCELEROGRAPH ROOM PLAN - BASEMENT

NOTE

Location of accelerograph room within the structure is shown in Fig. 14-2

STATION INSTRUMENTATION
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-3

COOK INLET
CHICKALOON BAY
KENAI MTNS
TURNAGAIN ARM
KNIK ARM
ANCHORAGE
PALMER
TALKEETNA MTNS
SUSITNA RIVER
BIG ISLAND
FIRE ISLAND
BIG LAKE
EAGLE RIVER FAULT
KNIK FAULT
MESOZOIC OR PALEOZOIC
MESOZOIC
CENOZOIC
TERTIARY
QUATERNARY
PLEISTOCENE
HOLOCENE

EXPLANATION

Qal
Alluvial, colluvial, eolian and beach deposits.
Silt, sand and gravel.

Qls
Landslide and debris flow deposits.
Unsorted mixtures of silt, sand, gravel, cobbles, and some boulders.

Qn
Naptowne Drift.
Clay, silt, sand and gravel; scattered cobbles and boulders.

Qu
Undifferentiated Holocene and Pleistocene deposits.
Silt, sand, and gravel; scattered cobbles.

Qk
Knik Drift.
Clay, silt, sand, and gravel; scattered cobbles and boulders.

Qe
Eklutna Drift.
Clay, silt, sand, and gravel; scattered cobbles and boulders.

Qpe
Pre-Eklutna drift and non-glacial deposits.
Clay, silt, sand, and gravel; scattered cobbles and boulders.

Ts
Mainly lower tertiary sedimentary rocks. Siltstone, sandstone, conglomerate, shale and some coal.

Mvm
Marine metasedimentary and metavolcanic rocks.
Predominantly weakly metamorphosed sandstone to conglomeratic sandstone, subordinate basaltic volcanic lavas and clastics, some chert and argillite; locally includes some undivided Permian to Jurassic metamorphic rocks.

Msm
Marine metasedimentary rocks.
Predominantly metagraywacke, metasiltstone and argillite; locally phyllitic.

MzPzu
Undifferentiated Paleozoic and/or Mesozoic rocks.
Predominantly ultramafic and gabbroic rocks. Includes some schist.

TKgd
Granodioritic plutonic rocks of Tertiary-Cretaceous age.

Mi
Intrusive rocks. Includes mafic dikes and sills, granitic plutonic rocks and some metamorphic rocks.

★ Accelerograph station location

● Epicentral locations of selected historic earthquakes listed in Table 14-1.

12-29-74 —— Date of occurrence (month-day-year)

I_0=V —— Maximum Intensity (MM)

M=5.6 —— Magnitude (Richter)

■ Faults that may have moved during Holocene time (approx. last 10,000 years)

CONTACT

FAULT — Dotted where concealed; barbs on upper plate of Thrust Fault.

Denotes location of present-day glaciers

NOTES:

1) Geology is generalized from published and unpublished reports indexed on Fig. 14-5.

2) Cross-Section N-N' is shown on Fig. 14-6.

3) Information on fault activity (Quaternary and historic) is from Detterman, et al.(1976). The seismic activity symbol used in this figure does not necessarily mean that the entire length of the fault shows evidence of the respective activity (Details in Detterman, et al.(1976).

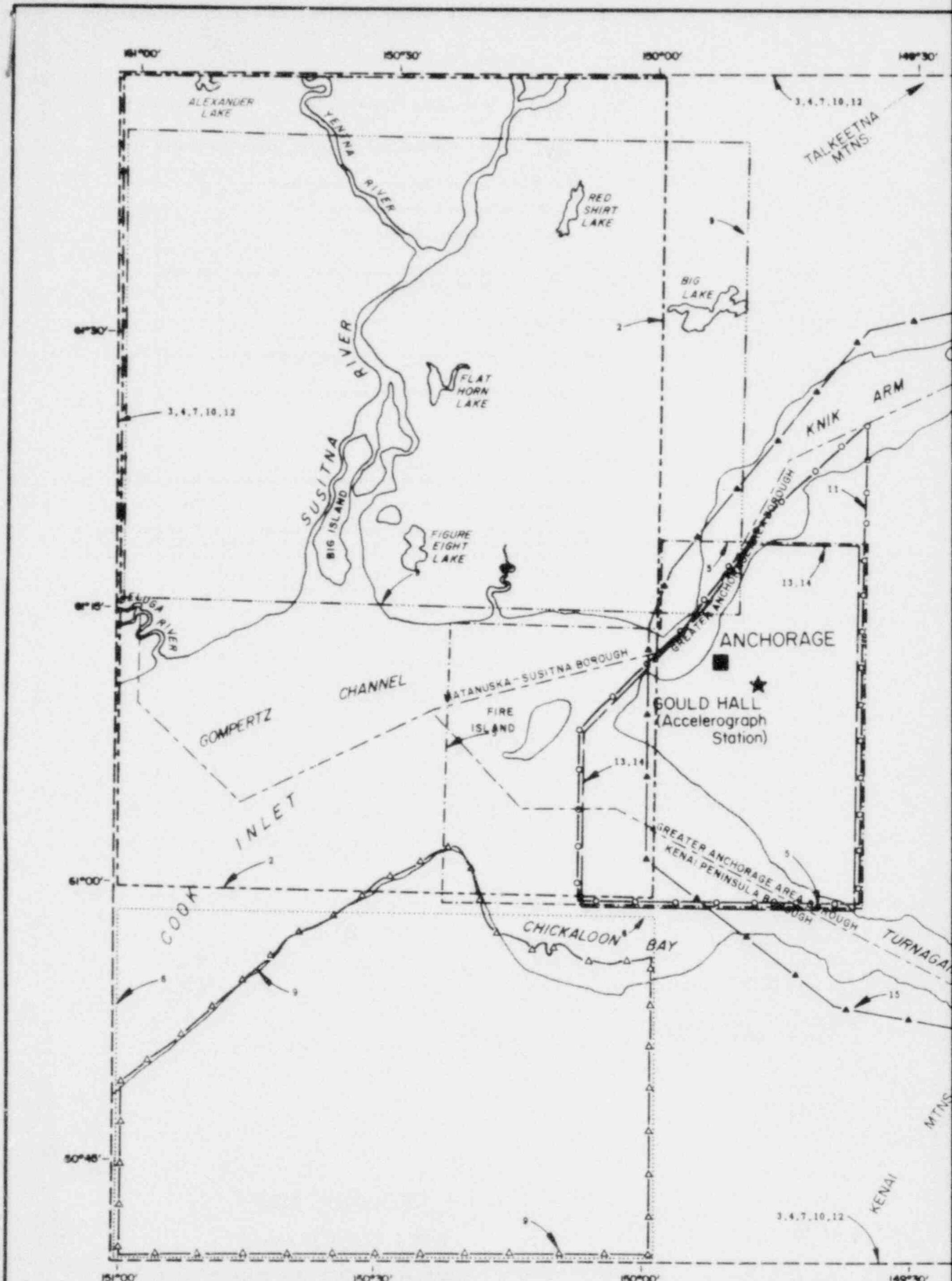
5 0 5 10 15 20 25 30
Scale in kilometers

5 0 5 10 15 20
Scale in miles

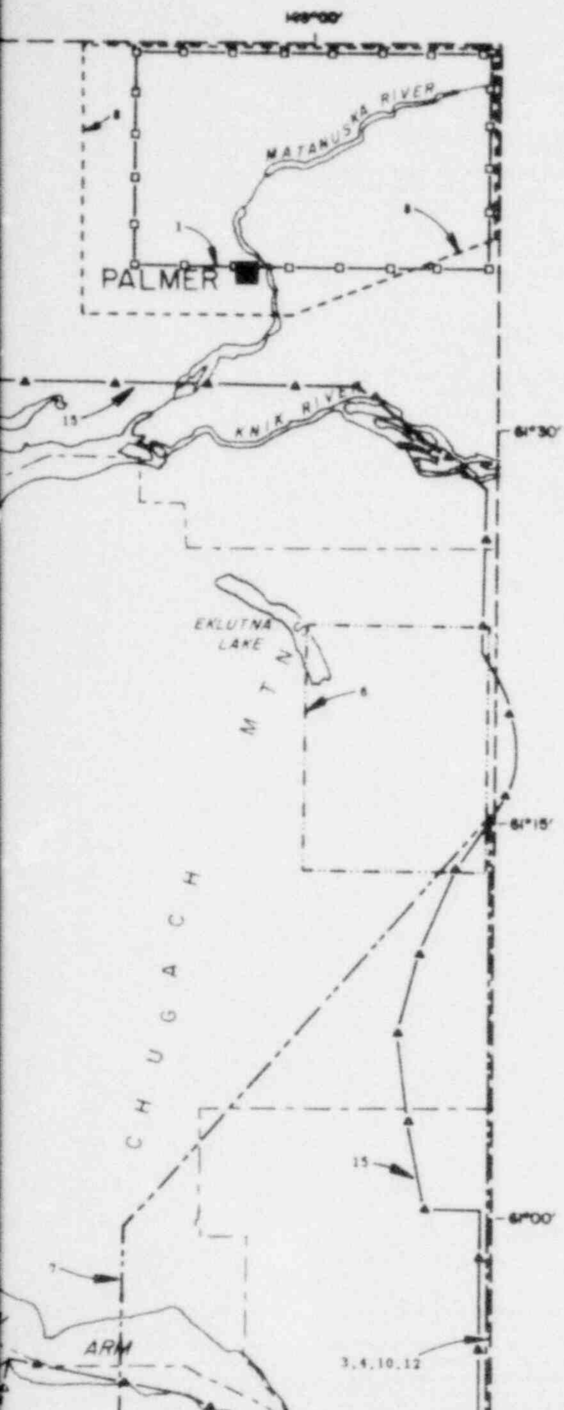
Location of Geologic Map

GEOLOGIC MAP
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-4

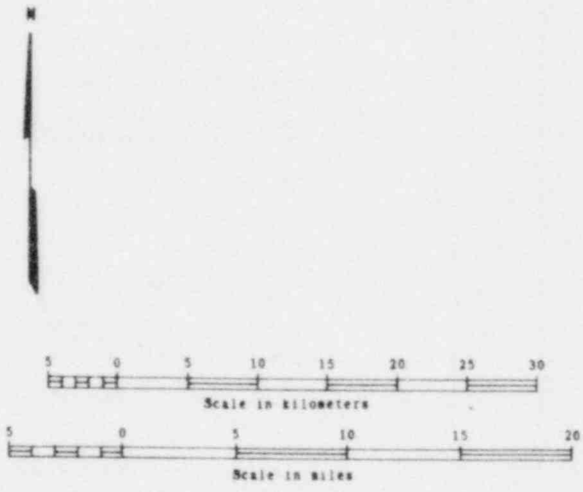


151°00'
150°30'
150°00'
149°30'
61°30'
61°15'
61°00'
60°45'
ALEXANDER LAKE
YENTNA RIVER
RED SHIRT LAKE
BIG LAKE
TALKEETNA MTNS.
SUSITNA RIVER
FLAT HORN LAKE
BIG ISLAND
FIGURE EIGHT LAKE
KNIK ARM
ANCHORAGE
GOULD HALL (Accelerograph Station)
FIRE ISLAND
MATANUSKA-SUSITNA BOROUGH
GREATER ANCHORAGE AREA BOROUGH
KENAI PENINSULA BOROUGH
GOMPERTZ CHANNEL
COOK INLET
CHICKALOON BAY
TURNAGAIN
KENAI MTNS
3, 4, 7, 10, 12
13, 14



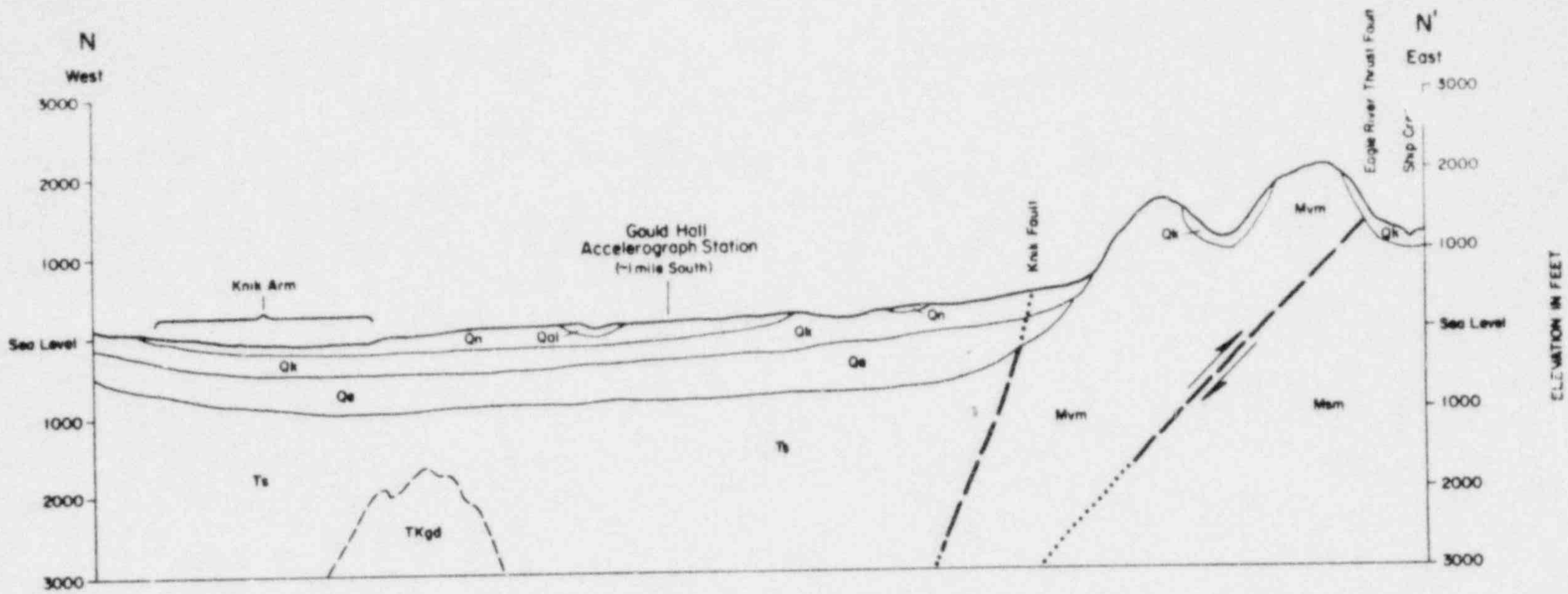
SOURCES USED IN COMPILING THE GEOLOGIC MAP

1. BARNES, 1962
2. BARNES, 1966
3. BEIKMAN, 1974
4. CAPPS, 1940
5. CEDERSTROM, et al., 1964
6. FOSTER and KARLSTROM, 1967
7. GRANTZ, et al., 1963
8. GRANTZ, 1964
9. KARLSTROM, 1964
10. MAGOON, et al., 1976
11. MILLER and DOBROVOLNY, 1959
12. PAYNE, 1955
13. SCHMOLL and DOBROVOLNY, 1972
14. SCHMOLL and DOBROVOLNY [illegible]
15. CLARK, 1972



GEOLOGIC INDEX MAP
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-5



EXPLANATION

QUATERNARY

HOLOCENE

Qal Alluvial, colluvial, eolian and beach deposits

Silt, sand, and gravel

PLEISTOCENE

Qn Naptowne Drift.

Clay, silt, sand, gravel, scattered cobbles and boulders

Qk Knik Drift.

Clay, silt, sand, gravel, scattered cobbles and boulders

Qe Eklutna Drift.

Clay, silt, sand, gravel, scattered cobbles and boulders.

TERTIARY

Ts Mainly lower tertiary sedimentary rocks

Siltstone, sandstone, conglomerate and shale.

TKgd Granodioritic plutonic rocks of Tertiary-Cretaceous age.

MESOZOIC

Msm Marine metasedimentary rocks.

Predominantly metagraywacke, meta-siltstone and argillite.

Mvm Marine metasedimentary and meta-volcanic rocks.

Predominantly weakly metamorphosed sandstone to conglomeratic sandstone; subordinate basaltic volcanic lavas and clastics; some argillite.

CONTACT

Dashed where approximately located

FAULT

Dashed where approximately located; dotted where concealed. Arrows indicate relative lateral movement

SCALE IN MILES (1 0 1 2)

NOTES:

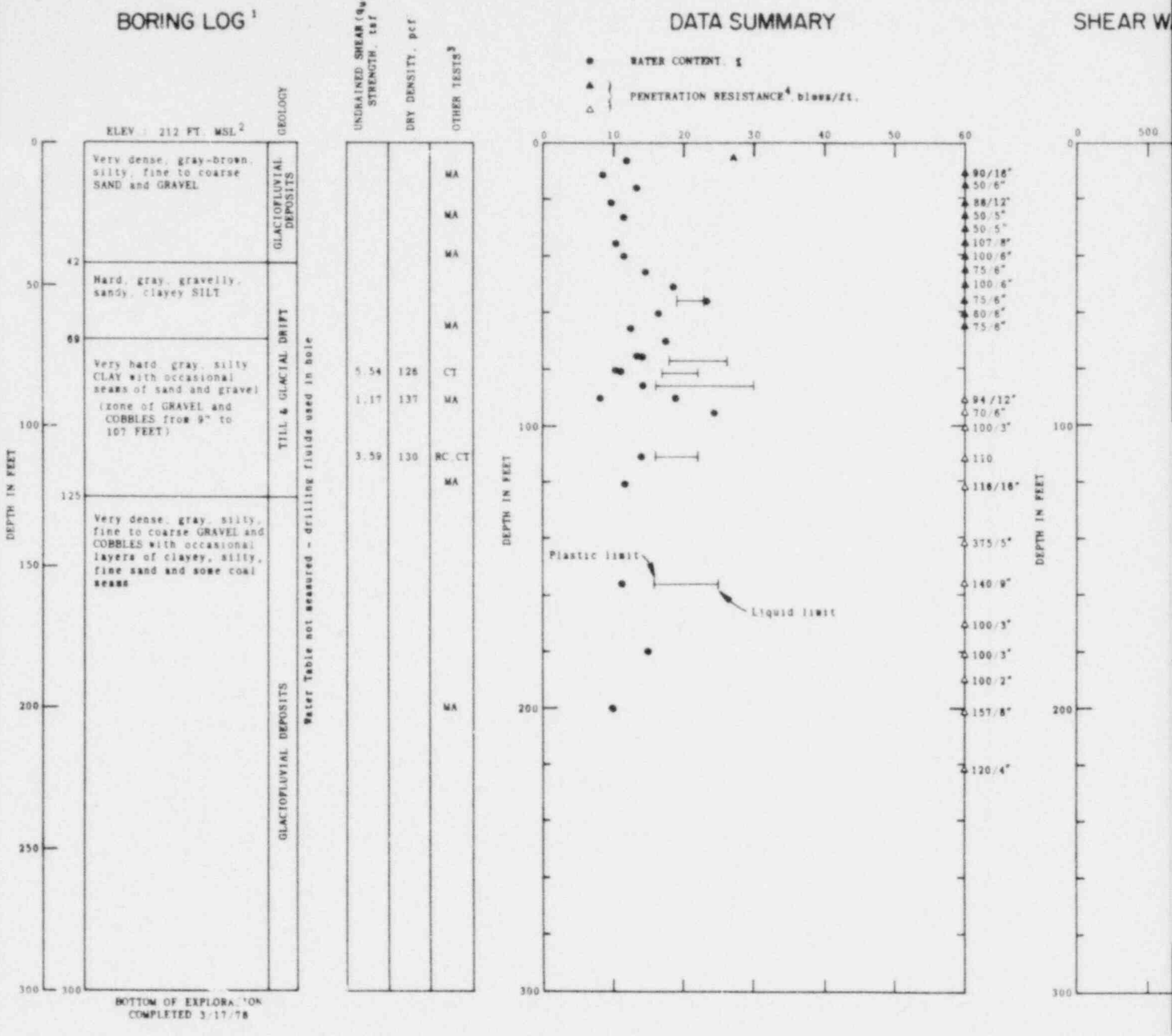
1) Plan view of Geologic Cross-Section N-N' shown on Fig. 14-4

2) The Cross-Section is a simplified and conceptual representation of significant geologic relationships

3) Left lateral or oblique slip motion has been speculated for the Knik fault (Grantz, et al., 1963, and Barnes, 1966).

GEOLOGIC CROSS-SECTION N-N'
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-6

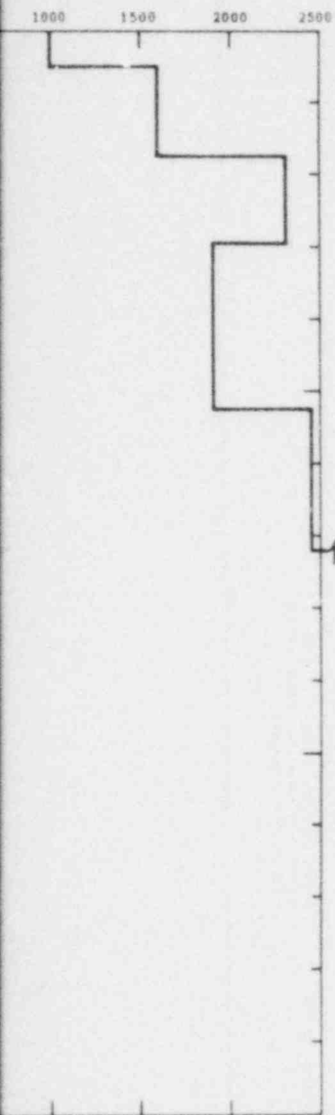


BOTTOM OF EXPLORATION
COMPLETED 3/17/78

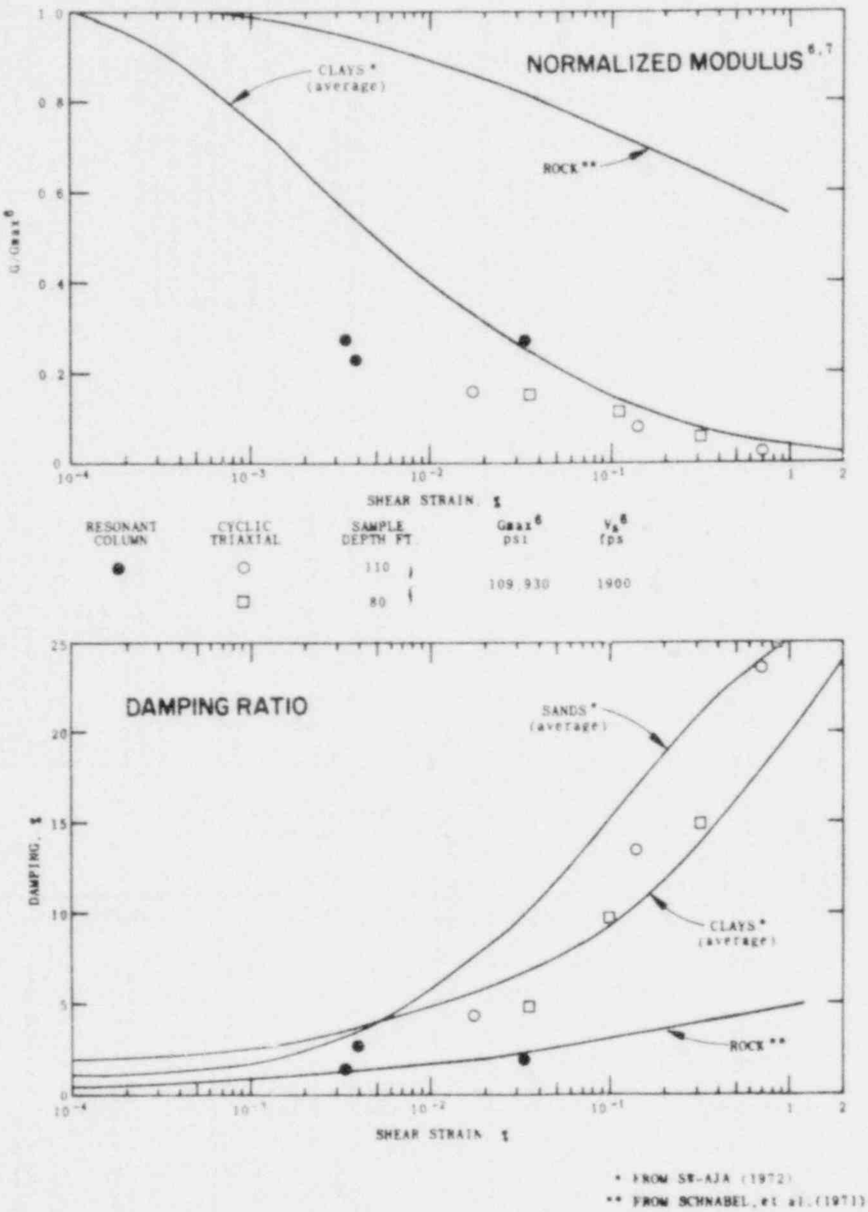
NOTES:

1) THE STRATIFICATION LINES IN THE BORING LOG REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL.
2) BORING ELEVATION INTERPOLATED FROM A TOPOGRAPHIC MAP OF THE ALASKA METHODIST UNIVERSITY CAMPUS. THE BORING IS LOCATED ABOUT 130 FEET NORTHWEST OF GOULD HALL.
3) DETAILED RESULTS OF LABORATORY TESTS ARE PRESENTED IN APPENDIX C. TEST ABBREVIATIONS ARE AS FOLLOWS:
   - RC - RESONANT COLUMN
   - CT - CYCLIC TRIAXIAL
   - MA - MECHANICAL ANALYSIS (GRADATION)
4) PENETRATION RESISTANCES ARE BASED ON DRIVING A 3-INCH O.D. SPLIT SPOON SAMPLER WITH A HAMMER DROPPED A DISTANCE OF 30 INCHES.
   - ▲ - 250LB. HAMMER
   - △ - 350LB. HAMMER
5) DETAILED RESULTS OF DOWNHOLE GEOPHYSICAL TESTING ARE PRESENTED IN APPENDIX B.
6) LABORATORY RESONANT COLUMN AND CYCLIC TRIAXIAL TEST DATA ARE NORMALIZED TO Gmax ($G_{max} = V_s^2 \rho$) AS DETERMINED FROM DOWNHOLE GEOPHYSICAL SHEAR WAVE VELOCITY MEASUREMENTS.
7) NORMALIZED LABORATORY MODULI ARE UNCORRECTED FOR POSSIBLE SAMPLE DISTURBANCE.

VE VELOCITY[5]- V_S (fps)



DYNAMIC PROPERTIES OF SUBSURFACE MATERIALS



BORING LOG AND
SUMMARY OF TEST RESULTS
AMU GOULD HALL
ANCHORAGE, ALASKA

FIG. 14-7

Section 15

Federal Office Building
Seattle, Washington

SECTION 15

FEDERAL OFFICE BUILDING, SEATTLE, WASHINGTON

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SECTION 15
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

15.1 STATION DESCRIPTION

15.1.1 Location and Building

Seattle is located in west central Washington on the east side of Puget Sound, which is an arm of the Pacific Ocean. The city lies between Elliott Bay of the Puget Sound and Lake Washington. Seattle, the largest city in the state, is located in King County.

The Federal Office Building is the older of two structures in downtown Seattle that are owned by the General Services Administration for housing government agencies. The Federal Office Building is located at 909 - 1st Avenue and is about a block east of the waterfront (Fig. 15-1). The building occupies the entire block, which is bounded by First & Western Avenues and Madison & Marion Streets. Directly across the street, at 915 - 2nd Avenue, is the new high rise Federal Building.

The Federal Office Building is a multistory, "U"-shaped structure (Fig. 15-2) with plan dimensions of about 220 by 230 feet. The highest portion of the building, located along 1st Avenue, forms the base of the "U". This section has 6- to 8-stories with a central tower (ninth story) which extends about 125 feet above street level. The two 5-story wings on the north and south form the remaining portion of the "U". The core of the "U", between the wings, is only one story high.

The entire building is underlain by a daylight basement and subbasement. Along 1st Avenue the basement is fully embedded, and the street entrance is on the first floor. From 1st Avenue the ground slopes down towards the waterfront, exposing the basement along Western Avenue. The subbasement is entirely below grade and has a floor elevation of 4.3 feet above Mean Sea level.

The Federal Office Building is constructed of steel and reinforced concrete. The building support framework consists of structural steel members encased in concrete. Reinforced concrete is used in some interior walls and in the exterior walls. The exterior of the building is faced with brick. Construction was completed in 1932.

The building is supported on a pile foundation system. Twelve inch diameter wood piles, driven at a spacing of 30 to 36 inches, are used for building support. Pile lengths range from 25 to 35 feet. Thirty foot piles support the northeast and southwest portions of the building, while 25 and 35 foot piles support the northwest and southeast areas, respectively. Base elevations of the pile caps are about 1 foot MSL. Typical allowable pile loads are 25 tons. The piles are an integral part of the subbasement floor slab.

15.1.2 Instrumentation and Earthquake Recordings

The Federal Office Building accelerograph station is part of the USGS strong motion instrument network and is identified as station number 2102. The Federal Office Building was initially instrumented on June 21, 1953, with a Coast and Geodetic Survey standard 12 inch accelerograph (S/N 18) with a Carder displacement meter. This accelerograph remained in place until January 25, 1977, when it was replaced with an RFT-250 recorder (S/N 513). Pendulum motion orientations for the original and replacement accelerographs are as follows (USGS, unpu

	Original C&GS Accelerograph	Replacement RFT-250 Accelerograph
Longitudinal	S32E	S[illegible]
Vertical	Up	Down
Transverse	S58W	N58E

Both instruments at the Federal Office Building have been located in the northeast portion of the subbasement (Fig. 15-2). A plan of the accelerograph room and a photo of the current instrumentation are shown in Fig. 15-3. All instruments at the site have been bolted to a concrete, accelerograph pier which is about 1.5 feet high. The pier is secured to the floor slab of the building with steel dowels. The subbasement floor is about 15 feet below grade.

Three earthquakes have been recorded at the Federal Office Building accelerograph station, all on the original C&GS standard accelerograph. Details of these earthquakes are presented in Appendix A. Summary data is given below.

Date (Mo-Da-Yr)	Magnitude (Richter)	Maximum Intensity (MM)	Peak Acceleration (g)
5-15-54	---	VI	≤0.01
7-09-58	7.9	XI	≤0.01
4-29-65	6.5	VII-VIII	0.08

The only station record of significance in earthquake engineering, having an acceleration of 0.05 g or greater, is the event of April 29, 1965. This record has been digitized and processed by the California Institute of Technology (Hudson, et al., 1971-1975 a and b) and is identified as record U310 in the CIT series. Time histories of ground motion and response spectra of this record are presented in Appendix A.

15.1.3 Other Installations

Although the Federal Office Building accelerograph station is the oldest operating station in Seattle, it was not the first instrumented site in the city. The first accelerograph in Seattle was located at the U.S. Army Corps of Engineers Seattle District Office at 4735 East Marginal Way South. This site is identified as number 2170 in the USGS strong motion accelerograph station network. A C&GS standard 6 inch accelerograph (S/N 29) was installed at the site on October 25, 1948, and remained in operation until June 22, 1953, when the station was discontinued. During this short period of time, the accelerograph recorded the April 13, 1949 Olympia earthquake.

The instrument shelter at the Corps of Engineers facility was located on the east bank of the Duwamish Waterway at an elevation of about 10 feet (USGS, unpub.). The accelerograph was housed in an 8 by 10 foot corrugated metal building with a concrete floor slab on grade. The instrument was bolted to a concrete accelerograph pier which rested on the floor. Some speculation exists (Roberts and Ulrich, 1952) that the pier was not directly fastened to the floor slab and that it shifted several times during the 1949 earthquake.

Subsurface conditions at the Corps of Engineers site are expected to be somewhat different from those at the Federal Office Building, which lies about 3 miles to the north. Consequently, subsurface information for the Federal Office Building would not necessarily be applicable to the Corps of Engineers site.

15.2 GEOLOGY AND SEISMICITY

15.2.1 Regional Geology

Surface geology of the Seattle region is depicted on the Geologic Map of Fig. 15-4. For the purpose of this report, the Seattle region is defined by the area within about 60 kilometers (37 miles) of Seattle. The extent of this region, relative to the state of Washington, is indicated on the map insert of Fig. 15-4. The Geologic Map was prepared from the data sources shown in Fig. 15-5. Symbols shown in parentheses in the following discussion refer to geologic units on the map.

The major physiographic provinces in the Seattle region are the Olympic Mountains on the west, the Cascade Range on the east, and between these two mountainous provinces, the Puget Lowland (McKee, 1972). The city of Seattle is located within the Puget Lowland province.

The Puget Lowland province comprises most of the area in the Seattle region. The Lowland is a broad, north-trending, structural and topographic depression that contains the inland waterways of western Washington and southern British Columbia. Owing to glaciation, much of its area is submerged; the remainder consists of numerous islands, peninsulas, low hills, and small alluvial plains, all averaging less than 300 feet in elevation.

Bedrock in the Seattle region is primarily exposed in the mountains adjacent to the Puget Lowland. In the Cascade Mountains to the east, the oldest exposed rocks consist of pre-Tertiary metasedimentary and metavolcanic strata (pTu) and Mesozoic to Tertiary marine sedimentary and volcanic strata (MTs and MTv). These older rock units are unconformably overlain by Tertiary continental volcanic and sedimentary rocks (Tvc and Tsc), and are cut by Tertiary intrusives (Ti). Tertiary marine volcanic and sedimentary bedrock (Tvm and Tsm) and minor amounts of continental sedimentary rock (Tsc) crop out in the Olympic Mountains, west of the Puget Lowland.

Bedrock underlying the Puget Lowland is largely obscured by a thick cover of Quaternary sediments. The few bedrock exposures in the lowland suggest that the geologic units of the adjoining mountains are continuous beneath the surficial deposits, and that they are transitional from continental to marine strata from east to west.

The Pleistocene deposits of the Puget Lowland record a complicated history of at least four major continental glaciations and associated alpine glaciations and interbedded non-glacial deposits. The latest of the continental glaciations, the Vashon Stade of the Fraser Glaciation, was the most extensive. During this glaciation, the continental ice sheet advanced southward from British Columbia, blocking the drainage of the Puget Lowland through the Strait of Juan de Fuca, and eventually extended as far south as the town of Centralia (Crandell, 1965). The Vashon ice lobe both scoured the older glacial deposits and mantled them with younger materials. Thus, because the Vashon drift (Qv) now covers most of the Puget Lowland, the older glacial strata (Qpv) are exposed only locally. The cumulative thickness of these Pleistocene strata is locally as much as 3,000 feet (Hall & Othberg, 1974).

Holocene deposits occur throughout the region, mostly as floodplain alluvium along the major drainages (Qal). Extensive mudflow deposits (Qmf) derived from the slopes of Mt. Rainier are exposed east of Tacoma (Crandell, 1963). Landslide deposits (Qls) are common throughout the region. Fills (m) have been used in several cities to reclaim tideland areas along the waterfront of the Puget Sound.

15.2.2 Local Geology

The local geology in the vicinity of Seattle is depicted diagrammatically in Geologic Cross-Section O-O' of Fig. 15-6. The section parallels the western shore of Lake Washington (Fig. 15-4).

Tertiary bedrock and thick accumulations of Quaternary sediments underlie Seattle and its immediate vicinity. The Tertiary strata include marine sedimentary and volcanic rocks of the Blakely and Tukwila Formations (Tsm and Tvm, respectively), and continental sedimentary rocks of the Renton Formation (Tsc). Outcrops of the Blakely and Renton Formations occur just southeast of Seattle, as indicated in crosssection O-O' (Fig. 15-6). Most of the Tertiary bedrock, however, is exposed only locally as a result of deep cuts of river channels or wave-cut terraces along some beaches.

The quaternary sediments, which unconformably overlie the Tertiary bedrock, are over 1600 feet thick in the downtown Seattle area (Hall and Othberg, 1974). These Quaternary deposits include Pleistocene drift of several pre-Vashon glacial and inter-glacial stages (Qpv), including deposits of the Orting, Stuck, and Salmon Springs Glaciations and the Puyallup Interglaciation. Younger deposits include glacial drift of the Vashon Stade of the Fraser Glaciation (Qv). The glacial deposits contain outwash sand and gravel, and till, which is an unsorted mixture of clay, silt, sand, gravel and boulders. Clay, silt and sand were the predominant deposits during interglacial periods.

Post-glacial deposits of late Pleistocene and Holocene Age (Qal) include peat, alluvial floodplain, and fan deposits. Also, large areas along the waterfront have been reclaimed by filling.

15.2.3 Structure and Seismicity

The structural geology of the Seattle region is illustrated in the Geologic Map (Fig. 15-4) and Cross-Section O-O' (Fig. 15-6).

The Tertiary units exposed in the foothills of the Cascade Range east of Seattle have been folded, faulted, and cut by numerous intrusive rocks. Pleistocene glacial deposits in the Puget Lowland are generally flat lying, except for some gentle tilting and warping that can be seen in some of the beach cliffs that border the Puget Sound. The few Pleistocene glacial deposits that are gently folded or tilted have relatively horizontal erosion surfaces, suggesting that the tectonism that deformed them was not very recent. Much of the Quaternary deformation in the Puget Lowland has resulted from isostatic adjustment after the glaciers retreated, rather than from tectonism. The ice is estimated to have been over 1,300 feet thick in the vicinity of Olympia and more than 3,000 feet thick in the vicinity of Seattle. This large mass of ice depressed the underlying rocks about 330 feet. Subsequent rebound has uplifted the glacial deposits left by the ice as much as 295 feet (Hall and Othberg, 1974; Crandell, 1965).

Faults are common in Tertiary and older rocks surrounding the Puget Lowland. Only a few of these structures can be traced into the lowland, however, because of the thick cover of Quaternary deposits that masks most of the bedrock. Thus far, the only Holocene fault recognized in the Puget Lowland is located 43 miles southwest of Seattle on the Olympic Peninsula (Carson, 1973a and b; Carson and Wilson, 1974). This small fault is not known to be associated with any historic earthquakes.

The Puget Lowland is an area of moderately high seismic activity. Most of the earthquakes in the region have occurred at comparatively shallow depths of less than about 15 miles; however, the larger events have occurred at depths of more than 25 miles. The primary cause of this seismicity is believed to be related to the motion differential occurring along the boundary between the North American and Pacific lithospheric plates (Crosson, 1972; USGS, 1975). None of the historic earthquakes in the region has been associated directly with any known or postulated faults.

The more significant historic earthquakes (those of Modified Mercalli intensity VI or greater) that have occurred in the Seattle region are listed in Table 15-1 and their approximate epicentral locations are shown on Figure 15-4. Of the 18 events listed, five had intensities of VII or greater. The largest of these were the April 13, 1949, magnitude 7.1, Intensity VIII shock and the April 29, 1965, magnitude 6.5, Intensity VII-VIII event. These earthquakes, which were respectively centered 39 and 14 miles from Seattle, caused considerable property damage in the city.

Other large earthquakes outside of the map area that have affected Seattle include one in the North Cascades of Washington and two in western British Columbia, Canada. The North Cascades earthquake of December 15, 1872, appears to have been one of the largest in the Pacific Northwest, as it was felt over an area of approximately 500,000 square miles. It has been estimated that this major shock had a magnitude near 7 and a maximum intensity of VIII. Although the epicentral location of this event is uncertain, owing to the sparse population in the area at that time, it apparently occurred somewhere in the Northern Cascades - Okanogan region (WPPSS, 1977).

In Canada, major earthquakes occurred on Vancouver Island on June 23, 1946, and in the Queen Charlotte Islands on August 21, 1949 (Coffman and Von Hake, 1973). The Vancouver Island event had a magnitude of 7.3 and a maximum intensity of VIII. Although the magnitude 8.1 Queen Charlotte Islands earthquake was felt over an area of more than 2,000,000 square miles, damage was minor owing to the sparse population in the epicentral area.

15.3 SITE CONDITIONS

Site conditions at the Federal Office Building were studied with a site reconnaissance, deep boring, in situ geophysical measurements, and laboratory testing. A 400-foot deep boring was drilled at a location about 100 feet southeast of the Federal Office Building to study the subsurface conditions. A downhole geophysical survey was performed for 390 feet of the boring to obtain shear wave velocities of the soils. Soil samples retrieved from the boring were tested in the laboratory to determine their index and engineering properties. Detailed results of the field drilling and geophysical testing are presented in Appendix B, and detailed results of the laboratory tests are presented in Appendix C. Summary findings from the field and laboratory studies are presented in Fig. 15-7 and discussed below.

15.3.1 Surface Features

The Federal Office Building is located about a block east of the Elliott Bay waterfront at the foot of a large hill. Ground elevations in the vicinity of the building range from about 13 to 32 feet MSL. The hill slopes upward to the east and at the top has an elevation of about 350 feet MSL.

The site area of the Federal Office Building, as well as much of downtown Seattle and the waterfront, was extensively modified shortly after the turn of the century. Prior to this modification, the old shoreline of Elliott Bay was several hundred feet east of its existing location. In fact, historic records indicate that the old shoreline intersected the site where the Federal Office Building now stands. In the period from 1908 to 1911 and again in 1929 to 1930 extensive regrading was conducted in the downtown area to eliminate some of the steeper cliffs that bordered the Sound and to increase the waterfront area. Much of this work consisted of sluicing down the hillsides and creating a hydraulic fill along the waterfront. However, a significant amount of fill along the waterfront was uncontrolled and included building rubble, sawdust, lumber from old wharfs and sawmill operations, etc. Consequently, the waterfront fill which may be as thick as 30 feet, is of varied consistency.

15.3.2 Subsurface Conditions

The 400-foot deep boring at the Federal Office Building site was drilled almost entirely within glacial sediments and did not encounter rock. The soil strata encountered in the drilling are generalized in the boring log of Fig. 15-7 and briefly discussed below.

Fill material was encountered to a depth of 23 feet in the site boring. The fill was predominantly a loose to medium dense, clayey, silty sand with large amounts of wood, gravel, and concrete or brick rubble. The fill had so much rubble that the boring had to be relocated several times to avoid obstructions (Appendix B). A shear wave velocity of 525 fps was obtained within the fill.

The natural site soils encountered below the fill to a depth of about 77 feet consisted of very dense, silty, gravelly, fine sand grading into a clayey, sandy, fine to coarse gravel below 54 feet. These granular soils had water contents ranging from 10 to 20 percent and blow counts generally above 100. Shear wave velocities within this zone increased from a value of 650 fps at the top of the layer to a maximum value of 2000 fps below a depth of 54 feet.

Between depths of 77 and 153 feet, a hard, silty clay was encountered. The clay had water contents generally within the 25 to 30 percent range. Shear strength values for this material, as measured in unconfined compression tests, ranged from 0.4 to 2.7 tsf. The low strength value occurred primarily as the result of slickensides in the test specimen. Shear strengths above 2 tsf are more representative of the massive clay. Shear wave velocities within the clay ranged from 2000 to 1400 fps.

The soils encountered below a depth of 153 feet were predominantly very dense, silty sands and gravels with some cobbles. These granular soils were observed to the base of the boring at a depth of 400 feet. Blow counts within this zone were all over 100. Shear wave velocities increased from a value of 1650 fps at the top of the layer to a maximum value of 3300 fps below 330 feet.

The groundwater table was measured at a depth of 14 feet in an abandoned boring. It is expected that the groundwater in the vicinity of the Federal Office Building is affected by tidal fluctuations in Elliott Bay, immediately to the west.

15.3.3 Dynamic Soil Properties

The strain-dependent, dynamic soil properties of shear modulus attenuation and damping ratio are presented in Fig. 15-7. These plots include data from laboratory resonant column and cyclic triaxial tests performed on the hard, silty clay encountered in the boring between depths of 77 and 153 feet. For comparison purposes, these plots also contain the behaviorial relationships for "clay" and "rock" that have been proposed by others (SW-AJA, 1972; Schnabel, et al., 1971). The laboratory shear modulus values presented in Fig. 15-7 have been normalized to the low-strain shear modulus of the soil. This low-strain shear modulus was computed from the shear wave velocity of the soil, determined from the field downhole geophysical survey measurements. This normalization permits direct comparison of the laboratory data with the modulus attenuation relationships proposed by others.

Review of the data in Fig. 15-7 indicate:

1) The laboratory moduli values should be adjusted to account for disturbances due to sampling, testing and other effects. The uncorrected laboratory moduli values fall fairly close to the "clay" curve. However, the hard, silty clays at the site are much stiffer than the soft to medium stiff soils that were used to develop the "clay" curve. Therefore, it is expected that the dynamic behavior of the site soils would fall somewhere between the "rock" and "clay" curves. Correction factors of 2 to 4 would bring the laboratory moduli within this range.

2) The laboratory damping data lie close to the "rock" curve in the low-strain range, but follow the "clay" curve for higher strain levels. Again, the dynamic behavior of the hard, silty clays that were tested is expected to fall somewhere between that of the "rock" and "clay" curves.

TABLE 15-1

SIGNIFICANT EARTHQUAKES IN THE SEATTLE REGION[1]

Source[2]	Year	Date Mo. Day	Time (PST) Hr:Min	Latitude[3] North (°)	Longitude[3] West (°)	Magnitude[4] (Richter)	Max. Intensity (MM)	Depth (miles)	Epicentral Distance From Accelerograph Station (miles)
A,C	1880	8 - 22	13:25	48	122	--	VI	--	32 NNE
A,C	1880	12 - 12	20:40	47.5	122.5	--	VI	--	10 SW
A	1928	2 - 2	04:52	47.8	121.7	--	VI	--	33 NE
A	1931	12 - 31	07:25	47.5	123.0	--	VI	--	32 WSW
A	1932	8 - 6	14:16	47.7	122.3	--	VI	--	7 N
A	1939	11 - 12	23:46	47.4	122.6	5.75	VII	--	19 SW
B	1945	4 - 29	12:16	47.4	121.7	--	VII	--	33 ESE
A	1946	2 - 14	19:18	47.3	122.9	5.75	VII	--	34 SW
B,C	1949	4 - 13	11:56	47.1	122.7	7.1	VIII	44	39 SSW
A	1950	4 - 14	03:04	48.0	122.5	--	VI	--	29 NNW
A	1954	5 - 15	05:02	47.4	122.3	--	VI	--	14 S
B	1955	3 - 25	22:56	48.05	122.03	--	VI	--	34 NNE
B	1960	4 - 10	22:48	47.57	122.25	--	VI	--	5 SE
A	1963	1 - 24	13:43	47.4	122.1	--	VI	--	17 SE
B	1965	4 - 29	07:29	47.4	122.3	6.5	VII-VIII	37	14 S
B,C	1965	10 - 23	08:28	47.5	122.4	4.5	VI	--	8 SSW
B	1975	4 - 22	15:04	47.08	122.65	4.0 (m_b)	VI	29	40 SSW
D	1976	9 - 8	00:21	47.38	123.08	4.6 (m_b)	VI	30	38 WSW

Notes:

1. Earthquakes selected for this tabulation have maximum intensities of VI or greater and have occurred within about 60 km (37 miles) of Seattle. The intent of this table is to provide a general indication of seismicity in the region; it is not a complete list of all earthquakes.

2. The following sources were used in compiling the earthquake data:

   A. Coffman and Von Hake (1973)

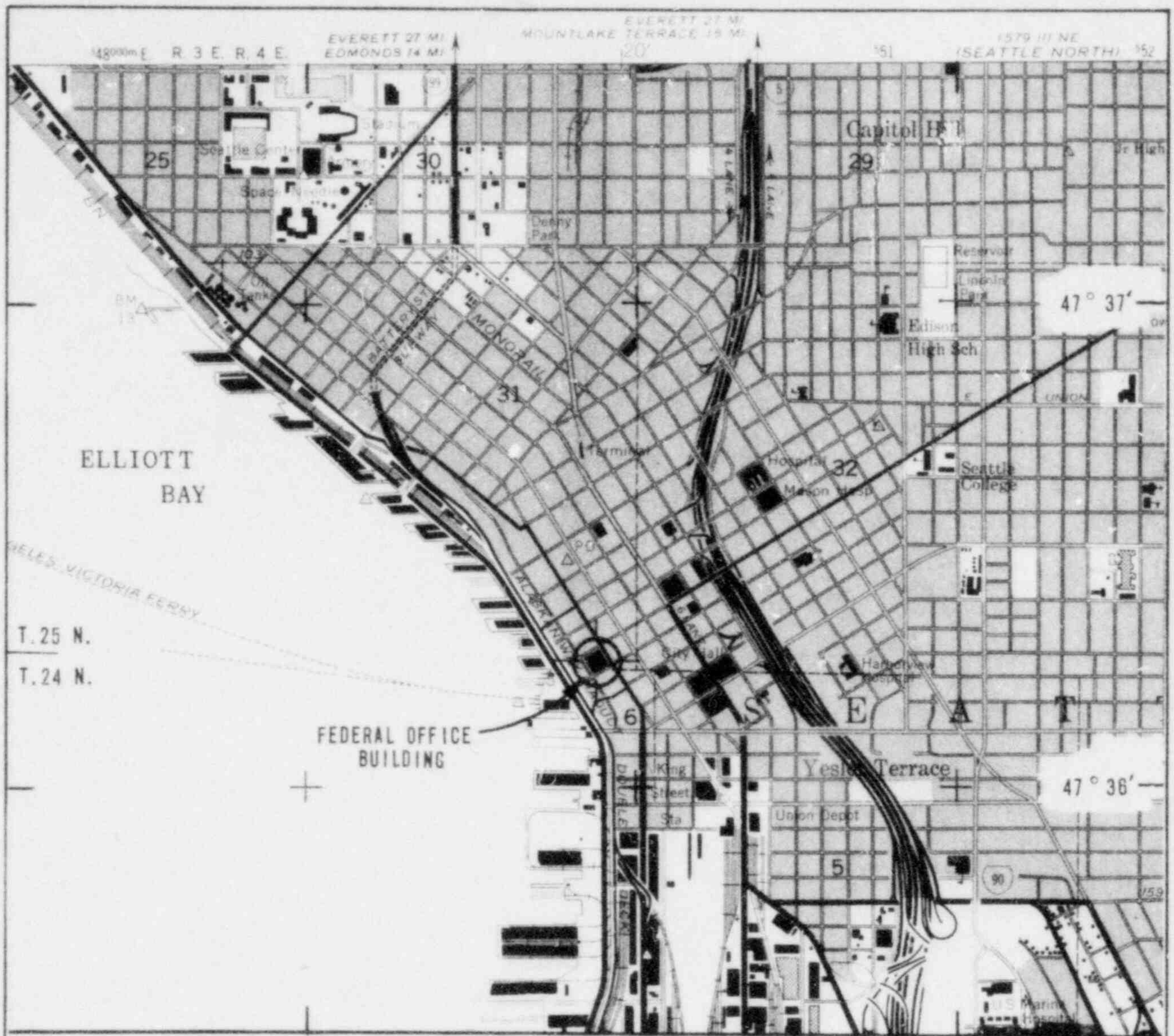
   B. United States Earthquakes

   C. U.S.G.S. (1975)

   D. Stover, et al. (1978)

3. The range of uncertainty for epicentral locations may be taken as about $\pm$ 0.5° for earthquakes prior to 1960 and as about $\pm$ 0.2° for those since 1960.

4. Magnitudes designated as m_b have been computed from body waves on a seismogram.



FEDERAL OFFICE BUILDING

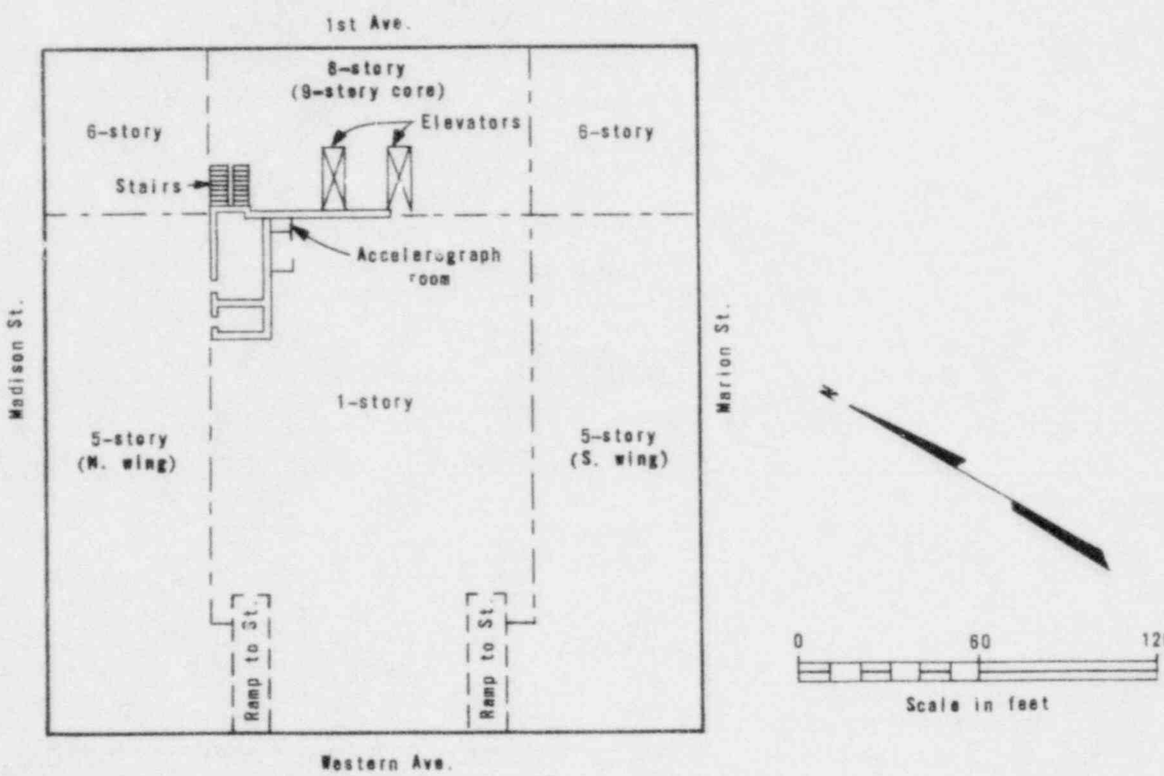
USGS Station No.:	2102
County:	King
USGS Topographic Quadrangle:	Seattle South, Wash. N4730-W12215/7.5 1949
Coordinates:	47° 36′ 15″ N. 122° 20′ 06″ W.
Location:	909 - 1st Avenue
Building:	Multistory (1-9) with a daylight basement and subbasement. Steel framing and reinforced concrete construction.

0 2000 4000
Scale in feet

STATION LOCATION
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-1

FEDERAL OFFICE BUILDING
VIEW: EAST



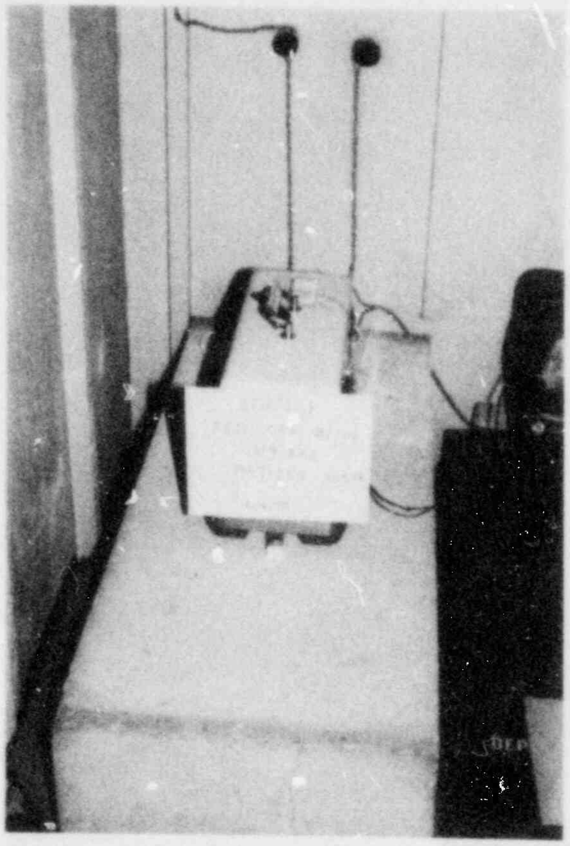
SUBBASEMENT PLAN

NOTE

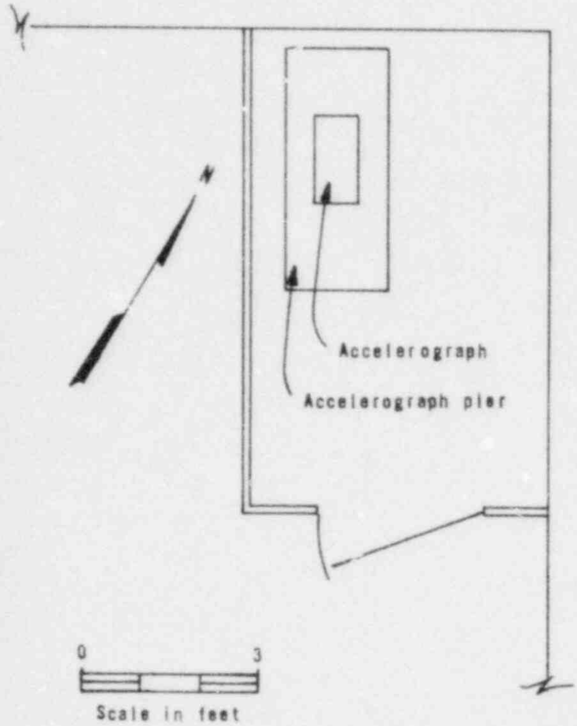
Accelerograph room plan shown on Fig. 15-3

BUILDING PLAN
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-2



RFT-250 ACCELEROGRAPH
FEDERAL OFFICE BUILDING - SUBBASEMENT
VIEW: NORTH



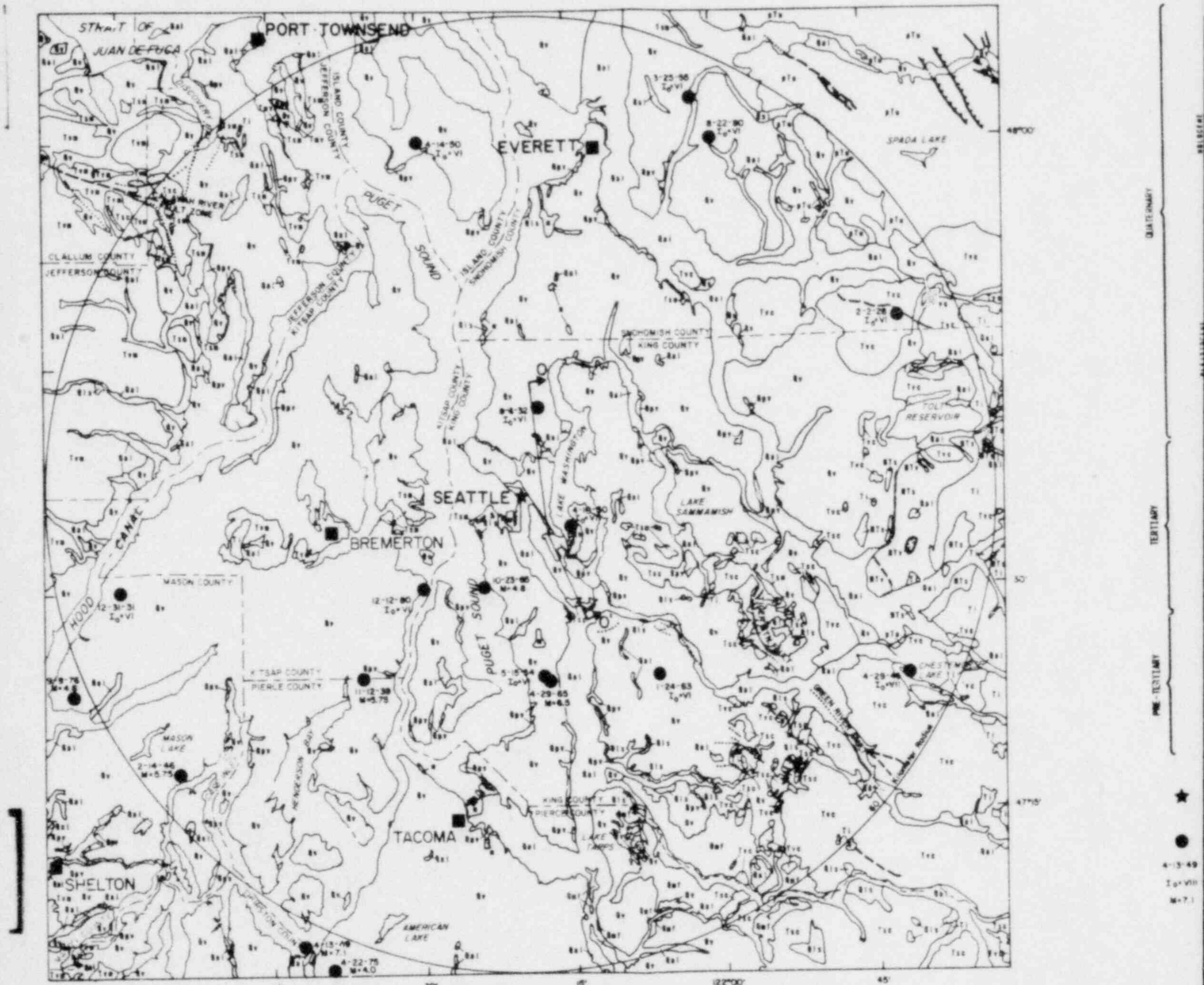
ACCELEROGRAPH ROOM PLAN - SUBBASEMENT

NOTE

Location of accelerograph room within the structure is shown in Fig. 15-2

STATION INSTRUMENTATION
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-3


STRAIT OF JUAN DE FUCA
PORT TOWNSEND
EVERETT
SEATTLE
BREMERTON
TACOMA
SHELTON
PUGET SOUND
HOOD CANAL
LAKE WASHINGTON
LAKE SAMMAMISH
TOLT RESERVOIR
SPADA LAKE
AMERICAN LAKE
MASON LAKE
ISLAND COUNTY
JEFFERSON COUNTY
CLALLUM COUNTY
KITSAP COUNTY
SNOHOMISH COUNTY
KING COUNTY
MASON COUNTY
PIERCE COUNTY
123°00'
45'
30'
15'
122°00'
48°00'
47°15'
QUATERNARY
TERTIARY
PRE-TERTIARY
4-13-49
I0=VIII
M=7.1

POOR ORIGINAL

EXPLANATION

QUATERNARY

HOLOCENE

m

Modified land and/or artificial fill.

Clay, silt, sand, and gravel.

Qal

Alluvial, colluvial, eolian and beach deposits.

Silt, sand and gravel.

Qls

Landslide and earthflow deposits.

Silt, sand, gravel, and boulders.

Qmf

Oceola and Electron Mudflows.

Unsorted mixtures of clay, silt, sand, gravel and boulders.

PLEISTOCENE

Qv

Vashon Drift, undifferentiated.

Clay, silt, sand, gravel, and scattered boulders.

Qpv

Pre-Vashon glacial and non-glacial deposits, undifferentiated.

Clay, silt, sand, gravel, and scattered boulders.

TERTIARY

Tsc

Continental sedimentary rocks.

Siltstone, sandstone, conglomerate and shale; some coal beds.

Tsm

Marine sedimentary rocks.

Sandstone, siltstone, shale, and minor conglomerate.

Tvm

Marine volcanic rocks.

Pillow basalt, volcanic breccia, and minor intrusives.

Tvc

Continental volca[nic rocks]

Andesite, rhyolit[e]

Ti

Intrusive rocks. Includes ... dikes and sills, and granitic rocks.

PRE-TERTIARY

MTs

Mesozoic to Tertiary marine sedimentary rocks.

Predominantly sandstone and shale.

MTv

Mesozoic to Tertiary marine volcanic rocks.

Basalt, volcanic breccia, and minor intrusives.

pTu

Metasedimentary and metavolcanic rocks, undifferentiated.

★ Accelerograph station location

● Epicentral locations of selected historic earthquakes listed in Table 15-1.

4-13-49 —— Date of occurrence (month-day-year)

Io=VIII —— Maximum Intensity (MM)

M=7.1 —— Magnitude (Richter)

CONTACT

FAULT

Dashed where approximately located, dotted wher[e] ...
Barbs on upper plate of Thrust Fault.

5 0 5 10 15 20 25 30

Scale in kilometers

5 0 5 10 15 20

Scale in miles

ic rocks.
, and basalt.

concealed

NOTES:

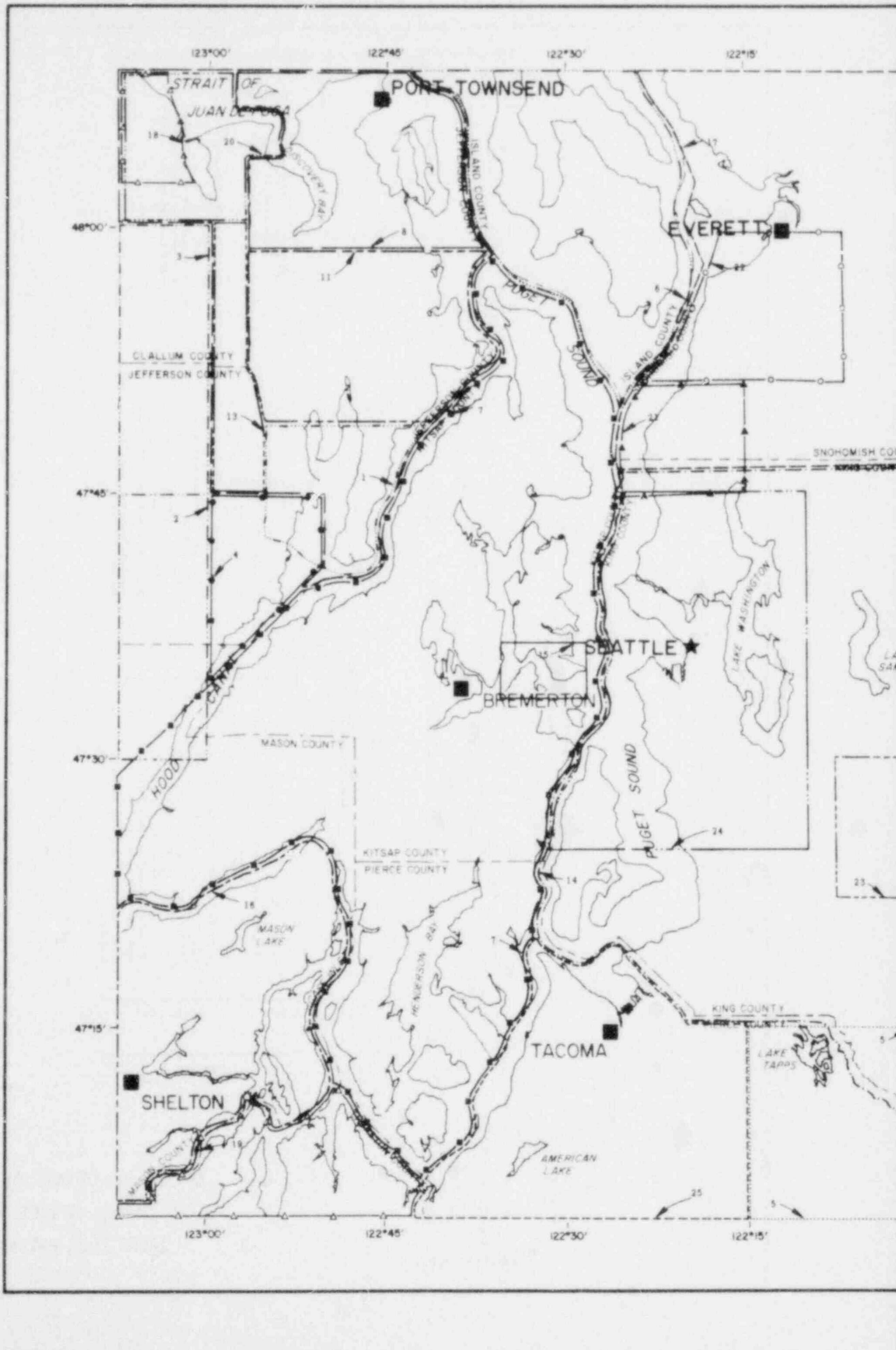
1) Geology is generalized from published and unpublished reports indexed on Fig. 15-5.

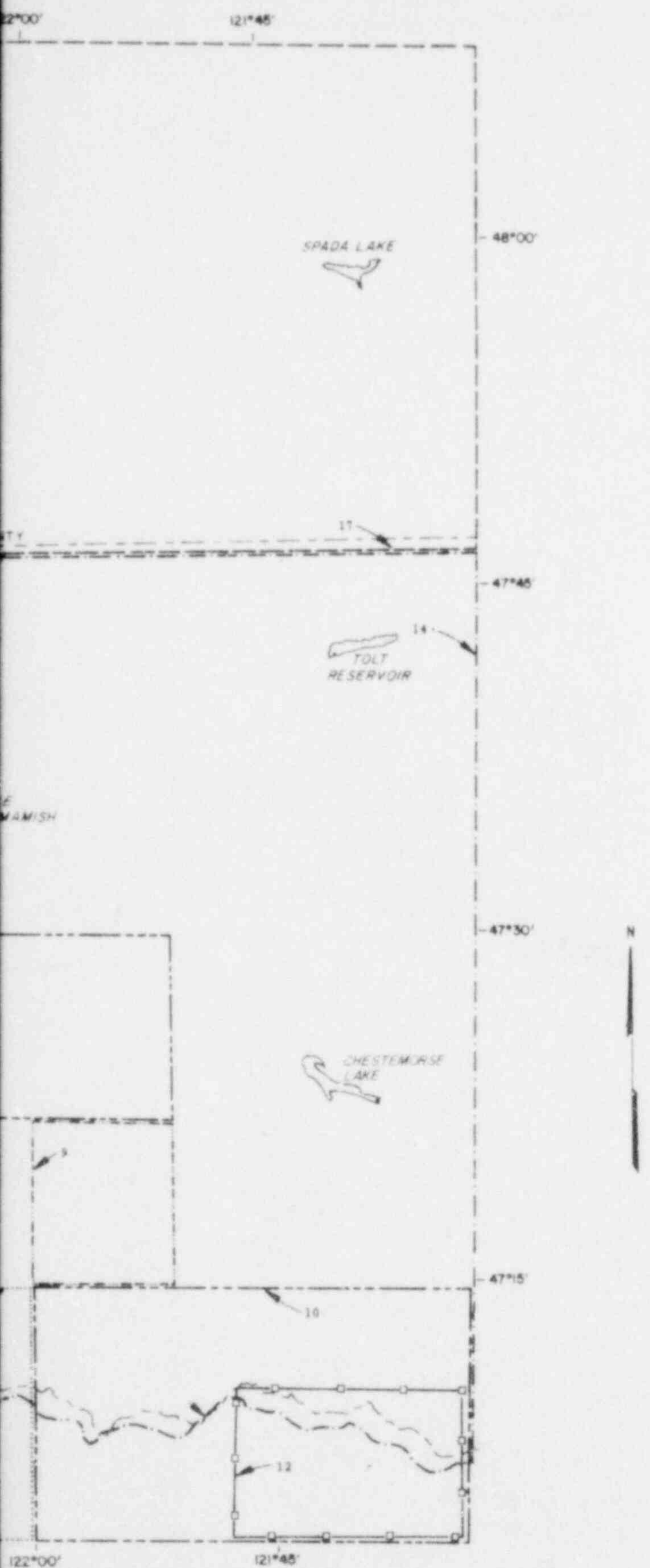
2) Cross-Section O-O' is shown on Fig. 15-6.

Location of Geologic Map.

GEOLOGIC MAP
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

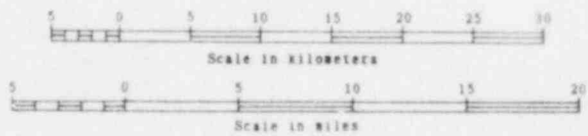
FIG. 15-4


123°00'
122°45'
122°30'
122°15'
48°00'
47°45'
47°30'
47°15'
STRAIT OF JUAN DE FUCA
PORT TOWNSEND
DISCOVERY BAY
ISLAND COUNTY
EVERETT
CLALLUM COUNTY
JEFFERSON COUNTY
SNOHOMISH COU
PUGET SOUND
SEATTLE
LAKE WASHINGTON
BREMERTON
HOOD CANAL
MASON COUNTY
KITSAP COUNTY
PIERCE COUNTY
MASON LAKE
HENDERSON BAY
KING COUNTY
TACOMA
LAKE TAPPS
SHELTON
AMERICAN LAKE



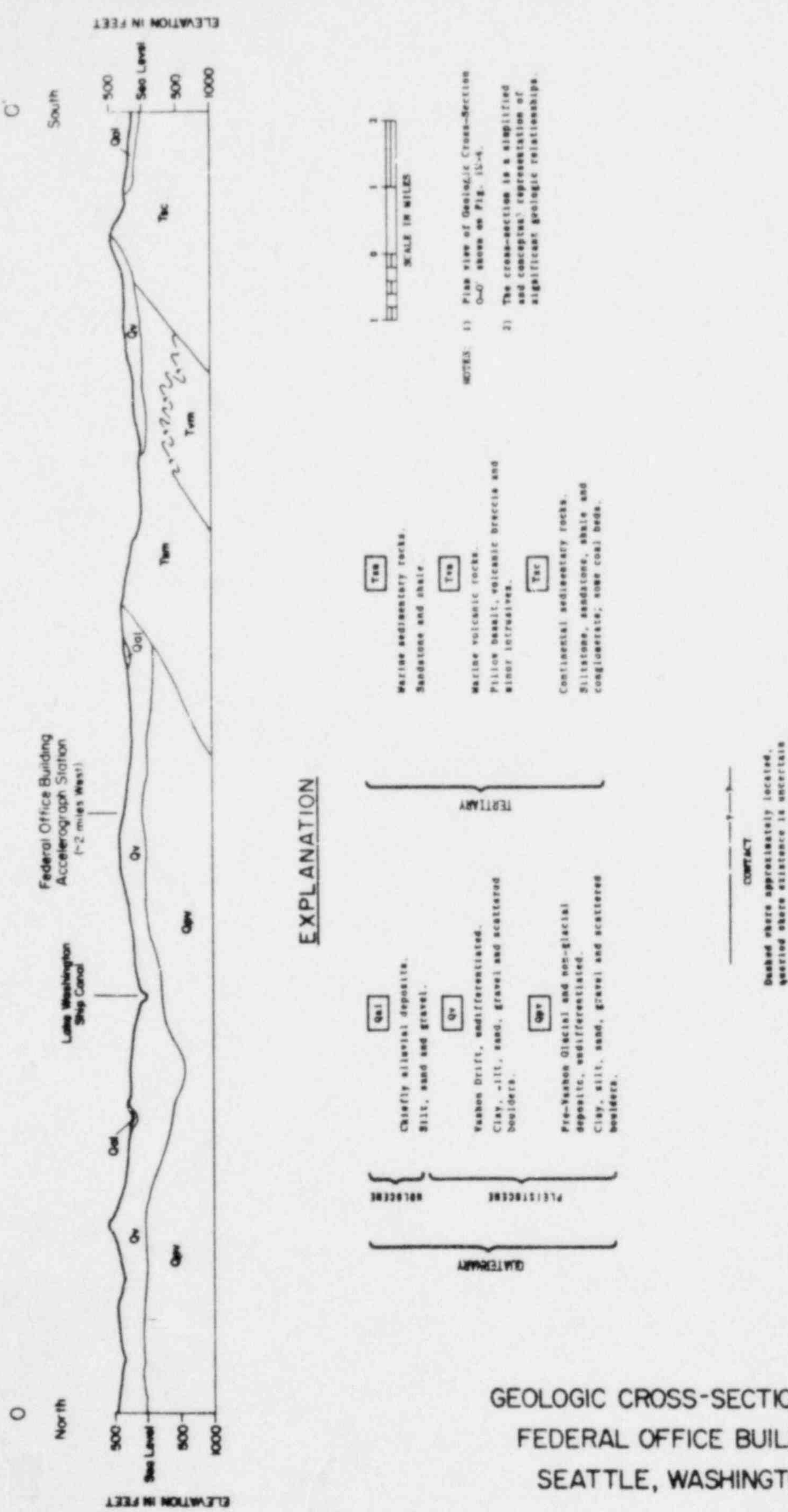
SOURCES USED IN COMPILING THE GEOLOGIC MAP

1. BIRDSEYE, 1978
2. CADY, et al., 1972a
3. CADY, et al., 1972b
4. CARSON, 1976
5. CRANDELL, 1963
6. EASTERBROOK, 1968
7. GABLING, et al., 1965
8. GAYER, 1976
9. GOWER and WANEK, 1963
10. HAMMOND, 1977
11. HANSON, 1976
12. HARTMAN, 1973
13. HUNTTING, et al., 1961
14. LIVINGSTON, 1971
15. McLEAN, 1977
16. MOLENAAR and NOBLE, 1970
17. NEWCOMB, 1952
18. NOBLE, 1960
19. NOBLE and WALLACE, 1966
20. OTHBERG, 1978
21. SMITH, 1975
22. SMITH, 1976
23. VINE, 1969
24. WALDRON, et al., 1962
25. WALTERS and KIMMEL, 1968



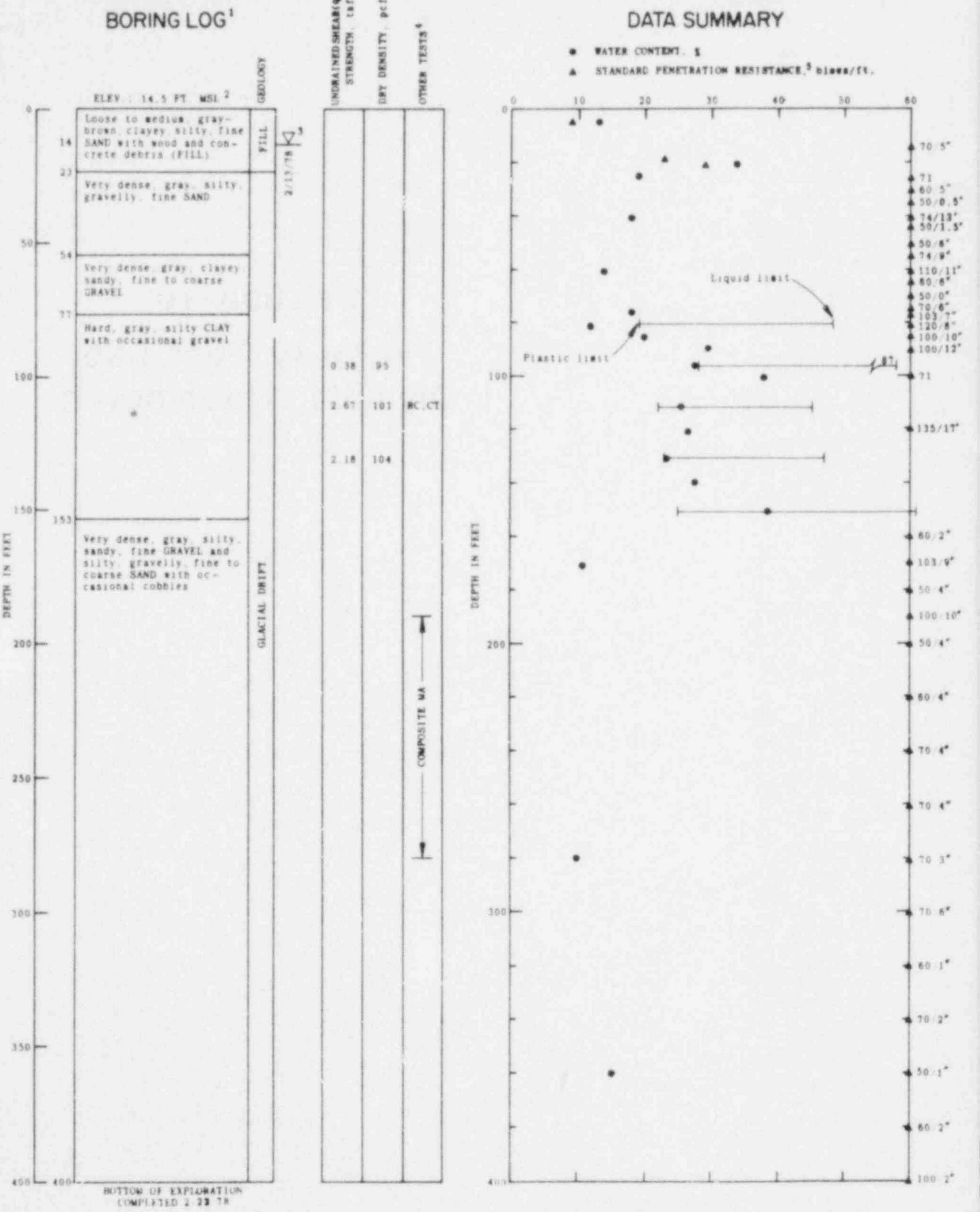
GEOLOGIC INDEX MAP
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-5



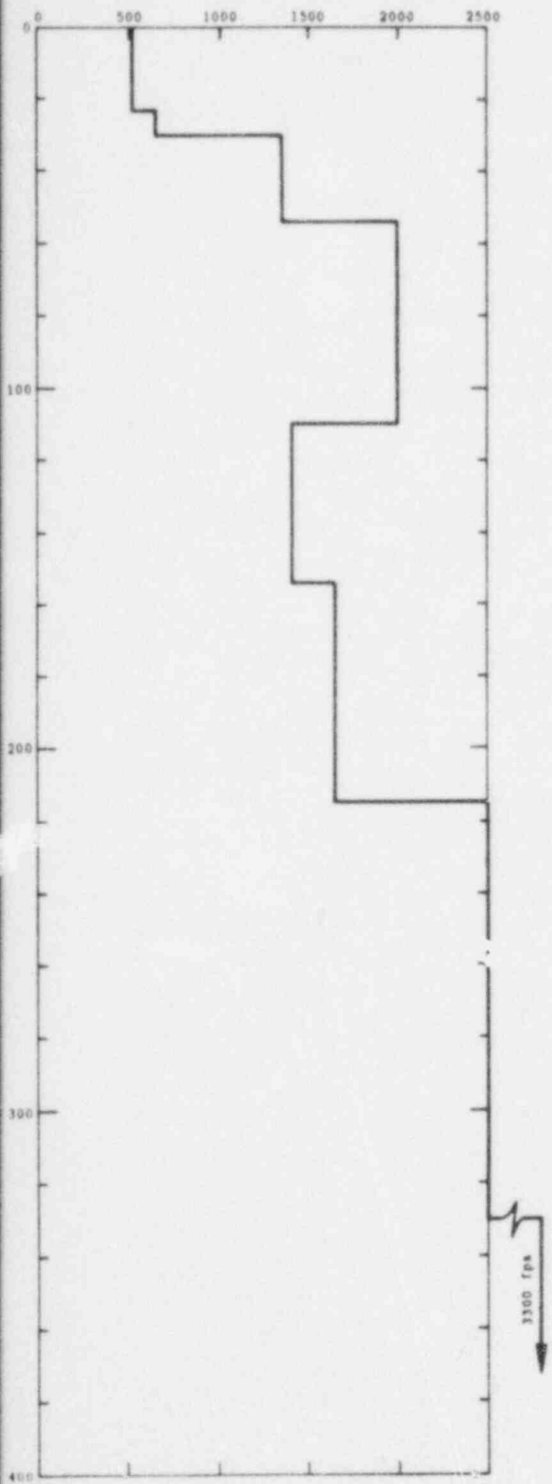
GEOLOGIC CROSS-SECTION O-O'
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-6

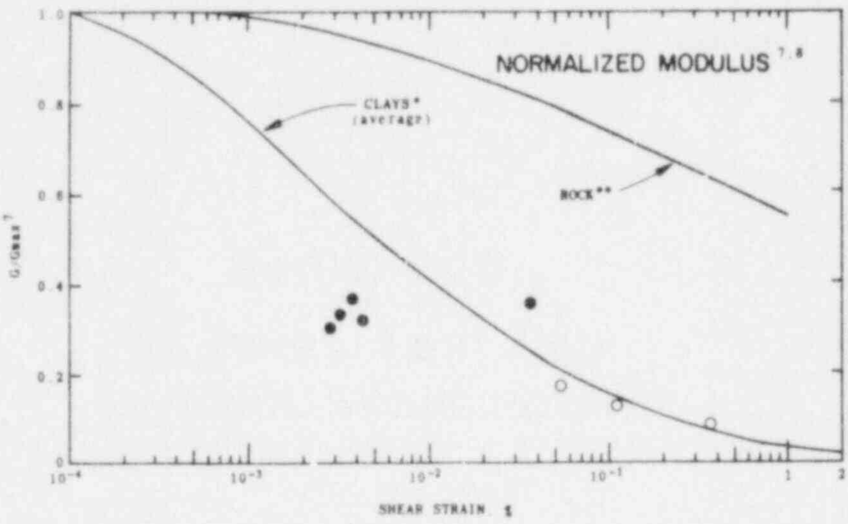


NOTES:
1) THE STRATIFICATION LINES IN THE BORING LOG REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES, AND THE TRANSITION MAY BE GRADUAL.
2) BORING ELEVATION OBTAINED BY LEVELING FROM CITY BENCHMARK. THE BORING IS LOCATED ABOUT 100 FEET SOUTHEAST OF THE FEDERAL OFFICE BUILDING.
3) WATER LEVEL MEASURED IN AN ABANDONED BORING.
4) DETAILED RESULTS OF LABORATORY TESTS ARE PRESENTED IN APPENDIX C. TEST ABBREVIATIONS ARE AS FOLLOWS: RC - RESONANT COLUMN
CT - CYCLIC TRIAXIAL
MA - MECHANICAL ANALYSIS (GRADATION)
5) STANDARD PENETRATION RESISTANCES (▲) AR
SPLIT SPOON SAMPLER WITH A 140-LB. HAMME
6) DETAILS OF DOWNHOLE GEOPHYSICAL TESTING
7) LABORATORY RESONANT COLUMN AND CYCLIC TR
Gmax ($G_{max} = V_s^2 \rho$) AS DETERMINED FROM DO
VELOCITY MEASUREMENTS.
8) NORMALIZED LABORATORY MODULI ARE UNC

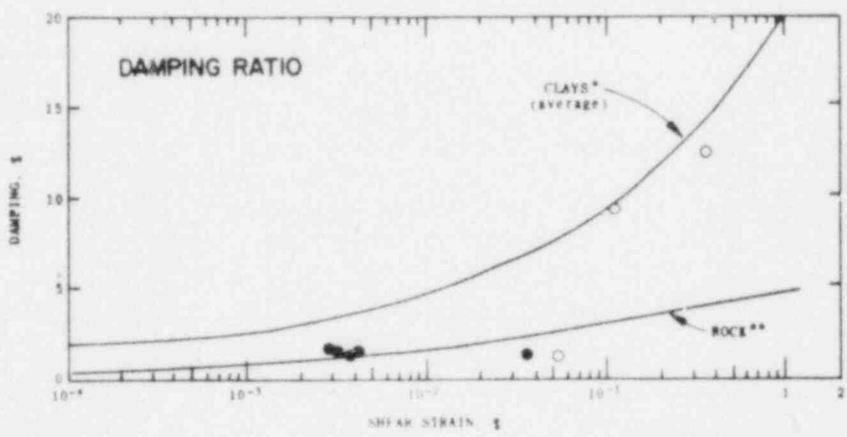
SHEAR WAVE VELOCITY*- V_s (fps)



DYNAMIC PROPERTIES OF SUBSURFACE MATERIALS



RESONANT COLUMN	CYCLIC TRIAXIAL	SAMPLE DEPTH FT	Gmax[7] psi	V_s[7] fps
●	○	110	52,800	1400



* FROM SEED-AJA (1972)
** FROM SCHNABEL, et al. (1971)

...BASED ON DRIVING A 2-INCH O.D.
...FALLING 30 INCHES.
...E PRESENTED IN APPENDIX B.
...AXIAL TEST DATA ARE NORMALIZED TO
...HOLE GEOPHYSICAL SHEAR WAVE
...TED FOR POSSIBLE SAMPLE DISTURBANCE.

BORING LOG AND
SUMMARY OF TEST RESULTS
FEDERAL OFFICE BUILDING
SEATTLE, WASHINGTON

FIG. 15-7

Section 16

Highway Test Lab
Olympia, Washington

SECTION 16

HIGHWAY TEST LAB, OLYMPIA, WASHINGTON

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SECTION 16

HIGHWAY TEST LAB, OLYMPIA, WASHINGTON

LIST OF FIGURES

SECTION 16
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

16.1 STATION DESCRIPTION

16.1.1 Location and Building

Olympia is located in western Washington at the southern extension of Puget Sound, which is an arm of the Pacific Ocean. The city lies about 60 miles south-southwest of Seattle. Olympia, the capital city of Washington, is located in Thurston County.

The Highway Test Lab accelerograph station shelter is located in a parking lot owned by the Washington State Department of Transportation in downtown Olympia (Fig. 16-1). The adjacent buildings at the site (318 State Ave.) once housed the materials testing facilities of the Highway Department, hence the name for the accelerograph station. However, the materials testing facilities have since been relocated to Tumwater, and the buildings at the site now serve as a Planning Annex for the state. The accelerograph station building is located about 250 feet northeast of the intersection of State Avenue and Franklin Street.

The accelerograph is contained in a one story, 8 by 10 foot shed (Fig. 16-2). Exterior walls of this wood-framed structure are finished with corrugated metal, and masonite wallboard is used on the interior walls. The shed has a concrete floor slab cast on grade (elevation about 12 feet MSL). The concrete accelerograph pier inside the shed is not connected to the floor slab. There is about a 1/2 inch gap between the perimeter of the pier and the slab. The pier extends about 1.5 feet above grade and possibly several feet below grade.

16.1.2 Instrumentation and Earthquake Recordings

The Highway Test Lab accelerograph station is part of the USGS strong motion instrument network and is identified as station number 2101. The site was initially instrumented on October 27, 1948, with a Coast and Geodetic Survey standard accelerograph (S/N 28) recording on 6 inch photographic paper. This instrument remained at the station until July 22, 1975, when it was replaced with an RFT-250 recorder (S/N 515). A plan of the shed and a photo of the current instrumentation are presented in Fig. 16-3. Both the original and replacement accelerographs were bolted directly to the instrument pier at the following orientations for pendulum motion (USGS, unpub.):

	Original C&GS Accelerograph	Replacement RFT-250 Accelerograph
Longitudinal	S04E	S04E
Vertical	Up	Down
Transverse	S86W	N86E

Two earthquakes have been recorded at the Highway Test Lab accelerograph station, both on the original C&GS standard accelerograph. Details of these earthquakes are presented in Appendix A. Summary data is given below.

Date (Mo-Da-Yr)	Magnitude (Richter)	Maximum Intensity (MM)	Peak Acceleration (g)
4-13-49	7.1	VIII	0.32
4-29-65	6.5	VII-VIII	0.20

Both of the earthquakes recorded at the station are the largest historic events in the Puget Sound region. Station records from both events have received a great deal of attention and study in the earthquake engineering field. Both records have been digitized and processed by the California Institute of Technology (Hudson, et al., 1971-1975a and b). The 1949 and 1965 events are identified as records B029 and B032, respectively, in the CIT series. Time histories of ground motion and response spectra for both records are presented in Appendix A.

16.2 GEOLOGY AND SEISMICITY

16.2.1 Regional Geology

Surface geology of the Olympia region is depicted on the Geologic Map of Fig. 16-4. For the purpose of this report, the Olympia region is defined by the area within about 60 kilometers (37 miles) of Olympia. The extent of this region, relative to the state of Washington, is indicated on the map insert of Fig. 16-4. The Geologic Map was prepared from the data sources shown in Fig. 16-5. Symbols shown in parentheses in the following discussion refer to geologic units on the map.

The major physiographic provinces in the Olympia region are the Olympic Mountains and Willapa Hills on the west, the Cascade Range on the east and between these two mountainous provinces, the Puget Lowland and Cowlitz-Willamette Lowland (McKee, 1972). The city of Olympia lies within the Puget Lowland, about 15-20 miles north of its boundary with the Cowlitz-Willamette Lowland.

The Puget Lowland and Cowlitz-Willamette provinces comprise most of the area in the Olympia region. Both of these lowlands originated as parts of a north-trending structural trough that was depressed during the late Tertiary orogenies that uplifted the adjoining mountain ranges. The Puget Lowland, which is a glaciated trough that extends into Canada, contains the inland waterways of western Washington and southern British Columbia. Much of its area is submerged and the remainder consists of numerous islands, peninsulas, low hills and small alluvial plains, all averaging less than 300 feet in elevation. The Cowlitz-Willamette Lowland, which extends south into Oregon, consists of low hills and intervening, broad alluvial valleys.

Bedrock in the Olympia region is primarily exposed in the mountains adjacent to the Puget Lowlands. In the Cascade Mountains to the east, the oldest exposed rocks are predominantly non-marine, andesitic volcanic rocks (Tvc) but include some marine and non-marine sedimentary rocks (Tsm and Tsc). In the Olympic Mountains west of the Puget Lowlands, bedrock consists of a peripheral band of relatively little deformed submarine basalts and minor interbedded marine sedimentary rocks (Tvm), which partly surrounds an inner core of intensely deformed, younger marine sedimentary rocks (Tsm).

South of the Puget Lowland, in the Willapa Hills and the Cowlitz-

Willamette Lowland, bedrock consists of Tertiary submarine basalts (Tvm) that are unconformably overlain by younger, less intensively deformed marine and non-marine sedimentary rocks (Tsm and Tsc), and by some non-marine volcanic rocks (Tvc). Locally, these Tertiary rocks have been intruded by mafic and felsic dikes and sills, and some mafic stock-like masses (Ti).

Bedrock underlying the Puget Lowland is largely obscured by a thick cover of Quaternary sediments. The few bedrock exposures in the lowland suggest that the geologic units of the adjoining mountains are continuous beneath the surficial deposits, and that they are transitional from continental to marine strata from east to west.

Most of the Quaternary sediments in the Puget Lowland have been deposited both during and between continental glaciations. The latest and most extensive of the continental glaciations was the Vashon Stade of the Fraser Glaciation. During this glaciation, the continental ice sheet advanced southward from British Columbia, blocking the drainage of the Puget Lowland through the Strait of Juan de Fuca, and eventually extended as far south as the town of Centralia (Crandell, 1965). The Vashon ice lobe both scoured the older glacial deposits and mantled them with younger materials. Thus, because the Vashon drift (Qv) now covers most of the Puget Lowland, the older glacial strata (Qpv) are exposed only locally. The cumulative thickness of these Pleistocene strata is locally as much as 3,000 feet (Hall & Othberg, 1974).

Older, deeply weathered Quaternary sediments (Qpv and Qt) of non-glacial origin are found outside the Puget Lowland in extensive areas south and east of Chehalis.

Holocene Quaternary deposits in the Olympia region include mudflow deposits (Qmf) derived from the slopes of Mt. Rainier, alluvial deposits (Qal), landslide deposits (Qls), and large areas of fill (m).

16.2.2 Local Geology

The local geology in the vicinity of Olympia is depicted diagrammatically in Geologic Cross-Section P-P' of Fig. 16-6. This north-south section is located about 2 1/2 miles east of Olympia (Fig 16-4).

Tertiary bedrock and a thick accumulation of Quaternary sediments underlie Olympia and its immediate vicinity (Noble and Wallace, 1966; Hall and Othberg, 1974). Although bedrock underlying Olympia is presumed to be submarine basalt of the Crescent Formation (Tvm), no deep wells have penetrated to rock in the immediate vicinity. These marine volcanic rocks, which are exposed locally in Tumwater, crop out in isolated monadnocks just southwest of Olympia and are exposed extensively in the nearby Black Hills to the west. Farther south, beyond the drift plain, a variety of Tertiary sedimentary and volcanic rocks (Tsc, Tsm, and Tvc) are exposed (Pease and Hoover, 1957; Snavely, et al., 1958; Huntting, et al., 1961; Weigle and Foxworthy, 1962).

The Quaternary sediments, which unconformably overlie the Tertiary bedrock, may be as much as 600 feet thick in the Olympia area (Hall and Othberg, 1974). The older pre-Vashon Pleistocene deposits (Qpv) include both glacial and non-glacial sediments. These sediments are overlain by the younger Pleistocene deposits of the Vashon Stage of the Fraser Glaciation (Qv). The Vashon Drift sediments include till and glaciofluvial sands and gravels.

Holocene Quaternary deposits in the Olympia area include varying thicknesses of alluvium (Qal). Also, areas of the waterfront, particularly in the vicinity of the accelerograph station, have been reclaimed by filling.

16.2.3 Structure and Seismicity

The structural geology of the Olympia region is illustrated in the Geologic Map (Fig. 16-4) and Cross-Section P-P' (Fig 16-6).

The Tertiary strata exposed in the foothills of the Cascade and Olympic Mountains near Olympia have been folded, faulted, locally intruded by mafic igneous rocks and deeply eroded. The Pleistocene glacial deposits in the Olympia area on the other hand, are generally flat lying, except for some gentle tilting and warping. The few Pleistocene glacial deposits that are gently folded or tilted have relatively horizontal erosion surfaces, suggesting that the tectonism that deformed them was not very recent. Much of the Quaternary deformation in the Puget Lowland has resulted from isostatic adjustment after the glaciers retreated, rather than from tectonism. The ice is estimated to have been over 1,300 feet thick in the vicinity of Olympia and more than 3,000 feet thick in the vicinity of Seattle. This large mass of ice depressed the underlying rocks about 330 feet. Subsequent rebound has uplifted the glacial deposits left by the ice as much as 295 feet (Hall and Othberg, 1974; Crandell, 1965).

Several faults are exposed in the Tertiary bedrock outcrops surrounding the Puget Lowland. Although some of these faults may be correlative with faults exposed in the few Tertiary outcrops in the Puget Lowland, most cannot be traced into this area. Geophysical investigations (magnetic, seismic, and gravimetric) provide the only sources of data on the subsurface bedding and structure in the Quaternary and Tertiary strata of the Puget Lowland (Danes, et al., 1965; Rogers, 1970; Hall and Othberg, 1974; Gower, 1978). Only one fault, near Lake Cushman in the Olympic Mountain foothills, about 32 miles north-northwest of Olympia, is known to offset Quaternary deposits (Carson, 1973 a and b; and Carson and Wilson, 1974). This small fault is not known to be associated with any historic earthquakes.

The Puget Lowland is an area of moderately high seismic activity, whereas seismicity in the adjoining mountainous areas has been relatively infrequent. Most of the earthquakes in the region have occurred at comparatively shallow depths; i.e., less than about 15 miles. The larger events, however, have occurred in a deeper zone at depths of more than 25 miles. The primary cause of this seismicity is believed to be the motion differential that is occurring between the North American and Pacific lithospheric plates (Crosson, 1972; USGS, 1975). None of the historic earthquakes in the region has been associated directly with any known or postulated faults.

The more significant historic earthquakes (those of Modified Mercalli intensity VI or greater) that have occurred in the Olympia region are listed in Table 16-1, and their approximate epicentral locations are shown on Fig. 16-4. Of the 13 events listed, four have been of intensity VII or larger. The largest of these was the event of April 13, 1949. This large shock, which was felt over an area of approximately 150,000 square miles, had a magnitude of 7.1 and a maximum intensity of VIII. This earthquake occurred about 10 miles east of Olympia and caused considerable damage in the region.

Two other smaller earthquakes that have affected Olympia include the February 14, 1946, intensity VII event, centered about 18 miles north of Olympia; and the April 29, 1965, magnitude 6.5 Seattle-Tacoma event, which occurred about 38 miles northeast of Olympia.

Several large earthquakes located outside of the map area have also affected Olympia. These include the North Cascades, December 15, 1872, intensity VIII event (WPPSS, 1977); the Vancouver Island, B.C., June 23, 1946, magnitude 7.3 earthquake (Coffman and Von Hake, 1973); and the Queen Charlotte Islands, B.C., August 21, 1949, magnitude 8.1 event (Coffman and Von Hake, 1973).

16.3 SITE CONDITIONS

Site conditions reported below for the Highway Test Lab are based on our reconnaissance of the site and on the subsurface conditions as reported by others (WPPSS, 1974). Subsurface conditions at the site were studied by Woodward-Clyde Consultants (WPPSS, 1974) with three borings drilled to depths of about 510 feet. Cross hole geophysical testing was performed in these borings to a depth of about 440 feet. Only one of the borings was sampled, and all samples from this boring were taken with a split spoon drive sampler. Consequently, the laboratory testing program was limited to determining the index properties of the soil. Details of the field drilling and results of the geophysical and laboratory testing are presented in Appendix B. Summary data from these studies are presented in Fig. 16-7 and discussed below.

16.3.1 Surface Features

The Highway Test Lab accelerograph station is located on a low lying, narrow peninsula which extends northward into Budd Inlet (Fig. 16-1). Much of this peninsula was created by filling former tideland areas with material dredged from Budd Inlet. As a result of these operations, much of the downtown business area, including the accelerograph station, is located on fill. Present elevation at the station is approximately 12 feet MSL.

16.3.2 Subsurface Conditions

The 511 foot deep boring at the Highway Test Lab site was drilled almost entirely within glacial sediments and did not encounter rock. The soil strata encountered in the drilling are generalized in the boring log of Fig. 16-7 and briefly discussed below.

Fill material was encountered to a depth of 10 feet in the site boring. The fill was predominantly a loose, fine to coarse sand with blow counts less than 10. A shear wave velocity of about 350 fps was obtained within this zone.

Underlying the fill and extending to a depth of about 40 feet is medium dense, fine to medium sand. Blow counts within this zone generally ranged from 20 to 40. The shear wave velocity of the sand was fairly constant at an average value of 725 fps.

Between depths of 40 and 135 feet, interbedded very stiff to hard, sandy silts and very dense, silty sands were encountered in the boring. Blow counts within this zone were quite variable, ranging from 10 to 68. The shear wave velocities, however, did not show as much variation. The velocities gradually increased from a value of 750 fps at the top of the layer to 1100 fps at the bottom of the stratum.

A very dense sand stratum was encountered between depths of 135 and 474 feet. Blow counts, which were reported in only the upper 20 feet of this stratum, were generally above 50. Shear wave velocities gradually increased within this zone from a value of about 1100 fps at the top of the stratum to 1900 fps at a depth of apprroximately 410 feet. Shear wave velocities greater than 3000 fps were obtained below a depth of 430 feet. This marked increase may be partially due to gravels, which were encountered in the stratum between depths of 420 and 455 feet.

Interbedded hard, silty clay and very dense, silty, fine sand was encountered between depths of 474 and 511 feet, which was the bottom of the boring. Shear wave velocities were not obtained in this zone.

The water table was not measured in the borings as a heavy bentonite slurry was used to return drill cuttings to the ground surface. However,it is anticipated that the water table at the site would be close to mean sea level, or about 12 feet below the ground surface.

16.3.3 Dynamic Soil Properties

Since only drive samples were retrieved from the boring, laboratory testing was not conducted to determine the dynamic properties of the subsurface soils.

TABLE 16-1

SIGNIFICANT EARTHQUAKES IN THE OLYMPIA REGION[1]

Source[2]	Year	Date Mo. Day	Time (PST) Hr:Min	Latitude[3] North (°)	Longitude[3] West (°)	Magnitude[4] (Richter)	Max. Intensity (MM)	Depth (Miles)	Epicentral Distance From Accelerograph Station (miles)
A,C	1880	12 - 12	20:40	47.5	122.5	--	VI	--	37 NNE
A	1892	4 - 17	14:50	47	123	--	VI	--	6 SW
A	1931	12 - 31	07:25	47.5	123.0	--	VI	--	32 N
A	1939	11 - 12	23:46	47.4	122.6	5.75	VII	--	28 NNE
A	1946	2 - 14	19:18	47.3	122.9	5.75	VII	--	16 N
B,C	1949	4 - 13	11:56	47.1	122.7	7.1	VIII	44	10 ENE
A	1954	5 - 15	05:02	47.4	122.3	--	VI	--	38 NE
B	1960	4 - 10	22:48	47.57	122.25	--	VI	--	47 NE
A	1963	1 - 24	13:43	47.4	122.1	--	VI	--	45 NE
B	1965	4 - 29	07:29	47.4	122.3	6.5	VII-VIII	37	38 NE
B,C	1965	10 - 23	08:28	47.5	122.4	4.8	VI	--	39 NNE
B	1975	4 - 22	15:04	47.08	122.65	4.0 (m_b)	VI	29	12 ENE
D	1976	9 - 8	00:21	47.38	123.08	4.6 (m_b)	VI	30	26 NNW

Notes:

1. Earthquakes selected for this tabulation have maximum intensities of VI or greater and have occurred within about 60 km (37 miles) of Olympia. The intent of this table is to provide a general indication of seismicity in the region; it is not a complete list of all earthquakes.

2. The following sources were used in compiling the earthquake data:

   A. Coffman and Von Hake (1973)

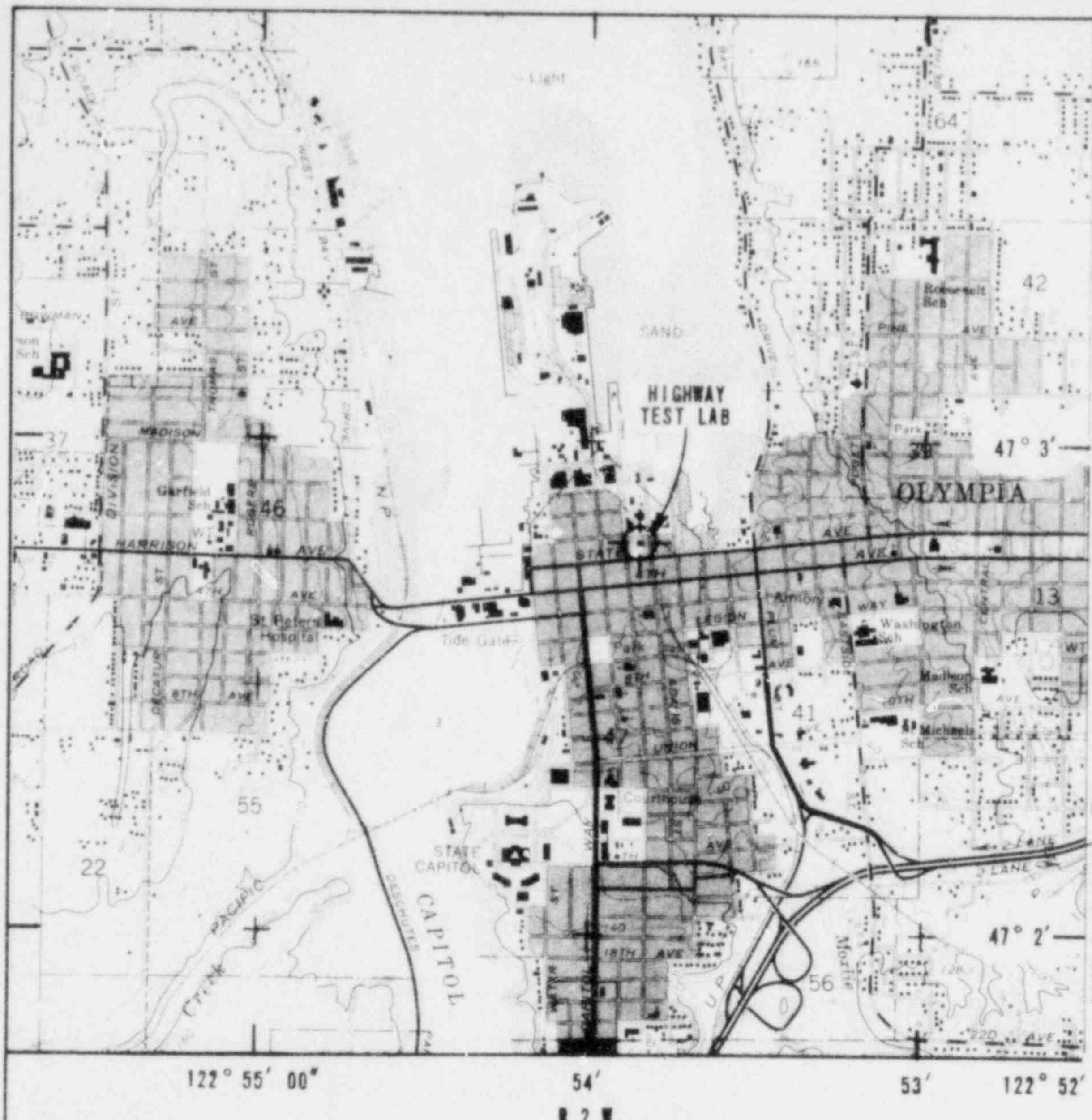
   B. United States Earthquakes

   C. U.S.G.S. (1975)

   D. Stover, et al. (1978)

3. The range of uncertainty for epicentral locations may be taken as $\pm 0.5°$ for earthquakes prior to 1960 and as $\pm 0.2°$ for those since 1960.

4. Magnitudes designated as m_b have been computed from body waves on a seismogram.



HIGHWAY TEST LAB

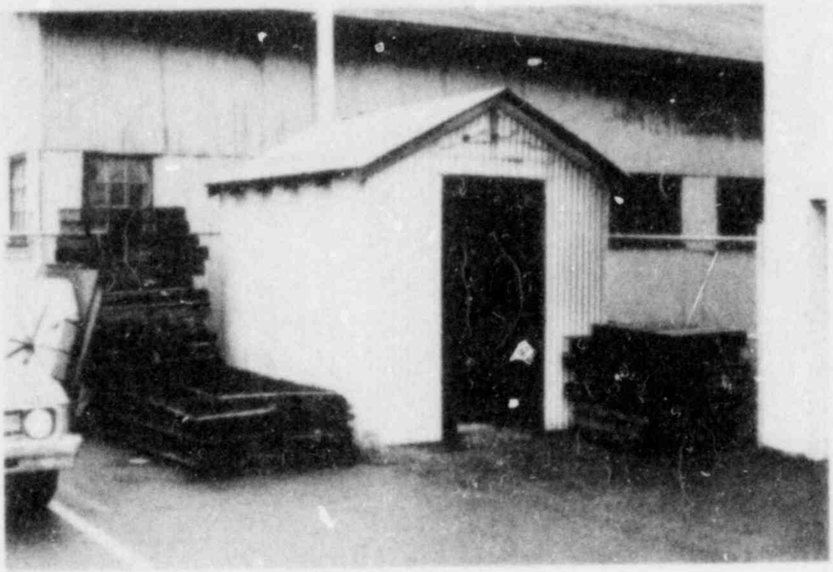
USGS Station No.:	2101
County:	Thurston
USGS Topographic Quadrangle:	Tumwater, Wash. N4700—W12252.5/7.5 1959
Coordinates:	47° 2' 48" N. 122° 53' 51" W.
Location:	318 State Ave.
Shelter:	1-story corrugated metal building

0 2000 4000
Scale in feet

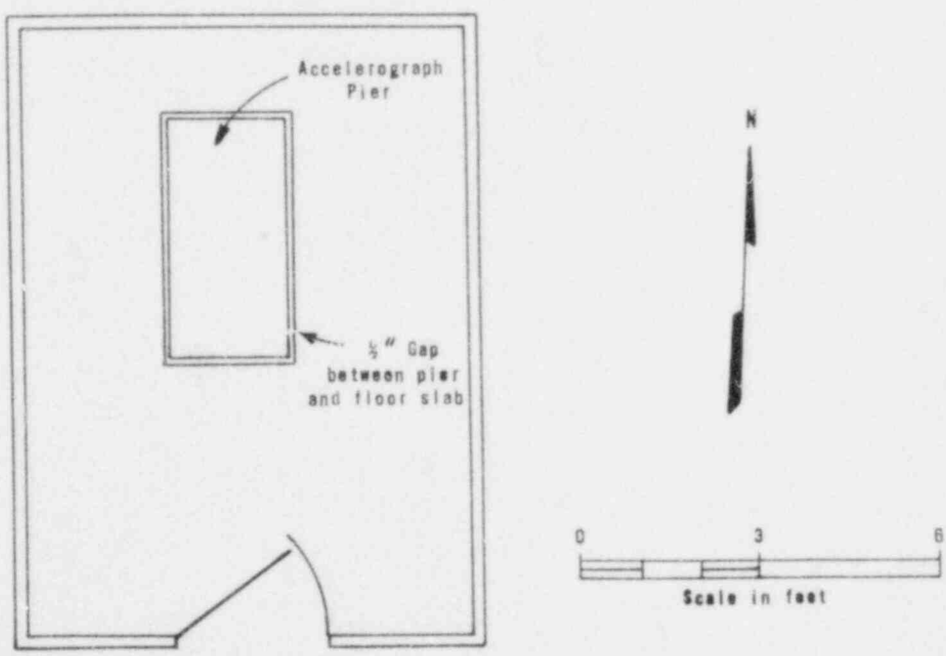
N

STATION LOCATION
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

FIG. 16-1



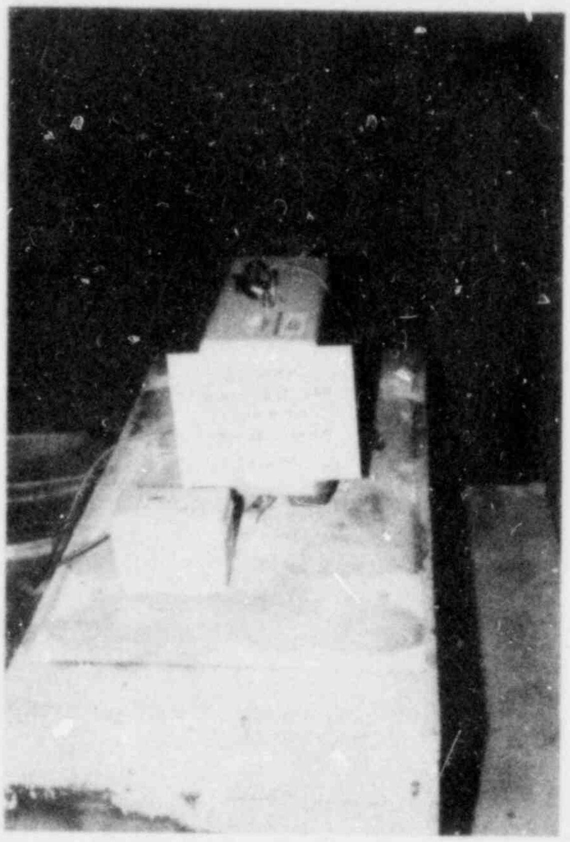
HIGHWAY TEST LAB INSTRUMENT SHELTER
VIEW: NORTHEAST



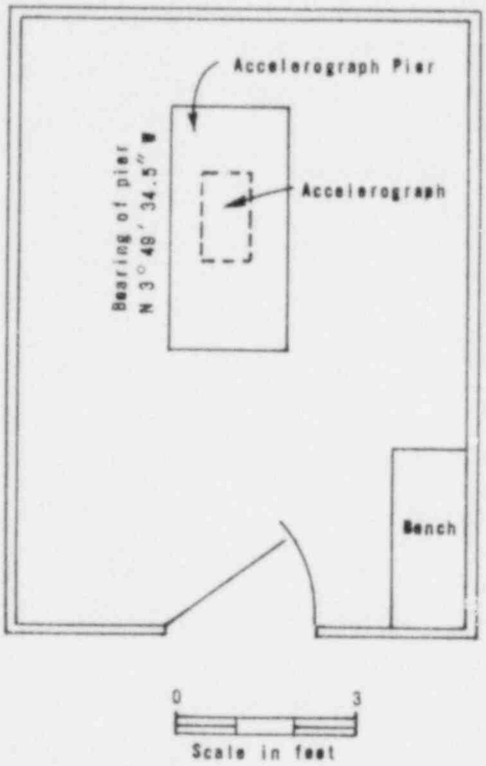
INSYRUMENT SHELTER PLAN

INSTRUMENT SHELTER
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

FIG. 16-2



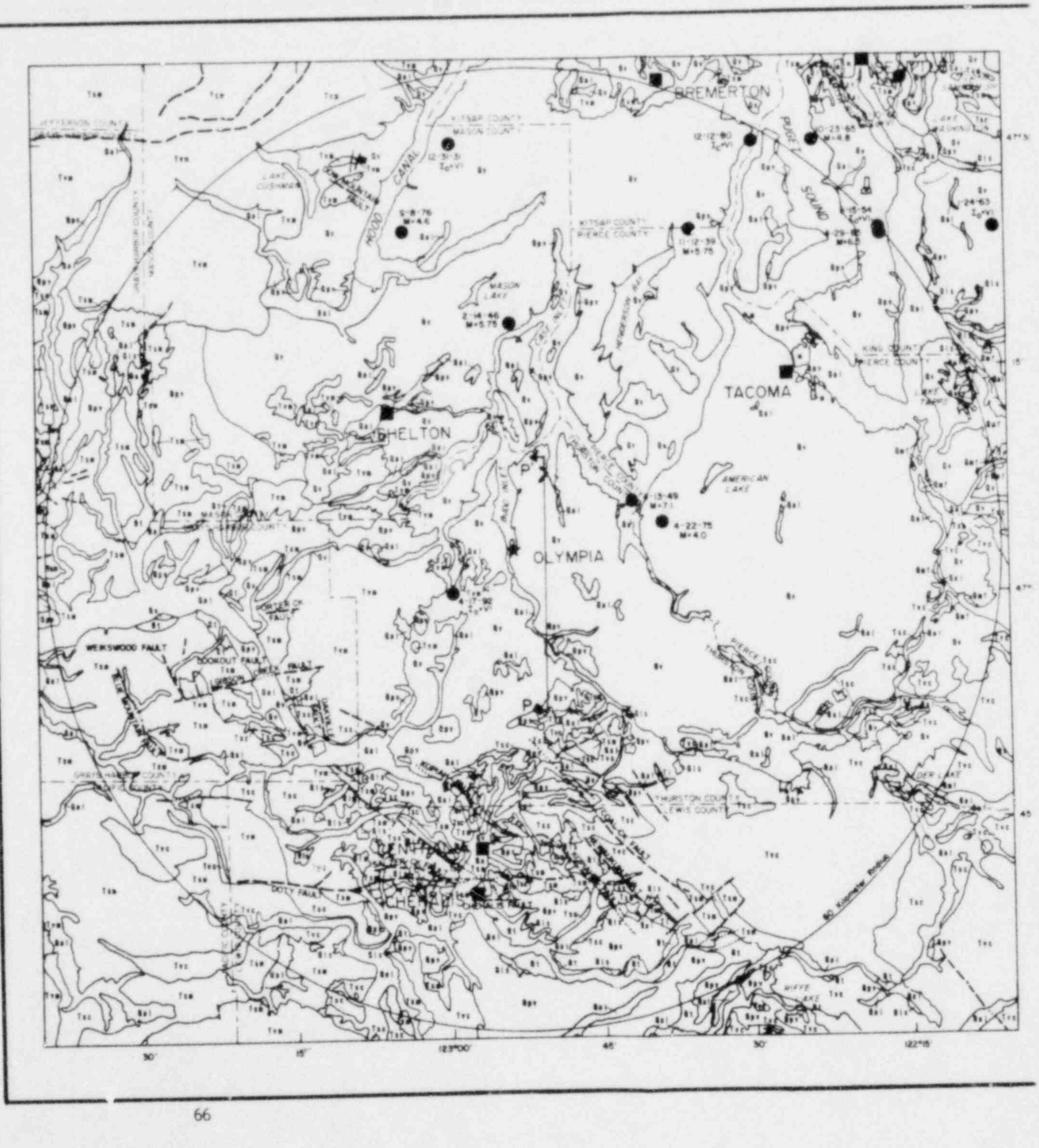
RFT-250 ACCELEROGRAPH
HIGHWAY TEST LAB
VIEW: NORTH



INSTRUMENT SHELTER PLAN

STATION INSTRUMENTATION
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

FIG. 16-3


BREMERTON
TACOMA
SHELTON
OLYMPIA
PUGET SOUND
HOOD CANAL
AMERICAN LAKE
MASON LAKE
KITSAP COUNTY
MASON COUNTY
PIERCE COUNTY
KING COUNTY
THURSTON COUNTY
LEWIS COUNTY
WEEKSWOOD FAULT
LOOKOUT FAULT
DOTY FAULT
30'
15'
123°00'
45'
30'
122°15'

POOR ORIGINAL

EXPLANATION

QUATERNARY

HOLOCENE

[*]

Modified land and/or artificial fill.

Clay, silt, sand and gravel.

[Qal]

Alluvial, colluvial, eolian and beach deposits.

Silt, sand and gravel.

[Qls]

Landslide and earthflow deposits. (Holocene and some Pleistocene)

Silt, sand, gravel and boulders.

[Qmf]

Oceola and Electron Mudflows

Unsorted mixtures of silt, sand, gravel and boulders.

PLEISTOCENE

[Qv]

Vashon Drift, undifferentiated.

Clay, silt, sand, gravel and scattered boulders

[Qt]

Terrace deposits.

Gravel and sand.

[Qpv]

Pre-Vashon glacial and non-glacial deposits, undifferentiated.

Clay, silt, sand, gravel and scattered boulders.

TERTIARY

[Tsc]

Continental sedimentary rocks.

Siltstone, sandstone, shale and conglomerate; some coal beds.

[Tsm]

Marine sedimentary rocks.

Sandstone, siltstone and shale.

[Tvm]

Marine volcanic rocks.

Pillow basalt, breccia and minor intrusives.

[Tvc]

Continental volc

Andesite, dacite, basalt.

[Ti]

Intrusive rocks, includes diabase andesite and dacite.

★ Accelerograph station location

● Epicentral locations of selected historic earthquakes listed in Table 16-1.

4-13-49 —— Date of occurrence (month-day-year)

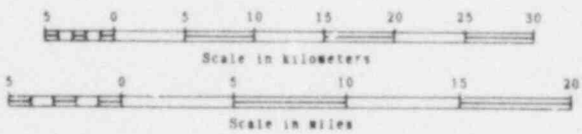
I_o=VIII —— Maximum Intensity (MM)

M=7.1 —— Magnitude (Richter)

■ Faults that may have moved during Holocene tim

CONTACT — Dashed where approximately located

FAULT — Dashed where approximately located, dotted whe Barbs on upper plate of Thrust Fault.



c rocks.
hyolite and

approx. 10,000 years)

concealed.

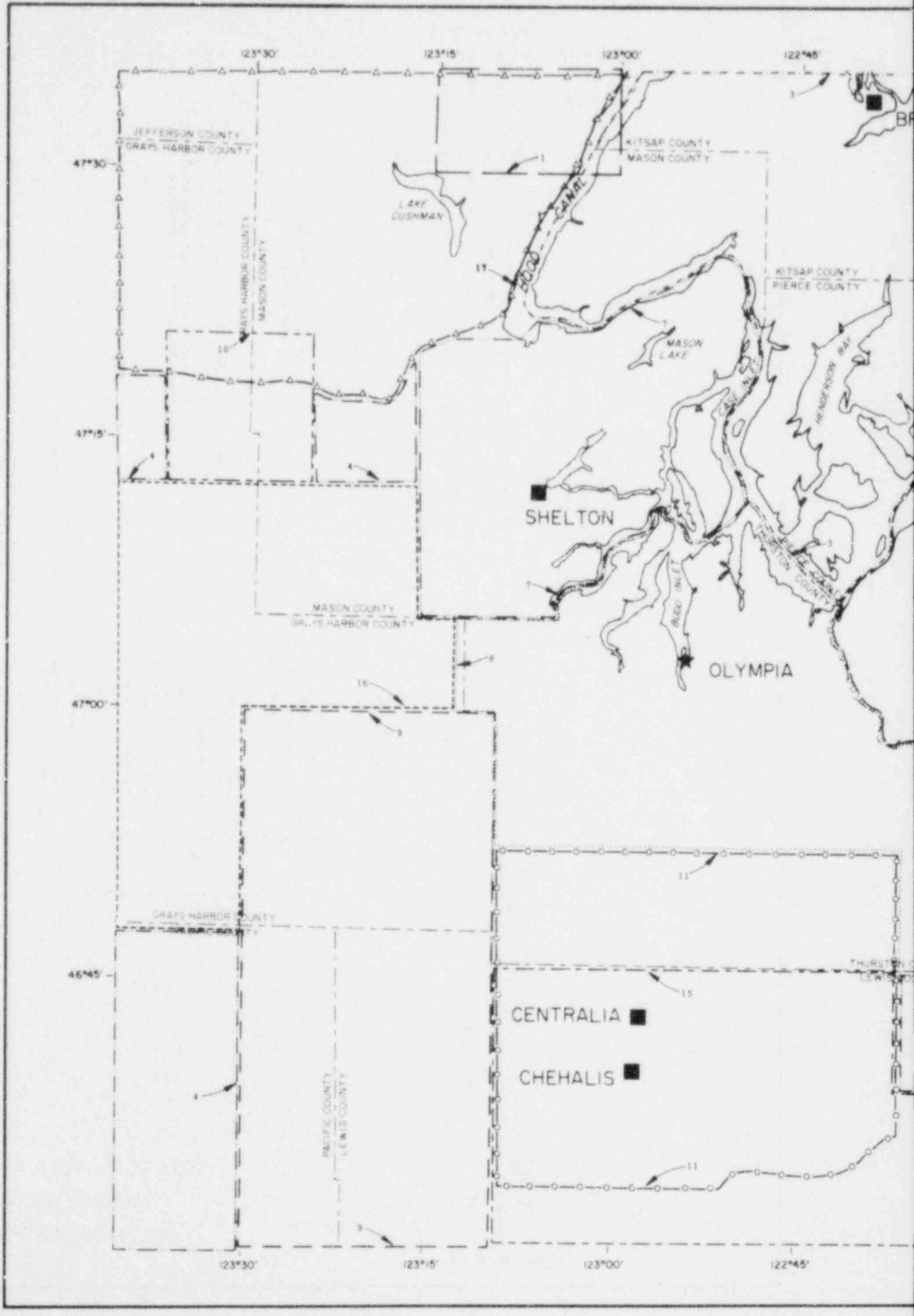
NOTES:

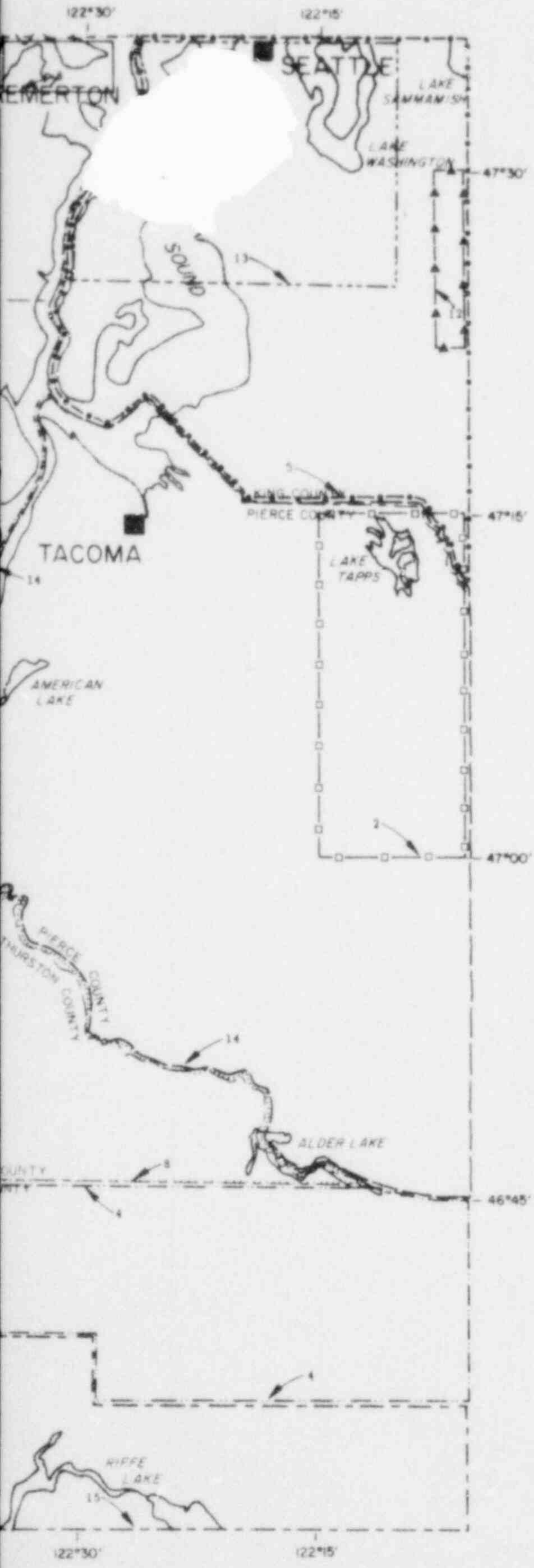
1) Geology is generalized from published and unpublished reports indexed on Fig. 16-5.
2) Cross-Section P-P' is shown on Fig. 16-6.
3) Information on fault activity (Quaternary and historic) is from Carson (1973a and b) and Carson and Wilson (1974).

Location of Geologic Map

GEOLOGIC MAP
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

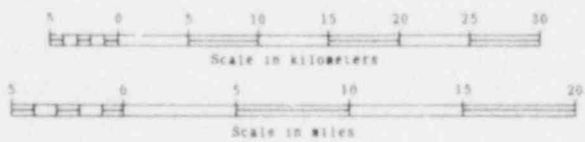
FIG. 16-4


123°30'
123°15'
123°00'
122°45'
47°30'
47°15'
47°00'
46°45'
JEFFERSON COUNTY
GRAYS HARBOR COUNTY
KITSAP COUNTY
MASON COUNTY
LAKE CUSHMAN
HOOD CANAL
GRAYS HARBOR COUNTY
MASON COUNTY
KITSAP COUNTY
PIERCE COUNTY
MASON LAKE
CASE INLET
HENDERSON BAY
SHELTON
THURSTON COUNTY
BUDD INLET
OLYMPIA
MASON COUNTY
GRAYS HARBOR COUNTY
GRAYS HARBOR COUNTY
CENTRALIA
CHEHALIS
PACIFIC COUNTY
LEWIS COUNTY
1
3
4
7
8
9
10
11
15
16
17



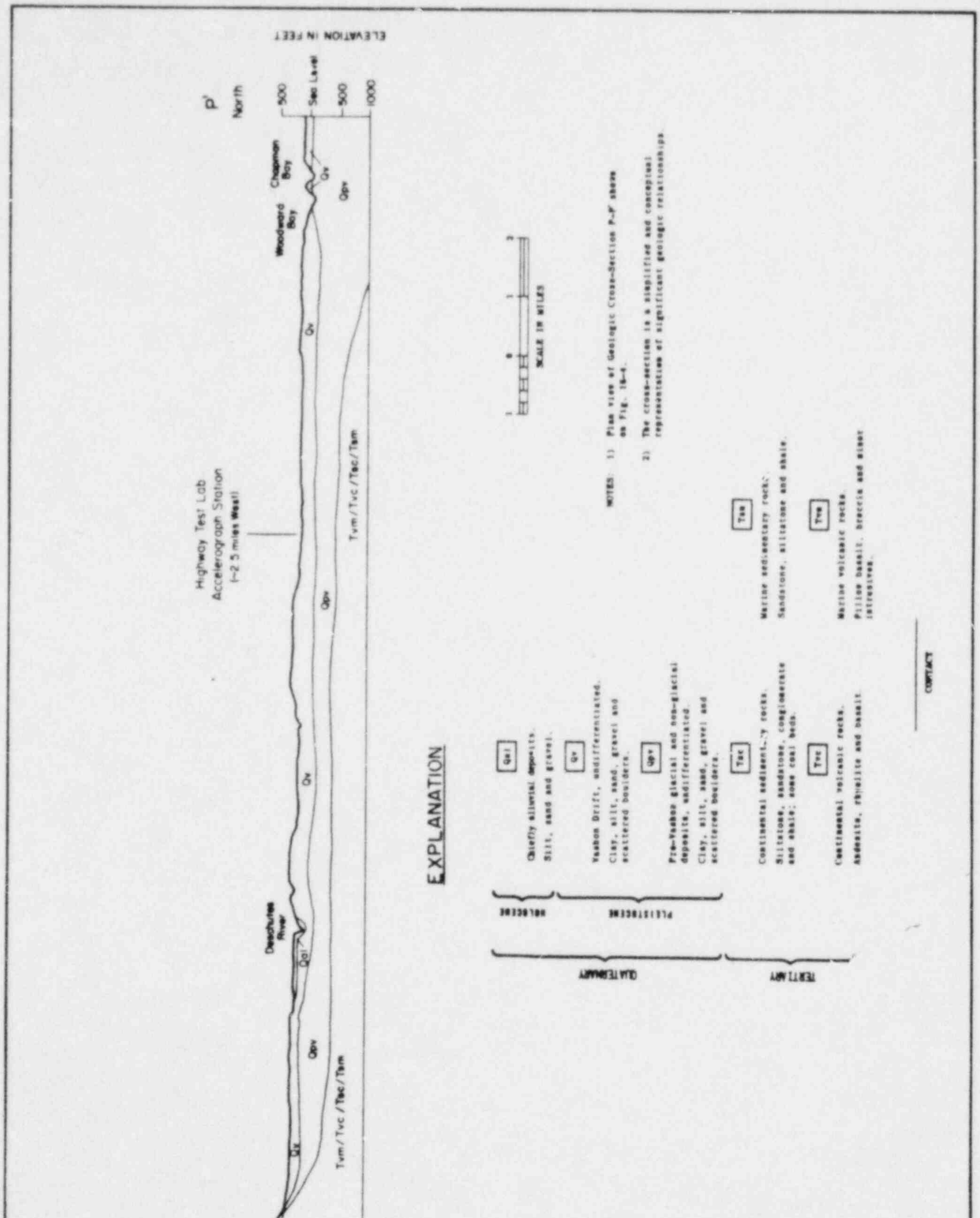
SOURCES USED IN COMPILING THE GEOLOGIC MAP

1. CADY, et al., 1972a
2. CRANDELL, 1963
3. GARLING, et al., 1965
4. HUNTTING, et al., 1961
5. LIVINGSTON, 1971
6. McLEAN, 1977
7. MOLENAAR and NOBLE, 1970
8. NOBLE and WALLACE, 1966
9. PEASE and HOOVER, 1957
10. RAU, 1966
11. SNAVELY, et al., 1958
12. VINE, 1969
13. WALDRON, et al., 1962
14. WALTERS and KIMMEL, 1968
15. WEIGLE and FOXWORTHY, 1962
16. WPPSS, 1974
17. TABOR AND CADY, 1978



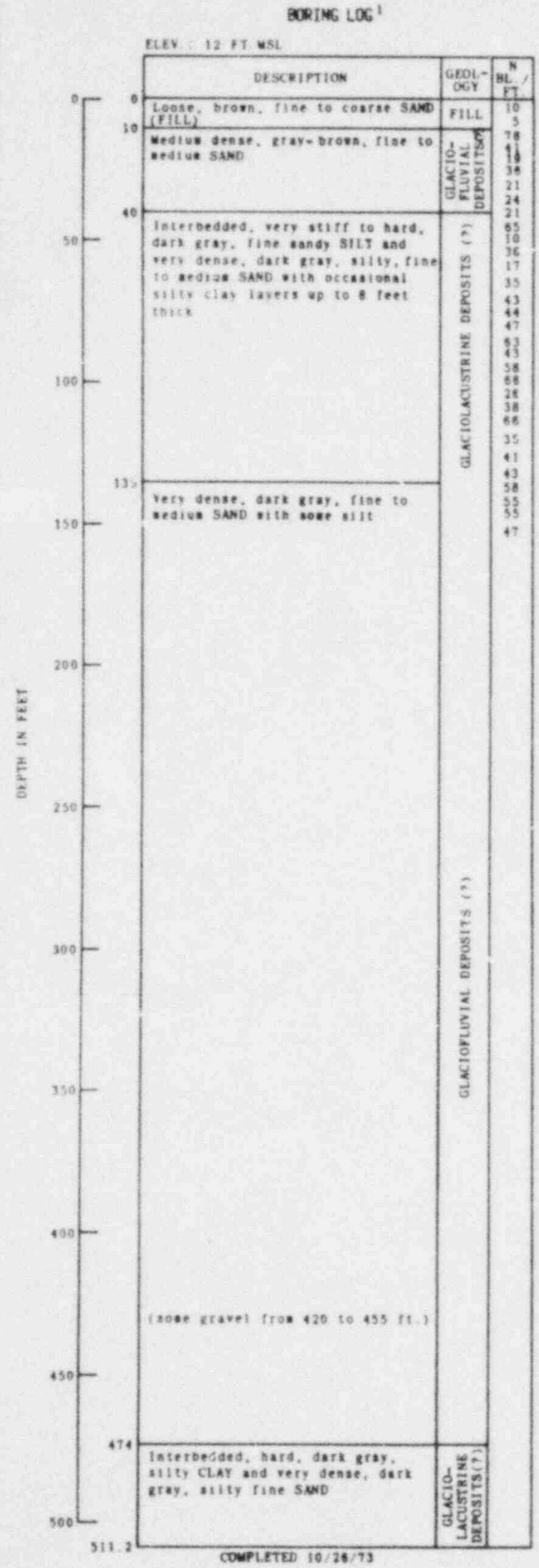
GEOLOGIC INDEX MAP
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

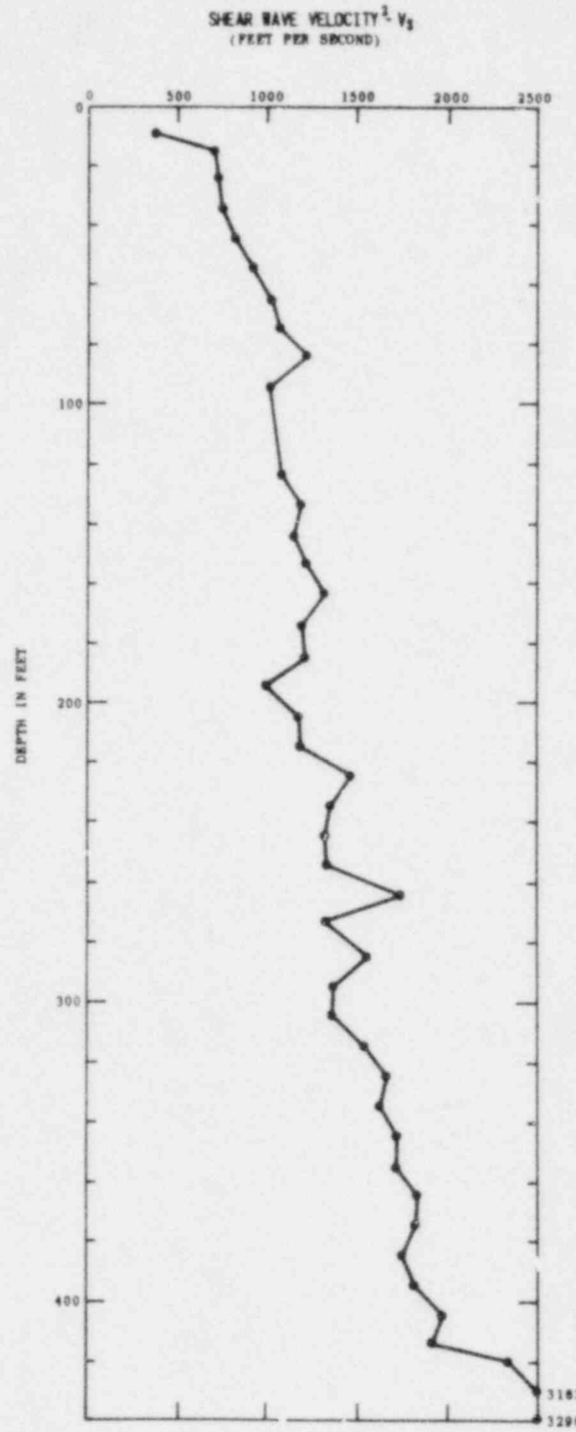
FIG. 16-5



GEOLOGIC CROSS-SECTION P-P'
HIGHWAY TEST LAB
OLYMPIA, WASHINGTON

FIG. 16-6





NOTES: 1) Information on the subsurface soils and shear wave velocities was obtained from WPPSS (1974). The boring log shown above has been generalized. A more detailed log is presented in Appendix B.

2) Cross hole geophysical measurements were made to a total depth of 440 feet.

BORING LOG AND SUMMARY OF TEST RESULTS

HIGHWAY TEST LAB

OLYMPIA, WASHINGTON

POOR ORIGINAL

FIG. 16-7

Section 17

Portland Sites
Portland, Oregon

SECTION 17

PORTLAND SITES, PORTLAND, OREGON

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PORTLAND SITES, PORTLAND, OREGON

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SECTION 17
PORTLAND SITES
PORTLAND, OREGON

17.1 INTRODUCTION

This section of the report contains discussions of two accelerograph station sites in Portland, Oregon. Portland is located in northwest Oregon on the Willamette River, about 10 miles southeast of the confluence of the Willamette and Columbia Rivers. Portland, the largest city in the state, is located in Multnomah County.

The stations discussed in this section are the State Office Building and PSU Cramer Hall. Station descriptions of each site are presented separately. However, since the sites are located within about 1200 feet of each other, the stations are discussed collectively in the geology, seismicity and site conditions sections.

17.2 STATION DESCRIPTIONS

17.2.1 State Office Building

17.2.1.1 Location and Building

The State Office Building is located at 1400 SW 5th Avenue in the south end of the downtown Portland business district (Fig. 17-1). The building occupies the entire block bounded by SW 4th and 5th Avenues and SW Columbia and Clay Streets, and it houses various state governmental agencies.

The State Office Building is an 11-story structure with a penthouse, and a partial basement for mechanical equipment (Fig 17-2). The first floor of the structure is square in plan and occupies the entire city block. The remaining stories (2 - 11) are set back from the first floor, and have a "U" shaped configuration. Plan dimensions of the first floor are about 200 feet square, and those for the tower section are about 120 by 200 feet.

The first level is the lowest complete floor of the building.

Because it is partially embedded below grade, the first floor may be called the "ground" floor or "basement" by others. Street entrance to the building is at the second level along SW 5th Avenue, as the west wall of the first floor is completely embedded in this area. Along SW 4th Avenue, however, the east wall of the first floor is fully exposed. Only the partial basement containing mechanical equipment is lower than the first floor. This partial basement, located between the elevator shafts and the north stairwell (Fig. 17-2), occupies an area of about 20 by 90 feet.

The State Office Building is constructed of steel and reinforced concrete, and it has a spread footing and mat foundation. The building support framework consists of structural steel members encased in concrete. Spread footings which support the columns in the high rise section are typically 12 feet square and loaded at less than 6.3 ksf. The spread footings are founded at elevations ranging between 70 and 80 feet MSL. The partial basement of the building has a mat foundation with a finished floor grade of 73.8 feet MSL. Finished grade for the first floor is 84.1 feet MSL. The building was completed in 1951.

17.2.1.2 Instrumentation and Earthquake Recordings

The State Office Building, while no longer instrumented, was part of the USGS strong motion accelerograph network and identified as station number 2110. The building was initially instrumented on June 18, 1953, with a Coast and Geodetic Survey standard accelerograph (S/N 14) recording on 6-inch photographic paper. The instrument was installed in the telephone switch room on the first floor as shown in Fig. 17-2. While at this location, the instrument had the following bearings (pendulum motion): Longitudinal - N20E; Vertical - Up; Transverse - S70E (USGS, unpub.).

Since its installation in 1953, the accelerograph was relocated several times. The first move occurred on January 20, 1967, when the accelerograph was moved from the telephone switch room on the first floor to an unused elevated shaft in the partial basement (Fig 17-2). This relocation was brought about by the addition of new telephone equipment to the switch room. Shortly after the accelerograph was installed in the elevator shaft it was learned that this location was in violation of safety codes. Almost two years elapsed before the instrument could be moved to a new location. It is assumed that the accelerograph was inoperative for most of this time since it was not moved immediately and station equipment servicing records were not found for this time interval. The instrument was finally removed from the elevator shaft on June 11, 1969, and placed in the women's lounge on the first floor (Fig. 17-2). The accelerograph remained at this location until December 4, 1972, when it was removed from the building and installed at PSU Cramer Hall.

All instrument locations in the State Office Building, have been either on the first floor or partial basement. In all cases, the accelerograph was bolted directly to the concrete floor slab, and the instrument was oriented at the same bearings as the initial installation. Instrument locations on the first floor were about 15 feet below the adjacent exterior grade, while the elevator shaft location was about 25 feet below grade. All instrument locations, except in the women's lounge, were directly over grade. The women's lounge is located above the partial basement.

While in operation, the accelerograph at the State Office Building recorded three earthquakes. All events were recorded during the time interval that the instrument was in the telephone switch room. Details of these earthquakes are presented in Appendix A. Summary data is given below.

Date (Mo-Da-Yr)	Magnitude (Richter)	Maximum Intensity (MM)	Peak Acceleration (g)
11-06-61	----	VI	≤0.05
11-05-62	4.75	VII	0.10
4-29-65	6.5	VII-VIII	≤0.01

The only station record of significance in earthquake engineering, as it has an acceleration of 0.05g or greater, is the event of November 5, 1962. Currently, this record has not been digitized, or processed. There is the possibility that this record may be processed by the USGS in the next year.

17.2.2 PSU Cramer Hall

17.2.2.1 Location and Building

Cramer Hall houses the Earth Sciences Department on the Portland State University (PSU) Campus. As indicated in Fig. 17-3, Cramer Hall is about 1200 feet southwest of the State Office Building. Cramer Hall occupies the entire block bounded by the extensions of SW Mill & SW Montgomery Streets and SW Park Avenue and SW Broadway.

As indicated in Fig. 17-4, Cramer Hall consists of four interconnected wings, each with plan dimensions of about 100 feet square. The total structure has four floors and a penthouse above grade and two basements. The basement of the building, which also may be called the ground floor, is partially embedded below grade. The south wall of the basement is completely embedded and the north wall is fully exposed. The subbasement is completely below grade and extends throughout the building except beneath the southeast wing. Floor elevations in the basement and subbasement are about 136 and 123 feet MSL, respectively. These elevations may vary among the wings since the basement floors are terraced.

Cramer Hall was constructed in three phases. The first phase of construction, which was completed in 1957, consisted of erecting the northwest wing. The southeast wing was completed in 1959 in the second phase construction activities. The third and final phase of construction was completed in 1970. This consisted of building the northeast and southwest wings.

All of the wings are of steel and reinforced concrete construction. The building support framework consists of structural steel members encased in concrete. Reinforced concrete is used in the exterior walls and interior shear walls. The outside walls of the building are faced with brick.

Both footing and pile foundation systems are used at Cramer Hall. The northwest and southeast wings are supported on spread footings. The footings are typicaly 8 to 12 feet square and designed for an allowable load of about 5 ksf. The northeast and southwest wings are supported on 12 inch diameter, 40 foot long, auger cast piles. Piles beneath the exterior walls and interior shear walls are cast into a grade beam. Individual columns are supported on pile groups containing from 2 to 10 piles.

17.2.2.2 Instrumentation and Earthquake Recordings

The Cramer Hall accelerograph station is part of the USGS strong motion instrument network and is identified as station number 2172. Cramer Hall was initially instrumented on December 4, 1972 with the accelerograph removed from the State Office Building. This instrument was a Coast and Geodetic Standard accelerograph (S/N 14) recording on 6 inch photographic paper. This instrument remained at Cramer Hall until January 27, 1976, when it was replaced with an RFT-250 accelerograph, S/N 157. Pendulum motion orientations for the original and replacement accelerographs are as follows (USGS, unpub.):

	Original C&GS Accelerograph	Replacement RFT-250 Accelerograph
Longitudinal	N70W	S70E
Vertical	Up	Down
Transverse	N20E	N20E

All instruments at Cramer Hall were placed in room S-21 in the subbasement of the northeast wing (Fig. 17-4). A plan of the accelerograph room and a photo of the current equipment are presented in Fig 17-5. Both the original and replacement accelerographs were bolted directly to the concrete floor slab. Floor elevation of the accelerograph room is 126.2 feet MSL, or about 20 feet below the exterior grade.

Currently, no earthquakes have been recorded by either of the accelerographs that have been at Cramer hall.

17.3 GEOLOGY AND SEISMICITY

17.3.1 Regional Geology

Surface geology of the Portland region is depicted on the Geologic Map of Fig. 17-6. For the purpose of this report, the Portland region is defined by the area within about 60 kilometers (37 miles) of Portland. The extent of this region, relative to the states of Oregon and Washington, is indicated on the map insert of Fig. 17-6. The Geologic Map was prepared from the data sources shown in Fig. 17-7. Symbols shown in parentheses in the following discussion refer to geologic units on the map.

The major physiographic provinces in the Portland region are the Coast Ranges on the west, the Cascade Range on the east, and between these two mountainous provinces, the Cowlitz-Willamette Lowland (McKee, 1972). The city of Portland lies within the Cowlitz-Willamette Lowland near its boundary with the Coast Ranges.

The Coast Ranges of Oregon extend from the Columbia River on the north to the Klamath Mountains on the south. The Tualatin Mountains (Portland Hills) constitute the easternmost part of the Coast Ranges in the Portland region. These mountains trend northwesterly and are predominantly underlain by folded and faulted lavas of the Columbia River Basalt Group (Tcr). Their steep, northeastern flank appears to be fault controlled (Beeson, et al., 1975; Hammond, et al., 1974), whereas the gentler, southwestern side is a dip slope away from the anticlinal crest of the mountains. The Columbia River lavas in the Tualatin Mountains overlie the older Tertiary volcanic and marine sedimentary strata (Tvm and Tsm) of the Coast Ranges further west.

The Cascade Range in Oregon is a north-trending mountain belt that is divided into two ranges, a Western Cascade Range and a High Cascade Range. The Western Cascade Range in the Portland region is comprised mostly of a thick sequence of folded and faulted lava flows and tuffs of Eocene to Miocene age (Tvc) (Callaghan and Buddington, 1938). Andesite is the most abundant rock type, but lithologies may range from basalt to rhyodacite and quartz latite. Younger, generally basaltic andesite lavas of late Tertiary to Quaternary age (QTvc) overlie the older volcanics in the eastern part of the region, and Oligocene to late Miocene dioritic plutons (Ti) intrude some of the older volcanic rocks.

Also, within the Cascade Range, particularly southeast of Portland, large areas are underlain by Quaternary mudflow deposits (Qmf) derived from the slopes of the young volcanoes. Quaternary glacial deposits (Qg) mantle the bedrock in a large area east of St. Helens, and large landslides (Qls) occur along the Columbia River east of Vancouver.

The Cowlitz-Willamette Lowland is an elongate, north-trending, topographic and structural depression which extends from Eugene, Oregon, northward into central Washington, where it merges with the Puget Lowland a few miles south of Olympia. It is underlain at depth by a thick accumulation of Tertiary strata, such as those exposed on the flanks of the bordering mountains. The only materials commonly exposed in the valley, however, are Quaternary terrace deposits (Qt), alluvium (Qal), and some Plio-Pleistocene basaltic lavas (QTvc) and sediments of the late Tertiary Troutdale Formation and Sandy River Mudstone (Tsc).

17.3.2 Local Geology

The local geology in the vicinity of Portland is depicted in Geologic Cross-Section Q-Q' of Fig. 17-8. The geology of this east-west section has been modified from that of Trimble (1963).

Tertiary bedrock and a thin mantle of Quaternary sediments underlie Portland and its immediate vicinity. The Tertiary strata include, from older to younger, continental lava flows and tuffs (Tvc), marine sedimentary rocks (Tsm), lavas of the Columbia River Basalt Group (Tcr) and Pliocene non-marine sediments (Tsc).

The non-marine sedimentary deposits (Tsc) have been subdivided into the Sandy River Mudstone (Tscs) and the Troutdale Formation (Tsct). The Troutdale Formation consists of semi-consolidated, non-marine clastic sediments. The lower part of the formation contains much clay and silt, whereas the upper part is predominantly sand and gravel. The Troutdale Formation occurs on both sides of the anticlinal ridge of the Tualatin Mountains that trend northwesterly in the west Portland area (Fig. 17-8).

Basaltic flows (QTvc), known locally as the Boring Lavas, spread out on the eroded surfaces of the Troutdale Formation and the Columbia River basalts. The Boring Lavas underlie some of the prominant mountains in the Portland area, such as Mount Sylvania, Swede Hill, Mount Scott, and Mount Tabor.

Quaternary sediments, which unconformably overlie the Tertiary strata, include Pleistocene terrace deposits (Qt) and Holocene alluvial and colluvial deposits (Qal). These deposits range in thickness from a trace to generally less than 100 feet.

17.3.3 Structure and Seismicity

The structural geology of the Portland region is illustrated in the Geologic Map (Fig. 17-6) and Cross-Section Q-Q' (Fig. 17-8).

The Portland region is situated near the boundary between the North American and Pacific lithospheric plates. Interaction along this boundary, owing to convergence and differential motion between the two plates, has resulted in repeated crustal uplift during the Tertiary, and the formation of subparallel, north-trending compressional features, such as the Coast and Cascade Ranges and the intervening Cowlitz-Willamette Lowland.

Tectonic activity in the region dates back at least as far as the early Tertiary (Baldwin, 1976). Deformation at this time was principally subsidence accompanied by volcanism and sedimentation. By the middle of the Miocene epoch, however, most of the Coast Range region had emerged from the Pacific Ocean. Strong northeast-trending folding and faulting, and some intrusion of igneous materials, accompanied this period of orogeny.

The present orogenic cycle, which probably began in late Miocene time, resulted in renewed uplift of the ranges and compressive deformation, generally in north to northwest directions. In late Pliocene-early Pleistocene time, a renewed period of volcanism, plutonism, and mild uplift occurred. Since that time, tectonic activity has been restricted largely to volcanic activity in the Cascade Range.

As can be seen in Fig. 17-8, the most significant geologic structure in the Portland area is the folded and faulted Columbia River basalts, which form the prominent northwest-trending Tualatin Mountains. A major fault, the Portland Hills fault, and several minor faults are associated with this structure (Benson and Donovan, 1974; Beeson, et al., 1975). Other mapped faults in this region appear to be relatively minor and not related to major structural elements, in the region. None of the known or postulated faults in the region can be correlated directly with seismic activity.

Historic seismic activity in the Portland region is much less than that of the Puget Sound area. The more significant historic earthquakes (those of Modified Mercalli Intensity VI or greater) that have occurred in the Portland region are listed in Table 17-1, and their approximate epicentral locations are shown on Fig. 17-6. Of the nine events listed, only two have been larger than intensity VI. These are the earthquakes of October 12, 1877, and November 5, 1962, both of which had maximum intensities of VII. The 1877 earthquake was originally believed to be centered further east of Portland in the Cascade Mountains. However, more recent investigations (PGE, 1978; Thenhaus, 1978) indicate that this event occurred within about 9 miles of Portland. The 1962 event also occurred close to Portland. The epicenter of this event was placed about [illegible] miles away, near Vancouver, Washington.

Only one earthquake located outside the map area has caused significant damage in Portland. This is the magnitude 7.1 earthquake of April 13, 1949, that occurred near Olympia, Washington. Although centered just over 100 miles north of Portland, this earthquake caused intensity level VII damage in the city.

17.4 SITE CONDITIONS

Site conditions of both the State Office Building and Cramer Hall are discussed collectively in this section. The site conditions were studied with a surface reconnaissance, a deep boring, in-situ geophysical measurements, laboratory testing, and a review of available boring logs of others.

Only one boring was drilled to study the subsurface conditions in this investigation. This boring was drilled to a total depth of 260.5 feet at a location 300 feet northeast of Cramer Hall and 900 feet southwest of the State Office Building. A downhole geophysical survey was performed for the full depth of the boring to obtain shear wave velocities of the subsurface materials. Soil samples retrieved from the boring were tested in the laboratory to determine their index and engineering properties. Detailed results of the field drilling and geophysical testing are presented in Appendix B, and detailed results of the laboratory tests are presented in Appendix C. Summary findings from the field and laboratory studies are presented in Fig. 17-9 and discussed subsequently.

The decision to study the subsurface conditions with only one boring was based on a review of available boring data in the vicinity of both stations. Sources of data used in this review included soils reports for structures adjacent to the State Office Building (Shannon & Wilson, 1969) and water well logs in the vicinity of Cramer Hall (Portland State University, 1970). Review of this data indicated that subsurface conditions at each site consisted of alluvium overlying a sequence of Tertiary strata, and that the top of the Tertiary stratum was encountered at about the same elevation ($\pm$ 10 feet) at each site. It was concluded from this that the major difference between the two sites may be the depth of alluvium, and that the subsurface conditions might be reasonably depicted with one boring advanced between the stations.

17.4.1 Surface Features

Both the State Office Building and Cramer Hall are located on a gently sloping, low-lying alluvial terrace. This hillside slopes down ot the northeast where it merges with the Willamette River, approximately 2000 feet east of the stations (Fig. 17-1). The ground surface in the vicinity of the State Office Building varies from a high of 105 feet to a low of 80 feet MSL. Cramer Hall, which is located uphill from the State Office Building, has surrounding ground surface elevations which vary from 150 to 135 feet MSL.

17.4 2 Subsurface Conditions

The single exploratory boring which was drilled between the two stations penetrated alluvium, sands and gravels of the Pliocene Troutdale Formation, and basalts of the Columbia River Group. The strata encountered in the drilling are generalized in the boring log of Fig. 17-9 and discussed below.

The exploratory boring encountered a surficial fill to a depth of 8 feet. The fill consisted of a very stiff, slightly clayey silt. A shear wave velocity of 775 fps was obtained within this material.

The natural alluvial sediments underlying the site fill to a depth of 92 feet, consisted of medium dense, silty sand and sandy silt. The silts were somewhat cohesive as evidenced by their shear strengths (unconfined compression tests) which varied from 0.2 to 0.6 tsf. Water contents of this material generally ranged from 20 to 35 percent. A shear wave velocity of 775 fps was obtained in this material above a depth of 40 feet. Below 40 feet, velocities of approximately 1300 fps were obtained.

The average depth of alluvium differs for both the State Office Building and Cramer Hall. Since the State Office Building is lower in elevation, there is less alluvium at this location - about 65 feet based on boring data of others (Shannon & Wilson, 1969). There is about 100 feet of alluvium at Cramer Hall, based on water well logs (Portland State University, 1970).

Very dense gravel of the Troutdale Formation was encountered in the single boring (Fig. 17-9) between depths of 92 and 232 feet. All blow counts within this zone were over 100. The first 25 feet of this stratum had a shear wave velocity of 1800 fps, and the remainder had a velocity of 3600 fps.

Below 202 feet, basalts of the Columbia River Group were encountered in the boring. The upper 16 feet of this material was a breccia. Underlying the breccia, to at least the base of the boring at 260.5 feet, was very hard basalt. Shear wave velocities ranging from 3600 to 4400 fps were obtained in the breccia and basalt.

The water table was not measured in the boring as a heavy bentonite slurry was used to return drill cuttings to the ground surface. However, data from water well logs drilled in the vicinity of Cramer Hall indicate that the water table lies close to Mean Sea Level (Portland State University, 1970).

17.4.3 Dynamic Soil Properties

The strain-dependent, dynamic soil properties of shear modulus attenuation and damping ratio are presented in Fig. 17-9. These plots include data from laboratory resonant column and cyclic triaxial tests performed on the medium dense silty sands and sandy silts encountered in the boring between depths of 8 and 92 feet. For comparison purposes, these plots also contain the behaviorial relationships for "clay", "sand", and "rock" that have been proposed by others (SW-AJA, 1972; Schnabel, et al., 1971). The laboratory shear modulus values presented in Fig. 17-9 have been normalized to the low-strain shear modulus of the soil. This low-strain shear modulus was computed from the shear wave velocity of the soil, determined from the field downhole geophysical survey measurements. This normalization permits direct comparison of the laboratory data with the modulus attenuation relationships proposed by others.

Review of the data in Fig. 17-9 indicate:

1) The laboratory moduli values should be adjusted to account for disturbances due to sampling, testing and other effects. The uncorrected laboratory moduli values fall fairly close to the "clay" curve. However, the medium dense, sandy silts and silty sands at the site are quite different from the soft to medium stiff clays that were used to develop the "clay" curve. Therefore, it is expected that the dynamic behavior of the site soils would fall somewhere between the "clay" and "sand" curves. Correction factors of 1 to 3 would bring the laboratory moduli within this range.

2) The laboratory damping data lie close to the "rock" curve in the low-strain range but follow the "clay" curve for higher strain levels. Again, the dynamic behavior of the silty sands and sandy silts that were tested is expected to fall somewhere between that of the "sand" and "clay" curves.

TABLE 17-1

SIGNIFICANT EARTHQUAKES IN THE PORTLAND REGION[1]

Source[2]	Year	Date Mo. Day	Time (PST) Hr:Min	Latitude[3] North (°)	Longitude[3] West (°)	Magnitude[4] (Richter)	Max. Intensity (MM)	Depth (Miles)	Epicentral Distance From Accelerograph Station (miles)
C	1877	10 - 12	8:00	45.5	122.5	--	VII	--	9 E
A	1092	2 - 3	20:30	45.5	122.8	--	VI	--	6 W
A	1896	4 - 2	03:17	45.3	123.3	--	VI	--	34 WSW
A	1941	12 - 29	10:37	45.5	122.7	--	VI	--	2 W
A	1953	12 - 15	20:32	45.5	122.7	--	VI	--	2 W
B	1961	9 - 15	19:25	46.0	122.0	--	VI	20	47 NE
B	1961	11 - 6	17:29	45.7	122.4	--	VI	20	19 NE
A,B	1962	11 - 5	19:37	45.6	122.7	4.75 (B)	VII	--	7 N
A	1963	12 - 26	18:36	45.7	123.4	4.5	VI	--	37 WNW

Notes:

1. Earthquakes selected for this tabluation have maximum intensities of V. or greater and have occurred within about 60 km (37 miles) of Portland. The intent of this table is to provide a general indication of seismicity in the region; it is not a complete list of all earthquakes.

2. The following sources were used in compiling the earthquake data:

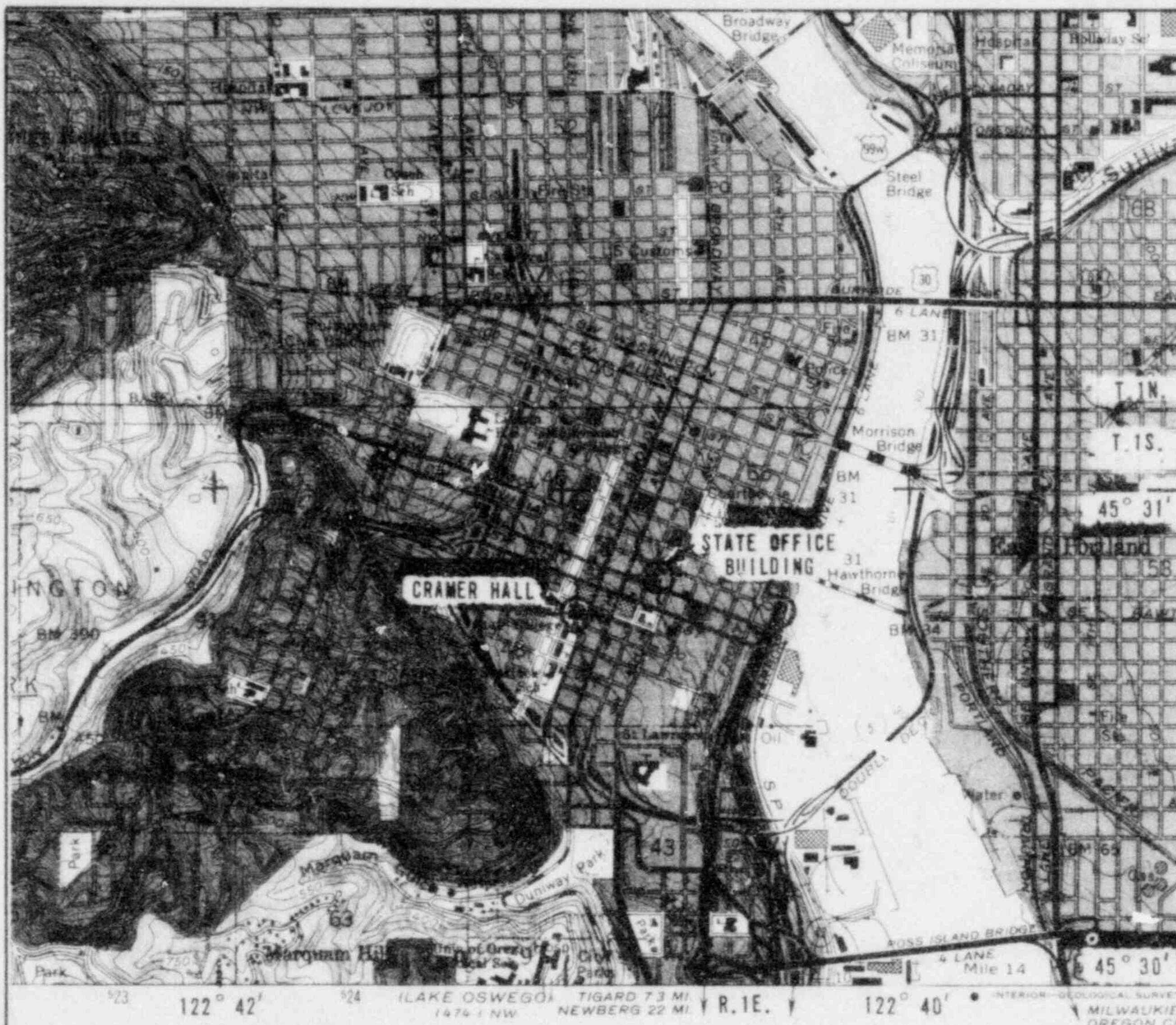
    A. Coffman and Von Hake (1973)

    B. United States Earthquakes

    C. Portland General Electric Co. (1978)

3. The range of uncertainty for epicentral locations may be taken as ± 0.5° for earthquakes prior to 1960, and as ± 0.2° for those since 1960.

4. Magnitudes designated as B have been computed by the University of California at Berkeley.



STATE OFFICE BUILDING

0 2000 4000

Scale in feet

N

USGS Station No.: 2110 (discontinued)

County: Multnomah

USGS Topographic Quadrangle:

Portland, Oreg.-Wash.
N4530 - W12237.5/7.5
1961

Coordinates: 45° 30′ 50″ N.
122° 40′ 44″ W.

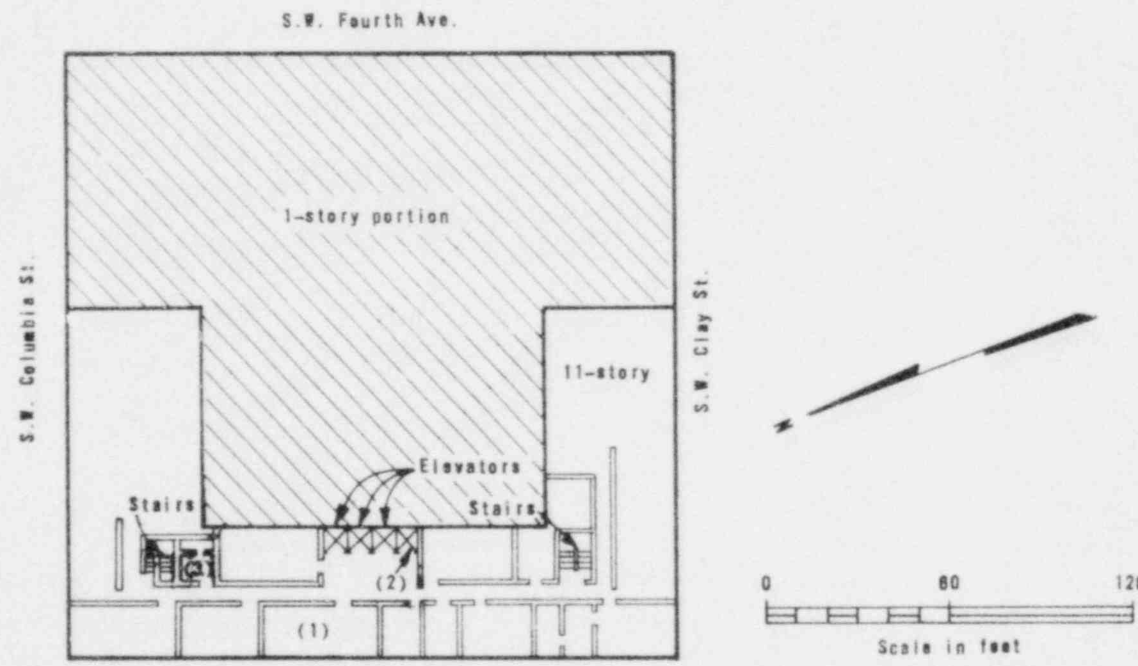
Location: 1400 S.W. 5th Avenue

Building: 11 stories with first floor located partially below grade; steel framing and reinforced concrete construction.

STATION LOCATION
STATE OFFICE BUILDING
PORTLAND, OREGON

FIG. 17-1

STATE OFFICE BUILDING
VIEW: EAST



FIRST FLOOR PLAN
(lowest level)

NOTES

(1) Telephone switch room, accelerograph location 8/53 to 1/67

(2) Unused elevator shaft (basement), accelerograph location 1/67 to 8/69

(3) Women's Lounge, accelerograph location 8/69 to 12/72

(4) First floor is the lowest in the building; it may be called the "ground floor" or "basement" by others.

BUILDING PLAN
STATE OFFICE BUILDING
PORTLAND, OREGON

FIG. 17-2

CRAMER HALL

0 2000 4000

Scale in feet

N

USGS Station No.: 2172

County: Multnomah

USGS Topographic Quadrangle:

Portland, Oreg.- Wash.
N4530-W12237.5/7.5
1961

Coordinates: 45° 30' 45" N.
122° 40' 59" W.

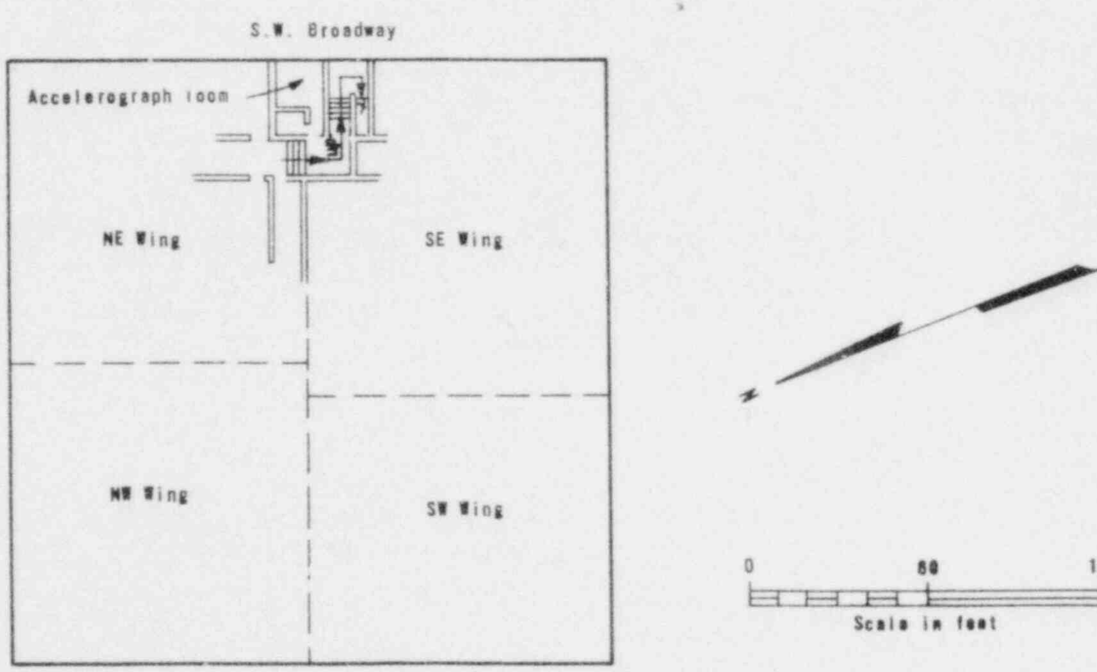
Location: S.W. Mill & S.W. Broadway

Building: 4 stories with a penthouse, daylight basement and subbasement. Steel framing and reinforced concrete construction.

STATION LOCATION
PSU CRAMER HALL
PORTLAND, OREGON

FIG. 17-3

CRAMER HALL
VIEW: SOUTHEAST



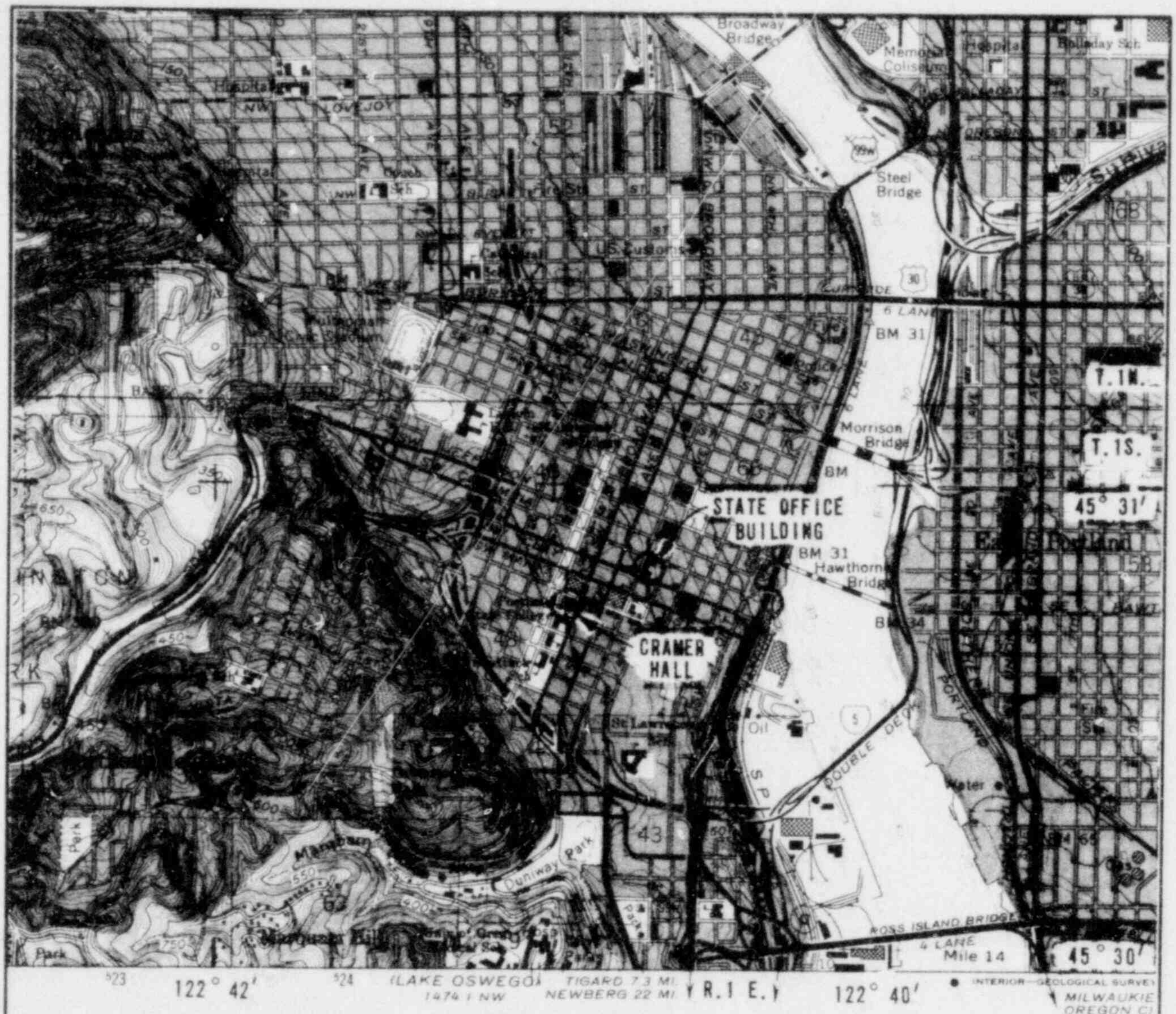
SUBBASEMENT PLAN

Notes:

1. Accelerograph room plan shown in Fig. 17-5
2. The subbasement is the lowest level in the building, and does not extend completely beneath the southeast wing.

BUILDING PLAN
PSU CRAMER HALL
PORTLAND, OREGON

FIG. 17-4



CRAMER HALL

0 2000 4000

Scale in feet

USGS Station No.: 2172

County: Multnomah

USGS Topographic Quadrangle:

Portland, Oreg.– Wash.
N4530–W12237.5/7.5
1961

Coordinates: 45° 30' 45" N.
122° 40' 59" W.

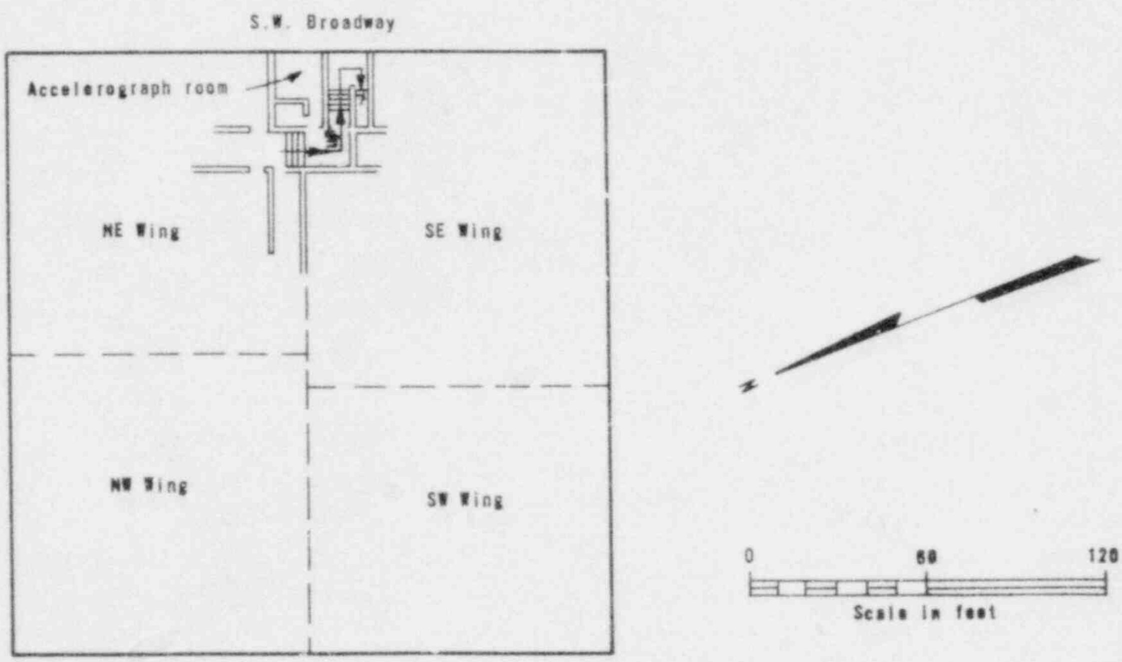
Location: S.W. Mill & S.W. Broadway

Building: 4 stories with a penthouse, daylight basement and subbasement. Steel framing and reinforced concrete construction.

STATION LOCATION
PSU CRAMER HALL
PORTLAND, OREGON

FIG. 17-3

CRAMER HALL
VIEW: SOUTHEAST



SUBBASEMENT PLAN

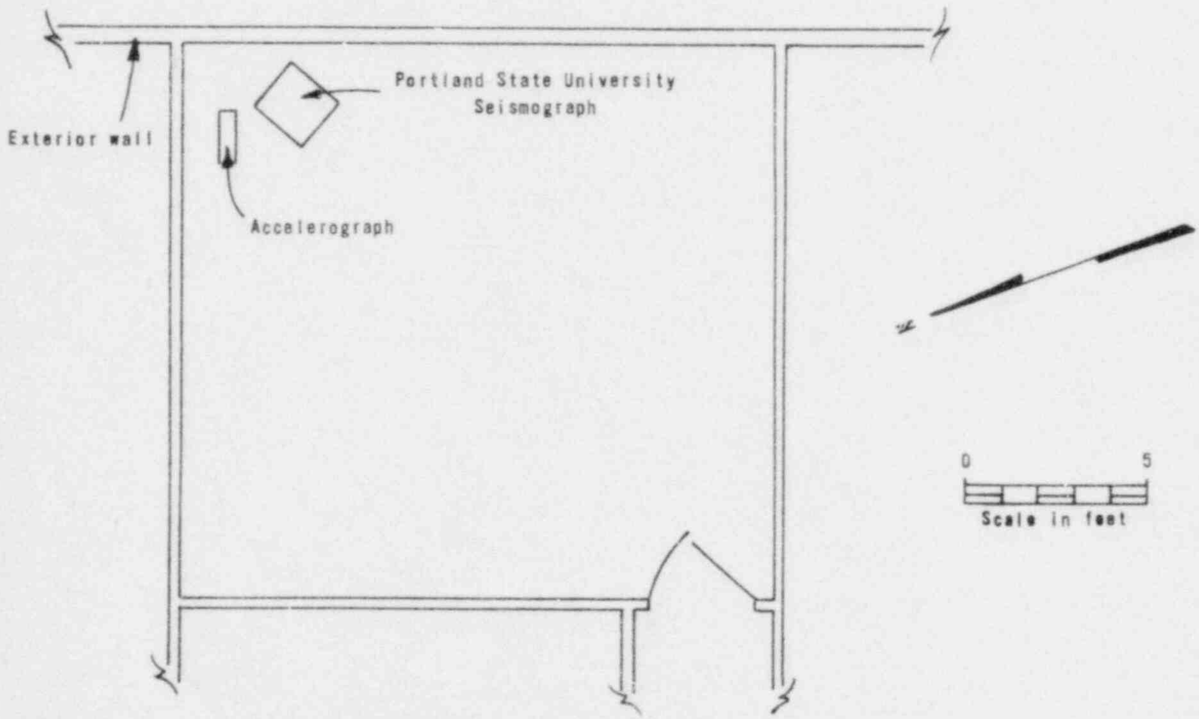
Notes:

1. Accelerograph room plan shown in Fig. 17-5
2. The subbasement is the lowest level in the building, and does not extend completely beneath the southeast wing.

BUILDING PLAN
PSU CRAMER HALL
PORTLAND, OREGON

FIG. 17-4

RFT-250 ACCELEROGRAPH
CRAMER HALL - SUBBASEMENT
VIEW: NORTHEAST



ACCELEROGRAPH ROOM PLAN - SUBBASEMENT

NOTE

Location of accelerograph room within the structure is shown on Fig. 17-4

STATION INSTRUMENTATION
PSU CRAMER HALL
PORTLAND, OREGON

FIG. 17-5


COLUMBIA RIVER
VANCOUVER
PORTLAND
HILLSBORO
McMINNVILLE
WILLAMETTE RIVER
VANCOUVER LAKE
LAKE MERWIN
YALE LAKE
SWIFT RESERVOIR
BULL RUN RESERVOIR
CLARK COUNTY
SKAMANIA COUNTY
TILLAMOOK COUNTY
12-26-63
M=4.5
11-6-61
12-15-53
2-3-92
12-29-41
10-12-77
4-2-96
46°00'
45°00'
123°00'
122°00'

EXPLANATION

QUATERNARY

HOLOCENE

Qal

Alluvial, colluvial and eolian deposits.

Silt, sand, and gravel.

Qls

Landslide and earthflow deposits. (Holocene and some Pleistocene)

Silt, sand and gravel.

PLEISTOCENE

Qg

Glacial deposits.

Clay, silt, sand, gravel and scattered boulders.

Qt

Terrace deposits.

Silt, sand and gravel.

Qmf

Mudflows.

Unsorted mixtures of silt, sand, gravel and boulders.

TERTIARY

QTvc

Continental volcanic rocks, predominantly basaltic flows and breccia with minor intrusives.

Tsc

Continental sedimentary rocks.

Siltstone, sandstone, shale, and conglomerate.

Intrusive
Intrusive
sills, a
gabbroic
tion. Ex
primaril

Tcr

Columbia River Basalt Group.

Basalt flows and breccia; minor intrusives and sedimentary interbeds.

Tsm

Marine sedimentary rocks.

Siltstone, sandstone, shale, and conglomerate.

Tvc

Continental volcanic rocks.

Andesite, dacite, rhyodacite, rhyolite, and basalt.

Tvm

Marine volcanic rocks.

Pillow basalt, breccia, and minor intrusives.

★ Accelerograph station location

● Epicentral locations of selected historic earthquakes listed in Table 17-1.

11-5-62 —— Date of Occurrence (month-day-year)

I_0=VII —— Maximum Intensity (MM)

M=4.75 —— Magnitude (Richter)

CONTACT — Dashed where approximately located.

FAULT — Dashed where approximately located, dotted queried where existence is uncertain. Barb Thrust Fault. U, upthrow side; D, downthro

5 0 5 10 15 20 25 30

Scale in kilometers

5 0 5 10 15 20

Scale in miles