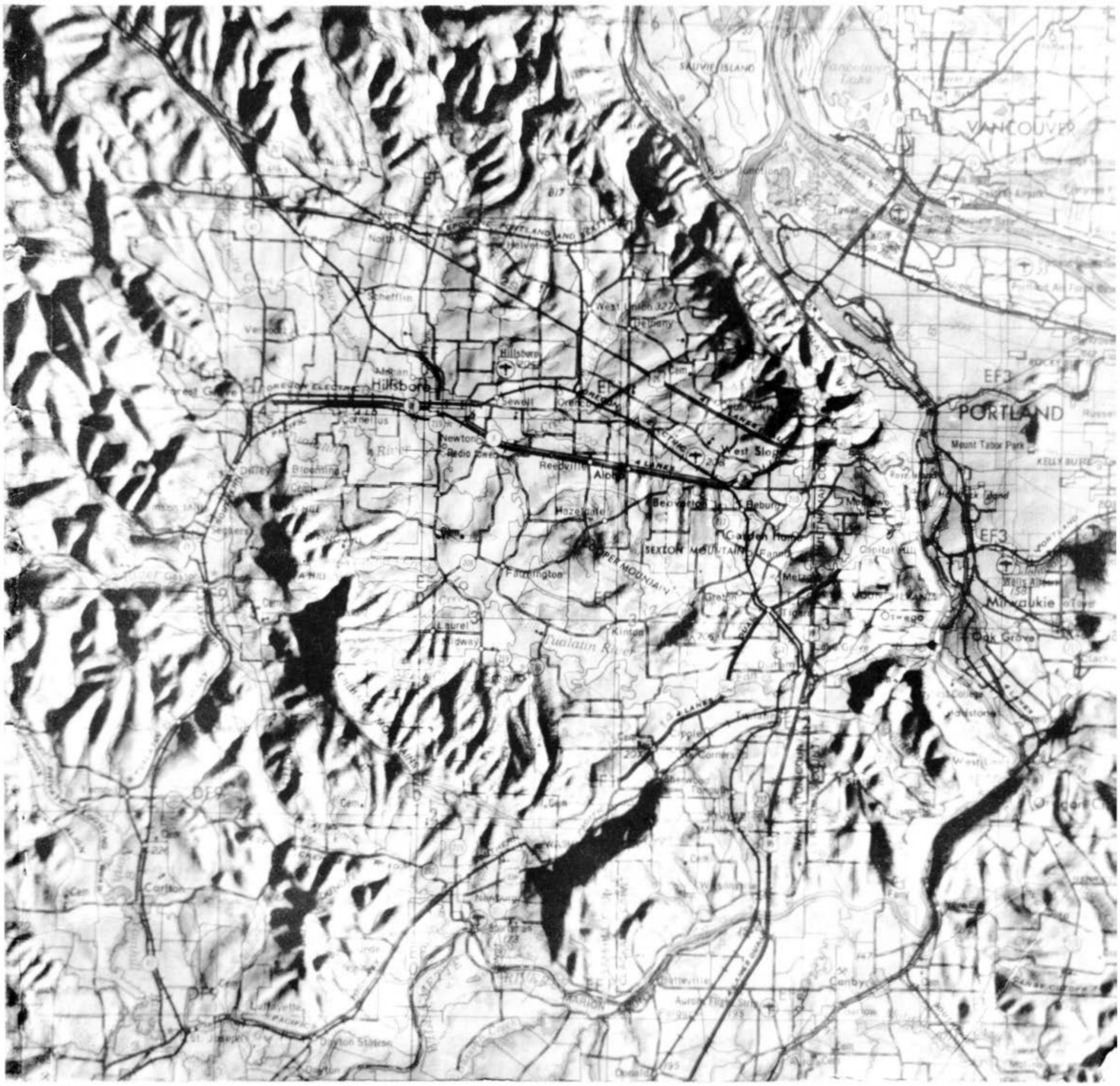
BULLETIN 60

ENGINEERING GEOLOGY OF THE TUALATIN VALLEY REGION, OREGON

Issued by
State of Oregon Department of Geology and
Mineral Industries



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 STATE OFFICE BUILDING
PORTLAND, OREGON 97201

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1967

ENGINEERING GEOLOGY OF THE TUALATIN VALLEY REGION, OREGON

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The preparation of this report was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended.

FOREWORD

Large-scale urbanization in the United States began in the latter part of the 19th century, and migration from rural to urban areas has continued to increase. Since 1940, metropolitan areas (major city centers and their environs) have nearly doubled in number. The urban districts account for the growth, while the centers of the metropolitan areas are declining in population.

A group of connected metropolitan areas, sometimes termed a "megalopolis," already exists in several parts of the nation. Within the next few decades the Willamette Valley is destined to become a megalopolis made up of merging urban areas extending all the way from Portland to Eugene, and laterally as far as the foothills of the Coast Range and Cascade Mountains.

In order to develop these urban areas to the best advantage, a detailed knowledge of the ground conditions should be a prime consideration. Planners will need the facts geologists and engineers can provide on bedrock, soils, and ground water. It is this kind of information that can make the task of urban planning meaningful.

To further the compiling of this record, the Department is engaged in a detailed study and mapping of the geology of urban areas in the Willamette Valley. Since the fastest growing portion of the Willamette Valley is the Tualatin Valley region, this area is the first to undergo investigation in the Department's long-range program. The preparation of this report was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended.

The report includes information for the Tualatin Valley on the character of the bedrock and unconsolidated deposits, on the distribution of surface and underground water, on the location of potentially valuable minerals and construction materials such as sand and gravel, and on the environment of hazards such as floods, landslides, and soft ground. Engineering problems related to these geologic factors have been analyzed, and this information should serve as a guide for those making detailed, on-the-site investigations.

This report also provides basic new information on the stratigraphy and structure, which will advance significantly geologic knowledge on this part of Oregon.

It is expected that the next phase in the engineering-geology study of the Willamette Valley will extend into the Salem region and that it will be followed by similar investigations in the Corvallis-Albany area and, finally, in the Eugene-Springfield area. It is the Department's sincere belief that investigations of this type can lay the foundation for safe and effective development of urban land.

Hollis M. Dole
State Geologist

March 17, 1967

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INTRODUCTION

Purpose and Scope of Report

The purpose of this report is to bring together information on the geologic and hydrologic factors pertinent to the urban development of the Tualatin Valley region. The necessity for such basic data is emphasized by current population trends, increased complexity in building practice, and the recognized need for careful planning for maximum land utilization.

The geology section of the report describes the surficial deposits and bedrock units of the area. Together with the geologic map, it provides the primary basis for interpretation and study of engineering problems. The engineering section describes the performance characteristics of the individual soil and rock units. It also outlines areas of landslides, floods, and compressible soils; reviews earthquake potentials; and summarizes data on ground water and construction materials.

It is hoped that this report will serve as a valuable aid to those whose task is to select future residential, commercial, and industrial sites, preserve agricultural and recreational lands, and locate mineral deposits and ground-water resources. The information is not intended to replace actual site evaluation, but, rather, to serve as a guide for engineering and land-use planning.

Previous Work

Regional studies and mapping covering the project area have been previously conducted by Warren, Norbisrath, and Grivetti (1945) and by Hart and Newcomb (1965). A geologic map of western Oregon (Peck, 1961) also covers the area. Detailed studies were carried out in portions of the area by Schlicker (1962, 1964), Treasher (1942) and Trimble (1963). Bretz (1925, 1928), Allison (1933, 1935, 1936), and Glenn (1965) discussed the origin of the Willamette Silt deposits on the valley floors. Lowry and Baldwin (1952), Theisen (1958), and Trimble (1963) discussed the genesis of the so-called aeolian silt (upland silt of this report). The U.S. Department of Agriculture Soil Conservation Service also published the following county soil maps: Washington County (Watson and others, 1923), Yamhill County (Kocher and others, 1920), Marion County (Torgerson and Glassey, 1927), and Clackamas County (Kocher and others, 1926).

Sources of Data

The geologic map (plate 1) was constructed from published and unpublished geologic data, with additional field mapping by the authors. The entire southwest portion represents new mapping and new information that was previously known only in gross character. Revision of previous mapping has developed additional and significant new information on the bedrock and unconsolidated surficial deposits in the remainder of the study area. Boring-log sections for the Newberg, Tualatin, Beaverton, Hillsboro, and Forest Grove areas have been adapted from subsurface investigations by consulting engineering firms. Eight geologic cross sections (plate 2) have been prepared by utilizing subsurface information provided by logs of water wells and records of private consulting firms.

Investigation of soils has included mapping of soil variation in the field, together with office study of published and unpublished information. Laboratory test data, presented in table and graphs, provide the basis for the classification of the soils. The information was obtained from the Oregon State Highway Department, the U.S. Soil Conservation Service, city and county planners, and private engineering consulting firms.

Information on construction material resources has been obtained primarily from the soils and geology section of the Oregon State Highway Department and from field investigations by the authors. Laboratory analyses for many of the samples are shown in tables.

A geologic hazards map (plate 3) has been prepared to show landslides, flood areas, and areas underlain by near-surface water, compressible clay, and soft, organic soils. Knowledge of these problem sites has been obtained through field studies and through interviews with city, county, state, and private engineers.

A map (plate 4) showing the depth below ground surface of the Columbia River Basalt formation in the Tualatin Valley has been constructed by utilizing water-well data from Hart and Newcomb (1965) and from well records obtained from the office of the State Engineer. The map is intended as a guide for determining depth to the top of the Columbia River Basalt where important ground-water aquifers are present.

Acknowledgments

The authors greatly appreciate the fine cooperation given by the many individuals, private consulting firms, and city, county, state, and federal agencies who supplied information for this report. Special gratitude is extended to Dr. Neil H. Twelker, Consulting Soils Engineer, Seattle, Wash., for critically reading the entire manuscript and particularly for his comments and suggestions for improving the engineering sections of the report. William C. Hill, Soils Engineer, Oregon State Highway Department, Bridge Division, and Albert M. Petska, Office of the State Engineer, Dams and Hydraulic Structures Division, also made many helpful suggestions on the engineering phases of the report. R.C. Newcomb, Research Geologist, U.S. Geological Survey, furnished advice on the geologic maps and discussed field problems. George Otte and Duane Setness of the U.S. Soil Conservation Service offered valuable suggestions on soils mapping and provided unpublished detailed soils maps to aid in mapping surficial deposits. Lloyd Woolfe and Dan Gano, Geologists, and Oscar A. White, Materials Engineer, State of Oregon Highway Department, contributed much valuable information on construction materials sources and soils.

Fossil determination were made by W. W. Rau, Washington Department of Conversation, G. A. Fowler, Department of Oceanography, Oregon State University, and W. O. Addicott, U.S. Geological Survey, Menlo Park, Cal.

Subsurface information and laboratory test data were provided principally by the Oregon Highway Department and the consulting firms of Shannon & Wilson, Inc. (Portland Office), Dames and Moore (Portland Office), and Northwest Testing Laboratories. Site investigation reports were also obtained from Cornell, Howland, Hayes, and Merryfield of Corvallis and from Green, Meyer & Klein Engineers, Inc., Beaverton.

Many other persons from private firms and government agencies contributed information, and they are listed as follows:

E. R. Hampton, Ground Water Branch, U.S. Geological Survey, Portland, Oregon.
Warren Westgarth, Oregon State Sanitary Engineer, Portland.
Dale C. Johnson, Edward C. Loidhamer, Robert N. McDougald, and Bailey A. Seida, Washington County Department of Planning, Hillsboro.
Robert E. Meyer of Green, Meyer & Klein Engineers, Inc., Beaverton.
James W. Barney, City Engineer, Hillsboro.
Kenneth A. Meng, Washington County Engineer.

Robert L. Nordlander, City Engineer, Forest Grove.
G. W. Probasco, Superintendent of Public Works, City of Newberg.
Rollie Call, Oregon State Highway Department, Portland.
F. B. Klayboe, G. L. Decker, Robert Forrester, Clarence Gregg, and F. W. Yarbrough, Oregon State Highway Department, Salem.
William S. Bartholomew, Office of State Engineer, Salem.
Wallace Hickerson, Publishers' Paper Co., Oregon City.
Walter L. Wright of Shannon & Wilson., Portland.
Kenneth Robbins of Dames & Moore, Portland.
E. M. Jannsen of Jannsen Drilling Co., Aloha.
Charles R. Lane, Northwest Testing Laboratories, Portland.
Gerry H. Simonson, Department of Agriculture, Oregon State University, Corvallis.
C. A. Balster and R. B. Parsons, U.S. Department of Agriculture, Soil Conservation Service, Oregon State University, Corvallis.
William Hill and Forrest Miller, U.S. Department of Agriculture, Soil Conservation Service, Portland.
Edgar C. Laird, U.S. Department of Agriculture, Soil Conservation Service, McMinnville.
Carl Schademeke, U.S. Department of Agriculture, Soil Conservation Service, Hillsboro.
Jerry Lee Glenn, Surface Water Branch, U.S. Geological Survey, Portland.
Parke D. Snavely, U.S. Geological Survey, Menlo Park, Cal.
Paul S. Day and Howard W. Thune, Gulf Oil Corp., Casper, Wyo.
W. E. Hickey, Oregon Division of Planning and Development.
Vaughn Sterling of Cornell, Howland, Hayes and Merryfield of Corvallis.

Department staff members whose special skills contributed much to the preparation and publication of this report are: R. G. Bowen, R. E. Corcoran, Loris Killian, James Powell, Miriam Roberts, and Margaret Steere.

GEOGRAPHY

Location and Extent of Area

The project area is situated in the northern part of the Willamette Valley in northwest Oregon. It is part of the regional Willamette-Cowlitz-Puget Lowland of the Pacific Border physiographic province (Fenneman, 1931). The area includes approximately 600 square miles and is bounded by longitudinal meridians 122°45' to 123°15' west and by latitudes 45°15' to 45°37'30" north. The area covers most of Washington County and portions of Yamhill, Marion, Clackamas, and Multnomah Counties. The plan dimensions of the area are approximately 26 miles by 26 miles (figure 1).

The district is serviced by U.S. Highways 99 W and 26, U.S. Interstate 5, and Oregon Highway 8. Southern Pacific Co., Oregon Electric Railway Co., and Spokane, Portland & Seattle Railway Co. all maintain trunk lines into the Tualatin Valley.

Climate and Vegetation

The climate is temperate and characterized by warm and relatively dry summers with mild but rainy winters. Forty percent of annual total precipitation occurs during November, December, and January and less than three percent during July and August. The average annual precipitation at Forrest Grove is 43.56 inches for a 25-year period. Annual precipitation on the flanks of the Coast Range along the west margin of the area increases to approximately 50 inches. Maximum temperatures during the four summer months range from 72° F. to 79° F., although maximum daily temperatures as high as 107° F. have been recorded. The normal minimum January temperature is 36°. Periods without killing frosts range from 207 days at Forest Grove to 299 days at Portland. Snow rarely lasts more than a few days in lowlands and foothills.

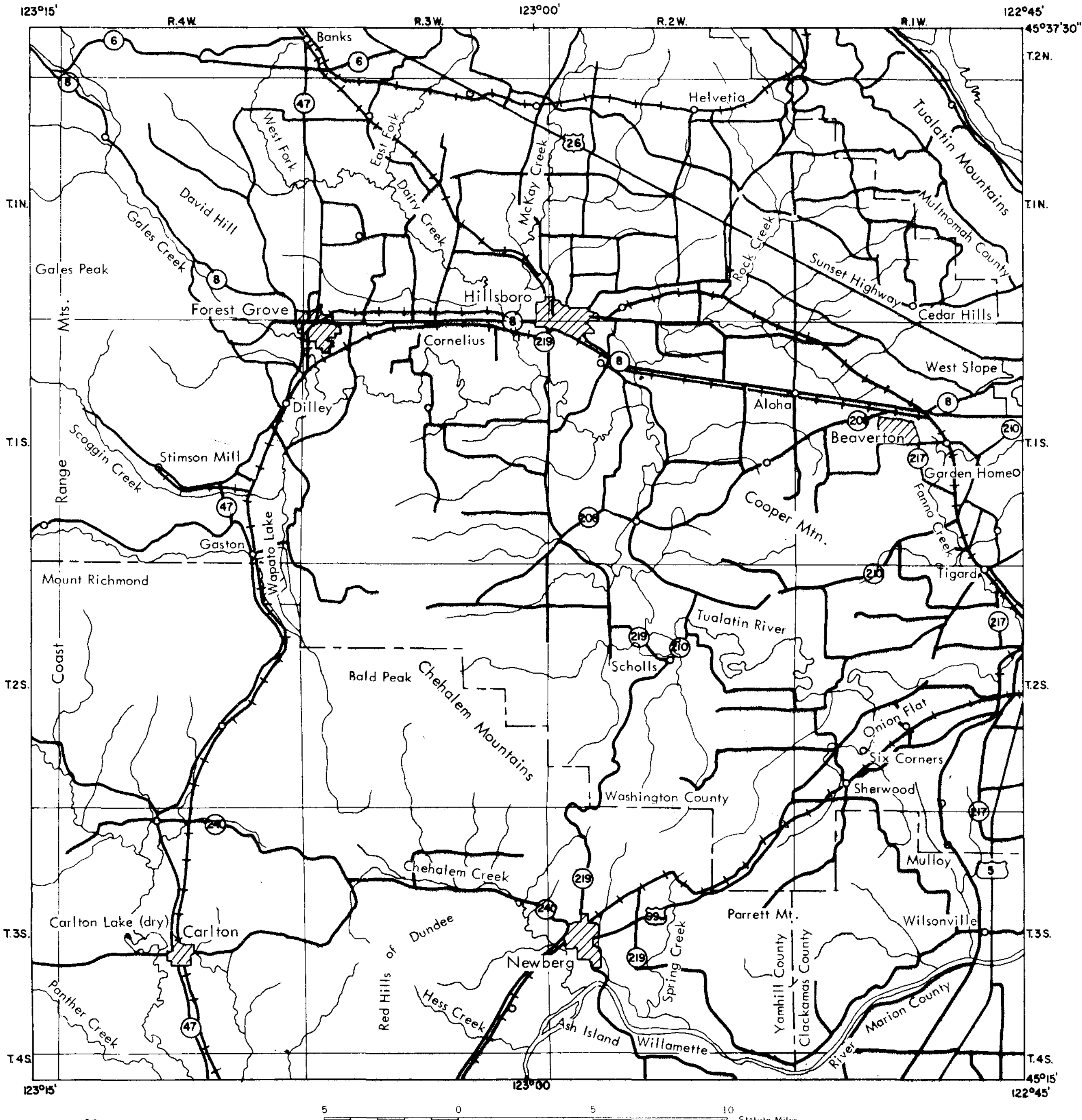
The abundant rainfall and mild climate help promote a variety of vegetation. On uncultivated land the most common trees are ash, cottonwood, vine maple, dogwood, willow, Oregon white oak, Douglas fir, Oregon red cedar, and Oregon hemlock. Smaller plants include: snowberry, Oregon grape, bracken, wild rose, poison oak, hazel, wild blackberries, and native grasses.

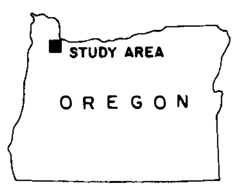
The area is suited to diversified farming and produces a wide variety of products including vegetables, fruits, nuts, and berries.

Population Trends and Industrial Growth

The eastern margin of the area is part of metropolitan Portland. Other principal cities and their populations according to the July 1966 census include: Beaverton - 11,400; Hillsboro - 11,000; Forest Grove - 6,550; Tigard - 2,203; Newberg - 4,500; and Cornelius - 1,377. Municipalities of less than 1,000 population include Yamhill, Gaston, Banks, and Wilsonville.

Population trends and industrial-growth predictions are discussed only for the Tualatin Valley





SECTIONIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Figure 1. Index map of the Tualatin Valley region.

within Washington County. Although other portions of the project area, such as the Wilsonville district, will doubtlessly receive significant increases in population and in new industry, they are not expected to experience the dramatic growth anticipated for the Tualatin Valley.

Population

The population of Washington County is experiencing one of the most rapid percentage-growth rates in the State of Oregon (Figure 2). As the figures below indicate, the population has increased 98 percent since 1950.

Year	Population
1950	61,500
1960	92,237
1966	125,000

(Data from: Center for Population Research and Census, Portland State College [MacCannell, 1966])

Recent population projections indicate that this increase may continue at the same rapid rate. The Portland City Planning Commission in its report, "Population forecasts and projections," of August 1965, states that the population of Washington County is expected to nearly double between 1960 and 1980, while the estimate of the SMSA (Standard Metropolitan Statistical Area) is for an increase of nearly 50 percent. At the present time a large percentage of the total population is located in the Cedar Hills-Beaverton-Tigard area, which lies directly west of the city of Portland. The U. S. Census statistics for 1960 show that nearly 40 percent of the total population is concentrated in this area, which accounts for only 3 percent of Washington County.

It is anticipated that the east Washington County area will receive the major portion of the 1960-1980 projected population increase. More than 75 percent of the future growth is foreseen for this region, with approximately 16 percent for the Hillsboro-Forest Grove district and an estimated 8 percent distributed over the remainder of the county. Population projections indicate that by 1980 the population of Washington County will reach 180,000 persons (Washington County City-County Joint Planning Department, 1965).

Industrial Growth

A recent survey conducted by the Washington County Planning Department showed that as of December 1965 industrial land uses occupied a total of 420 acres within the incorporated and unincorporated parts of the county. These regions include the Bonita Road Industrial Park, Cascade Industrial Park, Tualatin industrial area, Tigard industrial area, Sunset Science Park, Beaverton Industrial Park, Tectronix Industrial Park, and Hillsboro Industrial Park, most of which have been developed during the past five to eight years. On the basis of studies projecting industrial land needs for the Portland metropolitan area (Metropolitan Planning Commission, 1960; Battelle Memorial Institute, 1965), Washington County might reasonably expect 250 to 350 additional acres to be used for industrial purposes by 1975.

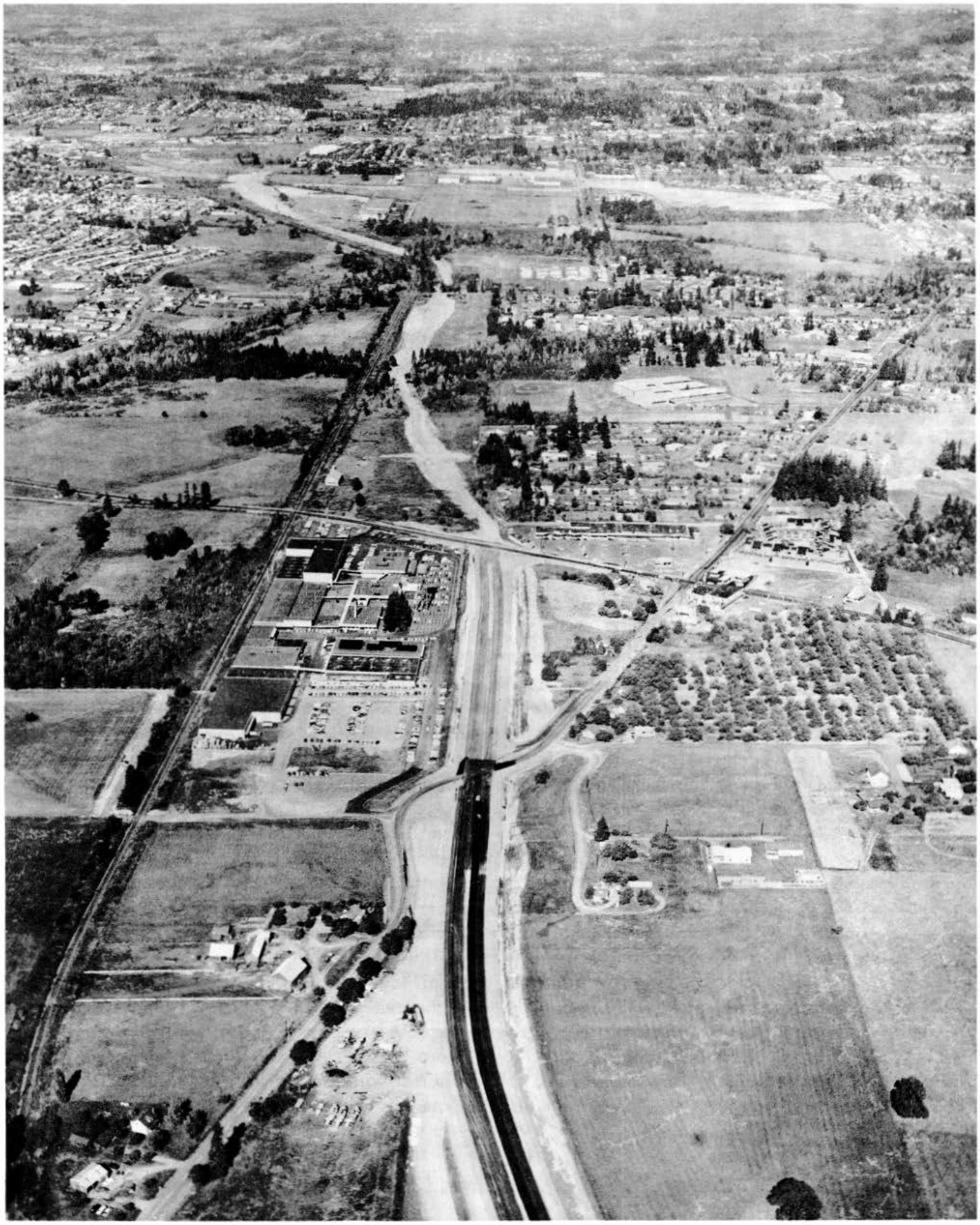


Figure 2. Rapid changes in land use as orchards and farm lands become freeways, industrial parks, shopping centers, and housing developments. View looking north towards Progress and Beaverton (photograph courtesy of Oregon Highway Department).

GEOLOGY OF THE TUALATIN VALLEY REGION

Topographic Features

The topography of the Tualatin Valley region is characterized by wide, flat lowlands and prominent uplands which are controlled primarily by the folding and faulting of the underlying bedrock. In general, these features trend in a northerly or northwesterly direction (figure 1 and cover photo).

The lowlands include the Tualatin Valley, which is the major topographic feature in the area, the Newberg, Wilsonville, and Yamhill valleys, and the Chehalem-Wapato Lake valleys. All of these valleys have a very low gradient and all but the Chehalem and Yamhill valleys contain a thick fill of sediments. The lowlands are drained by streams flowing either directly or indirectly into the Willamette River.

The uplands include the Tualatin Mountains (Portland Hills), Cooper and Bull Mountains, the Parrett Mountain-Chehalem Mountains-David Hill trend, the Red Hills of Dundee, and a part of the east flank of the Coast Range. These highlands rise from 500 to 800 feet above the adjacent valleys. With the exception of the Coast Range, the uplands are underlain by resistant Columbia River Basalt.

Lowlands

Tualatin Valley

The Tualatin Valley covers an area of approximately 300 square miles. It consists of a broad, elliptical plain surrounded by long terraces that slope toward the center of the valley. The valley averages about 200 feet in altitude but it ranges from 120 to 250 feet, with the exception of Bull and Cooper Mountains, which rise to an elevation of about 750 feet. The Tualatin River, originating in the Coast Range to the west, is the principal drainage course. Major tributaries flowing southerly into the Tualatin River include: Cedar Creek, East and West Forks of Dairy Creek, Rock Creek, and Fanno Creek. The Tualatin River and its tributary streams form sinuous courses in entrenched valleys over most of the lowland. In the northwestern part of the Tualatin lowland, stream valleys are characteristically incised about 20 feet below the main plain; in the southwestern part, stream valleys range from 30 to 40 feet deep. The valley floor rises gently from its center toward the nearly encircling highlands to an approximate terrace elevation of 250 feet, where slopes abruptly steepen. The change in slope angle occurs near the contact of the Willamette Silt with older rock. The northeast portion of the valley typically contains long terrace slopes that fall southwesterly, approximately 20 feet per mile at the margin of the valley to 10 feet per mile in the central portion. The southern portion of the valley contains steeper and more variable slopes because of the lower base level established by the Tualatin River flood plain; slope ratios in this area are commonly 20 to 30 feet per mile. About 30 percent of the Tualatin Valley lowland is a relatively flat valley plain with low, rolling hills, about 10 percent is isolated hills (Cooper and Bull Mountains), and the remaining 60 percent is low-angle, basinward-sloping terraces.

Newberg and Wilsonville valleys

These tributary valleys of the Willamette Valley contain similar physiographic features. The Newberg valley covers an area of approximately 35 square miles and is defined to the northeast by Parrett Mountain and Chehalem Mountains and to the southwest by the Red Hills of Dundee. The valley merges with the Willamette River valley at the southern edge of the map. The principal streams are Chehalem, Hess, Brook, and Spring Creeks. They are contained in steeply incised, flat-bottomed channels which drain southerly into the Willamette River. The margins of their valleys are characterized by long basinward terraces that slope approximately 50 feet per mile, while the central portion of the valley at Newberg is relatively flat and slopes less than 10 feet per mile.

The Wilsonville valley is located at the southeast corner of the project area and covers a lowland of approximately 12 square miles. The principal drainage is provided by Seely Ditch and Brockman Creek, which drain southerly into the Willamette River. Except for the steeply incised canyon of Brockman Creek, which has been cut 70 to 80 feet below the valley plain, the Wilsonville valley is gently undulating with slopes ranging from 30 to 40 feet per mile. Approaching the confining uplands of Parrett Mountain on the west, Tonkin Hills on the north, and Petes Mountain (not on map) on the east, slopes steepen abruptly above a terrace at an approximate elevation of 250 feet. Seely Ditch flows through a relatively flat valley that averages a quarter of a mile in width over most of its course. Highly irregular scabland topography is present just south of Mulloy and in the uplands to the north at the headwaters of Seely Ditch and Rock Creek.

The Willamette River has cut across both the Newberg and Wilsonville valleys leaving two prominent terraces; one at an approximate elevation of 100 feet, and the other at approximately 90 feet. The present river course is entrenched in the lower terrace, but the Willamette occasionally floods above 90 feet. Either lowering of the falls at Oregon City or regional uplift may be the cause of the entrenchment.

Yamhill valley

This valley covers an area of approximately 45 square miles in the southwest corner of the project area. It is drained principally by the Yamhill River and its main tributaries, Panther Creek and Hawn Creek. Within the project area, the central portion of the valley is approximately 5 miles wide and 6 miles long. Slopes in much of the valley are less than 20 feet per mile. On the sides of the valley, terrace height is at an elevation of about 200 feet; above the terrace elevation slope angles steepen abruptly. The Yamhill River flows southeasterly in a relatively flat valley that ranges in width from a few hundred feet to about one mile. The Yamhill River and its tributaries are incised 50 to 60 feet below the adjacent terraces.

The Yamhill valley is covered with a relatively thin layer of alluvium or Willamette Silt over bedrock and, with the exception of Chehalem valley, contrasts with other lowlands of the project area which contain thick sequences of sedimentary fill of Troutdale and younger age.

Chehalem-Wapato Lake valleys

The Chehalem-Wapato Lake valleys form a long, narrow link between the Tualatin and Newberg valleys. The Newberg valley narrows and merges northwesterly into the Chehalem valley in the vicinity of Ewing Young School. The Chehalem valley is about 4 miles long and not more than half a mile wide. It is drained by Chehalem and Wapato Creeks, which flow in opposite directions from a divide in the north half of the Chehalem valley. Bedrock crops out in the channel of Chehalem Creek. Numerous landslide masses have moved into the valley from adjacent hills.

The Chehalem valley trends northerly and merges with the Wapato Lake valley in the vicinity of Lakeview School. The Wapato Lake valley extends northward for about 6 miles, attaining a maximum width of about $1\frac{1}{2}$ miles north of Gaston, and merges with the Tualatin Valley near Dilley. Several unnamed streams drain into the southern part of the Wapato Lake valley, and the Tualatin River and Scoggin Creek enter the valley from the west in its central and northern portion.

Uplands

Tualatin Mountains (Portland Hills)

The northwest-trending Tualatin Mountains rise to an elevation of about 1,100 feet in the northeast portion of the map area. The flanks of the mountains are underlain by Columbia River Basalt, and slope 400 to 500 feet per mile. The northeast flank slopes to the flood plain of the Columbia and

Willamette Rivers, and the southwest flank to the Tualatin Valley. Local areas underlain by Boring Lava generally slope about 150 feet per mile into the Tualatin Valley and also control sharp conical peaks such as Elk Point in sec. 1, T. 1 S., R. 1 W. Both flanks of the Tualatin Mountains have been deeply dissected by streams.

Cooper-Bull Mountains

Cooper and Bull Mountains rise approximately 500 feet above the valley plain in the southeast portion of the Tualatin lowland. The mountains are separate domal highlands that are closely controlled by geologic structure. Bedrock dip slopes on the flanks of the mountains range from 200 feet to 500 feet per mile. Intermittent streams draining to the surrounding lowlands have cut deep canyons in these slopes.

Parrett Mountain-Chehalem Mountains-David Hill trend

These mountains trend northwesterly from the southeast corner of the project area to the northwest corner and mark the boundary of the Tualatin lowland. The maximum elevation on Parrett Mountain is 1,247 feet, at Bald Peak in the Chehalem Mountains 1,629 feet, and on David Hill 1,165 feet. The Chehalem mountains-David Hill system forms a cuesta in which the basalt slopes gently northeast from the crest at approximately 400 feet per mile into the Tualatin Valley; the erosional scarp faces southwest with slopes as much as 800 to 900 feet per mile. Parrett Mountain is also a cuesta, but it trends northeasterly at nearly right angles to the trend of the Chehalem Mountains. The basalt surface here slopes southeasterly toward the Willamette River at approximately 400 feet per mile, and the scarp slopes northwest from the crest about 800 feet per mile.

Parrett Mountain and the Chehalem Mountains have been extensively dissected by streams, with local stream canyons as deep as 350 to 400 feet.

Red Hills of Dundee

The Red Hills of Dundee form a cuesta that strikes north and northeasterly similarly to that of Parrett Mountain. Its surface slopes southeasterly toward the Willamette River at 400 to 450 feet per mile and has been extensively modified by steeply incised stream canyons. The hills rise to a maximum elevation of 1,087 feet.

Coast Range

Only the most eastern foothills of the Coast Range are present at the west margin of the project area. The topography is controlled primarily by east- and northeast-dipping volcanic and sedimentary bedrock. The portion of the range considered in this report commences in rolling foothills just west of Yamhill and extends northerly, including the hills west of Gaston and Dilley and southwest of Gales Creek. The highest elevations of the range occur at Mount Richmond at 1,230 feet and at Gales Peak at 1,788 feet. Major streams flowing easterly from the range include Gales Creek, Scoggin Creek, and the Tualatin and Yamhill Rivers. Most of the topography consists of moderately steep, rolling hills with some strike ridges that extend for several miles and dip gently eastward.

Geologic Units

Indurated rock units, ranging from middle Eocene through early Quaternary age, and unconsolidated deposits of Quaternary age underlie the project area. The consolidated units include crystalline and pyroclastic rocks, marine sedimentary rocks, and lacustrine and fluvial rocks. They have been divided into the following formational units from oldest to youngest: volcanics and sediments of late middle Eocene age; Yamhill Formation of early late Eocene age; marine sediments of Spencer Formation of late Eocene age; undifferentiated Oligocene marine sediments; Columbia River Basalt of middle to late Miocene age; semiconsolidated lacustrine and fluvial deposits of the Helvetia and Troutdale Formations of Pliocene age; and late Pliocene or early Pleistocene age Boring Lava. Unconsolidated Quaternary deposits include upland silt, Willamette Silt of lacustrine origin, lacustrine sand and gravel, terrace gravels, and young alluvium on the flood plains of the principal streams and rivers. The occurrence and distribution of consolidated and unconsolidated units are shown on plate 1.

Eocene Volcanics and Sediments Undifferentiated

A sequence of structurally complex basalt flows, pillow lava, tuffs, agglomerates, and breccias with well-indurated marine siltstone and sandstone interbeds is present along the west edge of the map area. These rocks are exposed in a nearly continuous belt commencing near Carlton and extending northerly beyond Gales Creek. They have been invaded by numerous dikes and sills of gabbro, basalt porphyries, and diabase. Weathering has been extensive and much of the sequence is soft and crumbly.

The sequence is correlative with similar volcanics mapped by Baldwin and others (1955 and 1952) in the Sheridan, McMinnville, and Spirit Mountain quadrangles to the southwest of the area. In these localities the rocks were considered to be upper middle Eocene and early late Eocene in age. Foraminiferal data from a locality within the project area (F-1 on plate 1) indicate a Narizian age (Rau, written communication, 1964). The sequence dips east and northeast and is overlain, probably conformably, by marine sediments of the Yamhill Formation. The section is several thousand feet thick and thickens to the west in the Coast Range.

Yamhill Formation

The Yamhill Formation within the map area consists primarily of well-indurated, thin-bedded shale and siltstone with occasional interbeds of green basaltic sandstone and poorly sorted tuffaceous sandstone. Locally, basalt and gabbro dikes and sills have invaded the formation (figure 3). The Yamhill Formation underlies most of the Yamhill valley in the southwest portion of the project area and trends northerly in a thinning outcrop belt to within a short distance north of Scoggin Creek. It is also present in isolated exposures in the bed of Gales Creek. Its thickness ranges from probably less than 1,000 feet in the Scoggin Creek area to more than 2,000 feet in the Yamhill River valley. Its primary structure is monoclinal eastward with local irregularities.

The formation is similar in composition to its type section on Mill Creek 20 miles to the southwest, where it attains a maximum thickness of approximately 4,500 feet. Faunal data (foraminifera) obtained from three localities (F-2, F-3, and F-4) within the area and identified by W. W. Rau (written communication, 1962) indicate that the formation is lower upper Eocene (A-2 Laiming) in age.

(A)

(B)

Figure 3. A. Well-indurated, thin-bedded siltstone of the Yamhill Formation in roadside cut west of the town of Yamhill.
B. Detail of Yamhill Formation.

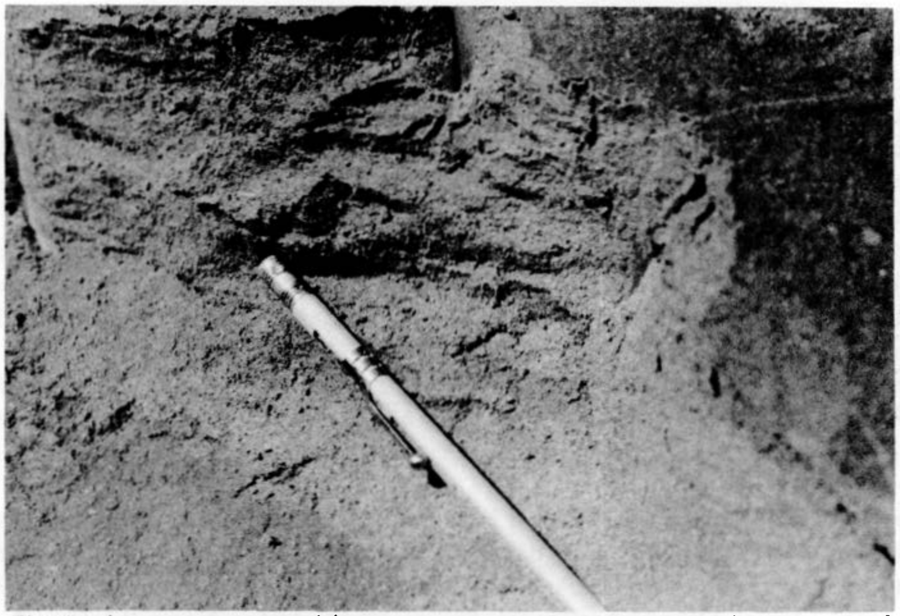


Figure 4. Massive, friable Spencer sand exposed in road cut on north side of Patton Valley west of Gaston.

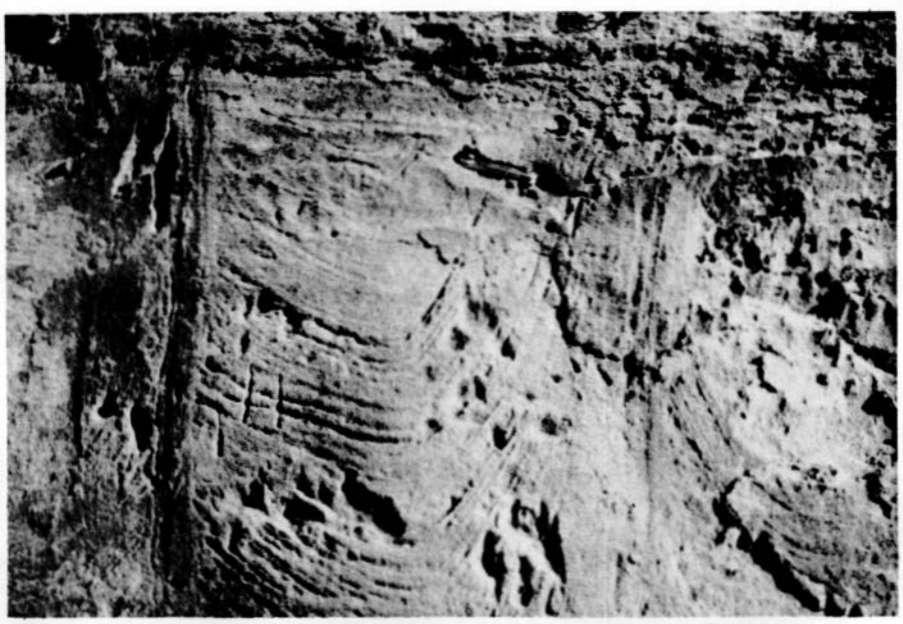


Figure 5. Spencer sandstone in roadcut showing displacement along small faults.

Spencer Formation

The Spencer Formation is exposed in a nearly continuous, 17-mile belt that commences just east of Carlton and trends northwesterly nearly to Gales Peak, a few miles north of Scoggin Creek. The formation is more than a mile wide east of Carlton and narrows to about a quarter of a mile where it crosses the Tualatin River and Scoggin Creek. The formation consists of thick-bedded to massive, well-sorted, friable, fine- to medium-grained felspathic sandstone (figure 4) with occasional thin carbonaceous siltstone and claystone interbeds. In the top and bottom portions of the formation, thin-bedded siltstone and claystone predominate.

The sandstone is typically composed of about 40 percent quartz, 55 percent plagioclase feldspar, and 5 percent muscovite, biotite, and chlorite. In the northwest two-thirds of its outcrop belt, where it averages 200 feet in thickness, the formation is composed almost entirely of friable, fine sandstone (figure 5). To the southeast it contains more siltstone interbeds (± 50%) and occasional lenses of pebble conglomerate (figure 6) and reaches an estimated thickness of about 500 feet. Where the formation is primarily sand, it weathers into relatively thin, permeable, sandy soils, but in areas where it contains a significant percentage of siltstone, such as east of Carlton, weathering has produced plastic clay.

The Spencer Formation has been extended from its type locality near Eugene into the Yamhill County area by Schlicker (1962). Schlicker dates the Spencer Formation as upper Eocene on the basis of its position between the lower upper Eocene Yamhill Formation and the overlying marine sedimentary beds which contain lower Oligocene Keasey fauna. Foraminiferal assemblages (F-5) from core samples taken from U.S. Bureau of Reclamation foundation borings at the proposed Scoggin Creek dam (NE$\frac{1}{4}$ sec. 20, T. 1 S., R. 4 W.) have been identified by W. W. Rau (written communication, 1963) as Narizian (upper Eocene). Field evidence indicates that the Spencer Formation lies upon a folded and eroded surface of the Yamhill Formation.

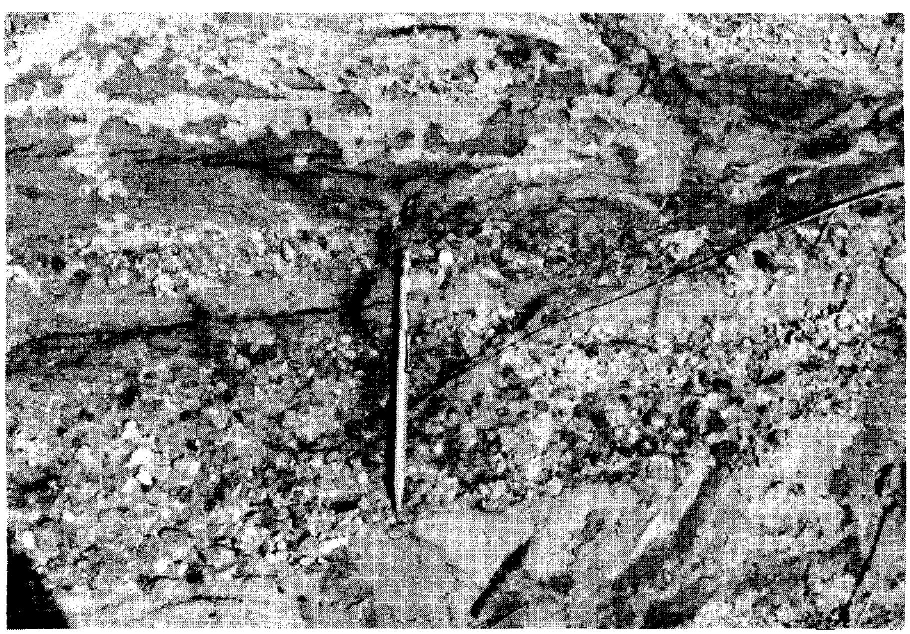


Figure 6. Pebble lens in Spencer Formation west of Yamhill.

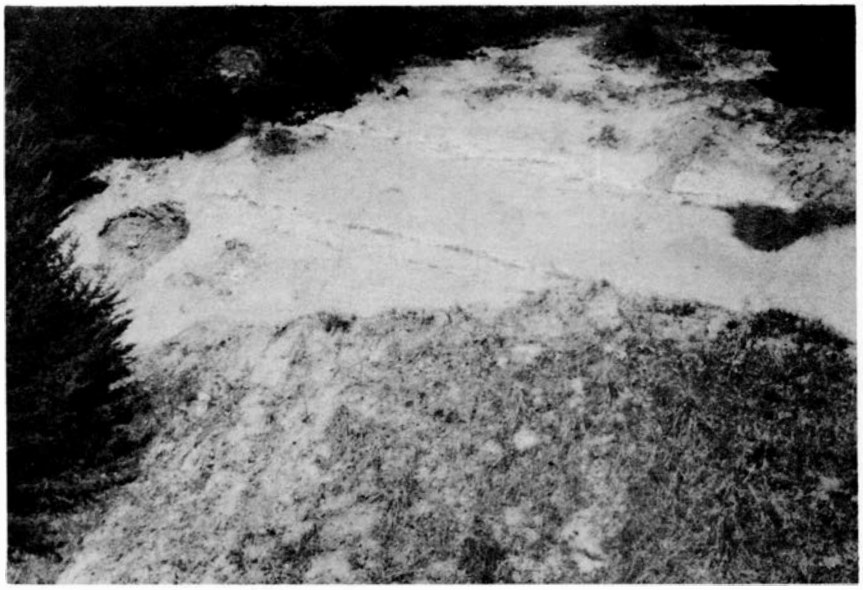
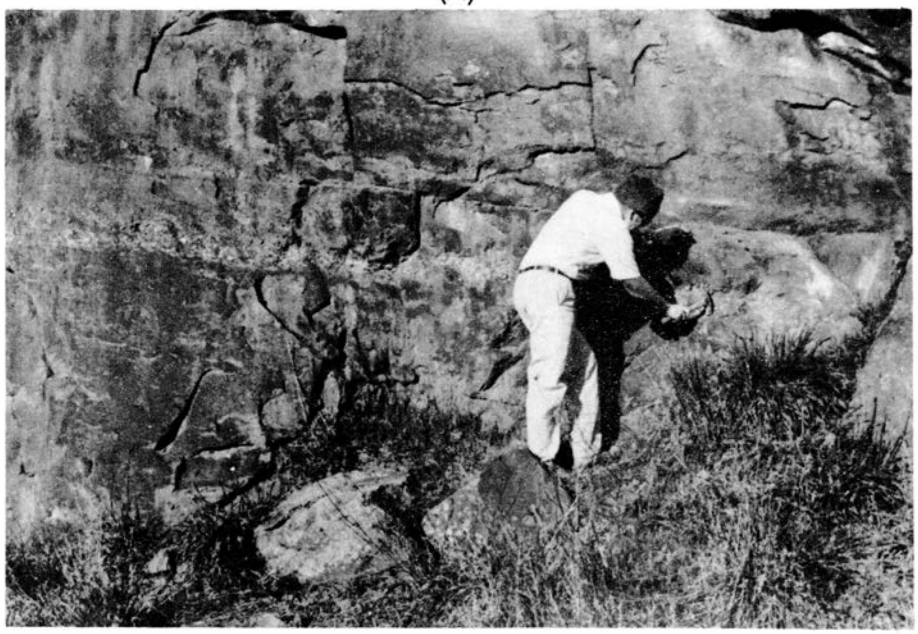


Figure 7. Dipping Oligocene shales and thin, sandy tuff beds in road cut west of Forest Grove.

Figure 8. Sandstone quarry in Oligocene rocks on Scoggin Creek a short distance east of the Stimson mill.

(A)



(B)

Figure 9. A. Fossil bed in basaltic sandstone of Oligocene age at quarry on Scoggin Creek.
B. Detail of fossil bed shown above.

Oligocene Marine Sediments Undifferentiated

The rocks mapped as Oligocene marine sediments undifferentiated contain foraminiferal assemblages of Refugian (lower Oligocene) (F-6) and Zemorrian (upper Oligocene) age (F-7) (Rau, written communication, 1962). The Scoggin Creek quarry (sec. 27, T. 1 S., R. 4 W.) contains abundant megafossils which have been correlated with Gries Ranch fauna of western Washington by Addicott (written communication, 1964). Although the Oligocene rocks are distinct in gross character, no persistent lithology has been recognized in the map area to permit recognition of separate formations. Faulting, landslides, poor exposures, and lack of adequate faunal control are principal factors that prevent separation of rocks in this study.

The uppermost rocks of the Oligocene sequence are composed of tuffaceous sandstone and siltstone (figure 7). Beneath this sequence in most areas is a section of moderately indurated quartzitic sandstone. The lower part of the Oligocene section generally consists of siltstone, basaltic sandstone, and local conglomerate. In the Scoggin Creek quarry basaltic sandstone and conglomerate occur below a well-indurated, limy sandstone which contains abundant megafossils in several 1-foot layers (figures 8 and 9).

The total maximum thickness of the undifferentiated Oligocene sequence is estimated to be about 3,000 feet, although its thickness varies considerably in the map area. On the basis of faunal data, the lower Oligocene section is estimated to be about 1,000 feet thick and the upper Oligocene about 2,000 feet thick.

The Oligocene sequence generally dips to the east and northeast at low to moderate angles. Locally near faults, beds dip 40° to 50°, and in a few areas dips are reversed to the south and southwest to form local anticlines.

Columbia River Basalt

The Columbia River Basalt forms the bedrock of the Tualatin Mountains (Portland Hills), Cooper and Bull Mountains, Parrett Mountain-Chehalem Mountains-David Hill trend, and the Red Hills of Dundee. The formation underlies the entire Tualatin Valley at depths ranging from a few feet to a maximum of about 1,500 feet. It also lies beneath a portion of the Newberg valley and all of the Wilsonville valley. The lavas unconformably overlie Oligocene marine sediments.

The name "Columbia River basalt" was given to the basaltic lavas of the Pacific Northwest by Russell (1901). At that time Russell included flows ranging in age from Eocene to Recent which spread over much of eastern Washington, eastern Oregon, and the plains of southern Idaho. Merriam (1901) later restricted the formational name to the basalts that are exposed along the Columbia River Gorge and in the John Day Basin farther to the east. Waters (1961) proposed raising the Columbia River Basalt to group status so as to include "the Yakima basalt as defined by G. O. Smith, and the older basalts of the John Day Basin, called the 'Columbia lava' by Merriam, but herein renamed the Picture Gorge Basalt."

Not enough petrographic and chemical work has been done on the basalts in the Tualatin basin to determine whether one or both formations in the Columbia River Group are present in this region. The authors have, therefore, used the name "Columbia River Basalt" for these lavas because they are essentially correlative with flows exposed in the Columbia River Gorge.

The Columbia River Basalt has been moderately deformed by folding and faulting. The lavas have been folded into broad anticlines in most of the upland areas and broad synclines in the valley areas. In the center of the Tualatin Valley the lavas have been depressed beneath the valley floor approximately 1,500 feet and in the Newberg and Wilsonville valleys more than 500 feet. Faulting with displacement from less than 100 feet to several hundred feet has locally broken the lavas.

The formation is composed of a series of weathered and unweathered lava flows with occasional interflow zones of breccia, ash, and baked soil horizons. The unweathered surfaces are brownish gray to dark blue-gray, dense, and finely crystalline. The lavas show a joint system that ranges from massive-columnar to close cubic (Figure 10). Rectangular and platy joint systems are present locally. Bottom and top portion of flows are commonly vesicular and in some places are scoriaceous (figure 11).

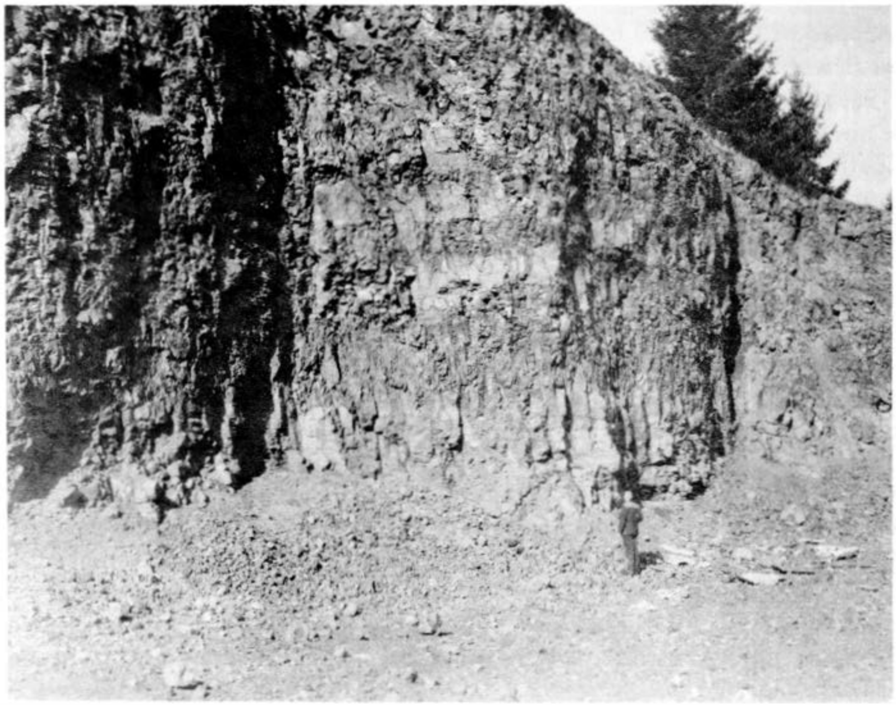


Figure 10. Columbia River Basalt showing cubic and columnar jointing, Krueger quarry, west of Cornelius Pass.

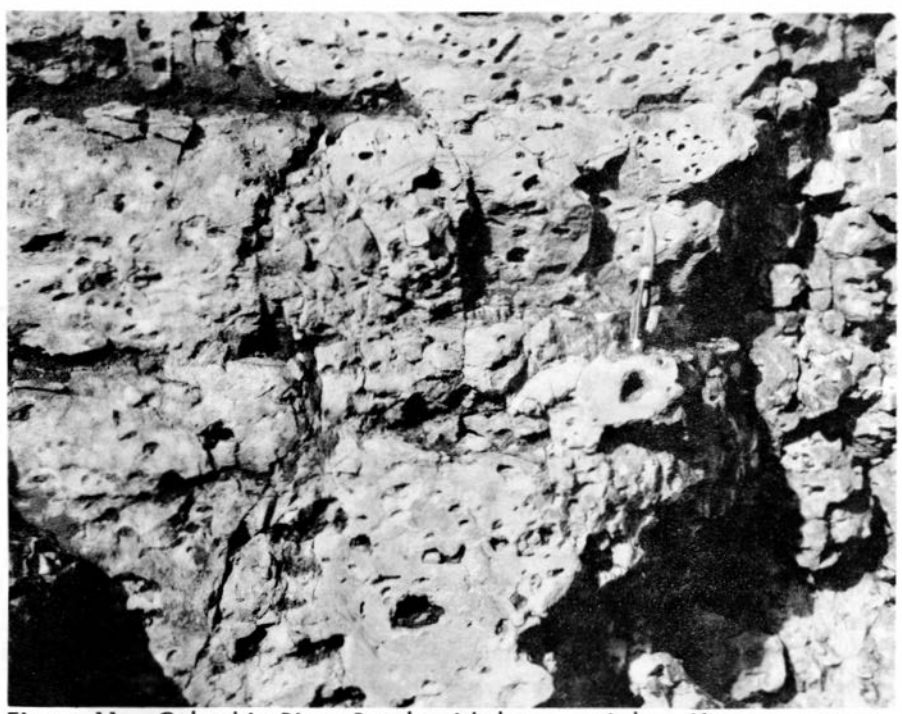


Figure 11. Columbia River Basalt with large vesicles, Krueger quarry.

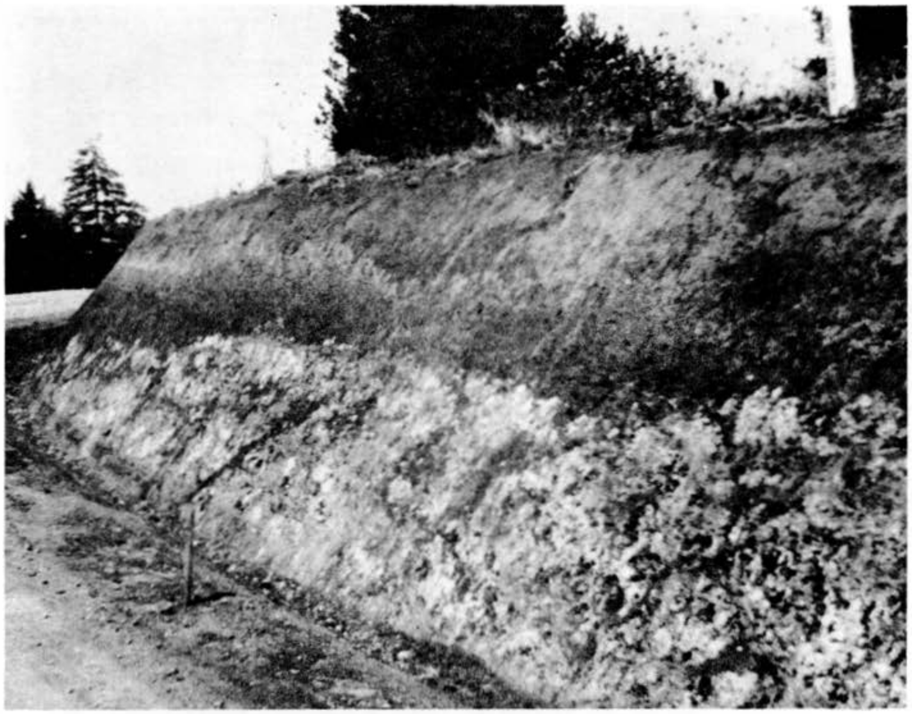


Figure 12. Deeply weathered surface of Columbia River Basalt overlain by silt.

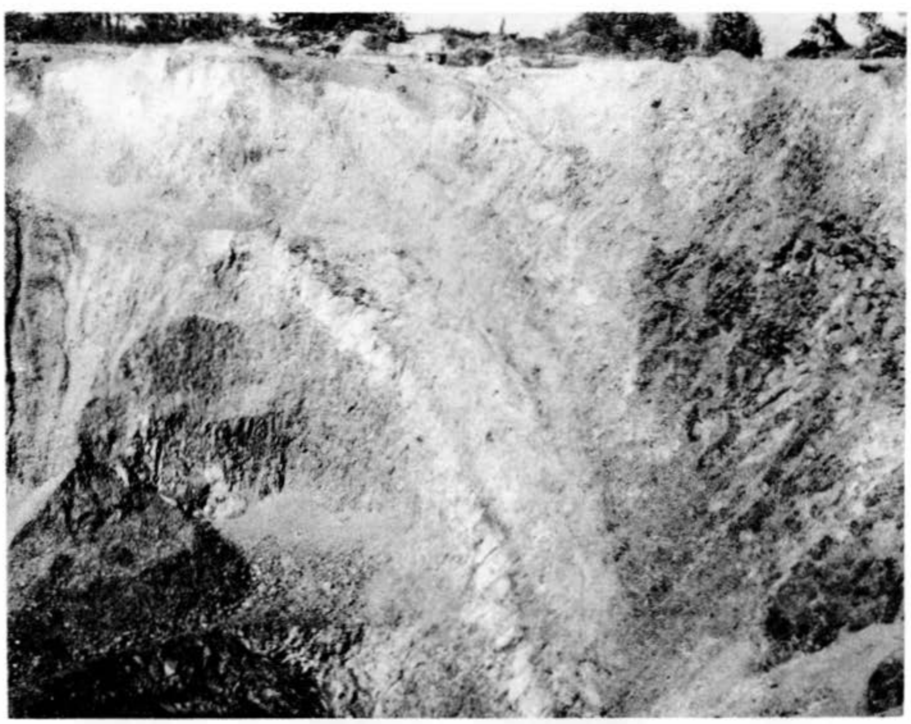


Figure 13. Dipping weathered Columbia River Basalt flows in Cobb quarry at Sexton Mountain.

Figure 14. Massive, clayey silt of the Helvetia Formation.

Figure 15. Massive, poorly indurated pebbly sand and silt of the Helvetia Formation.

The weathered flows are generally present in the upper portion of the series and consist commonly of reddish-brown to gray-brown, crumbly to medium-dense basalt (figures 12 and 13). They show a joint system similar to the unweathered flows, but joints have been opened and their surfaces contain thick coatings of iron and manganese oxide minerals. The basalt weathers to thin, reddish-brown, stony, heavy cloy soils. In local areas laterization has completely reduced basalt flows to bauxite.

The Columbia River Basalt ranges in thickness from a few tens of feet at outcrop edges to a maximum of about 1,000 feet in the central part of the Tualatin Volley. Individual basalt flows commonly range from 30 feet to 60 feet in thickness.

Helvetia Formation

The nome Helvetia Formation is applied in this report to poorly indurated sedimentary deposits of laterized pebbly sand, silt, and cloy that overlie the Columbia River Basalt (figures 14, 15, and 16). These deposits have been previously mapped as residual soils derived from in situ weathering of the Columbia River Basalt, and careful study is required to distinguish residual soils from the Helvetia Formation.

The type locality is just north of the community of Helvetia in sec. 3, T. 1 N., R. 2 W., where road cuts expose several feet of firm, reddish-brown, pebbly silty sand, sandy silt, and clayey silt. Pebbles contained in the formation consist of weathered basalt with lesser amounts of granite and quartzite. Road cuts in the vicinity of Helvetia expose a minimum of 25 feet of this material, and water-well logs in other places indicate reddish-brown clayey soils up to about 75 feet thick overlying the Columbia River Basalt. The scope of this report does not allow for a detailed stratigraphic study or description of this formation.

Reddish-brown, lateritic Helvetia Formation is present around almost the entire periphery of the Tualatin Volley. It is always found directly above the weathered surface of the Columbia River Basalt and extends up the volley slopes to elevations ranging from 200 feet to about 900 feet. In the

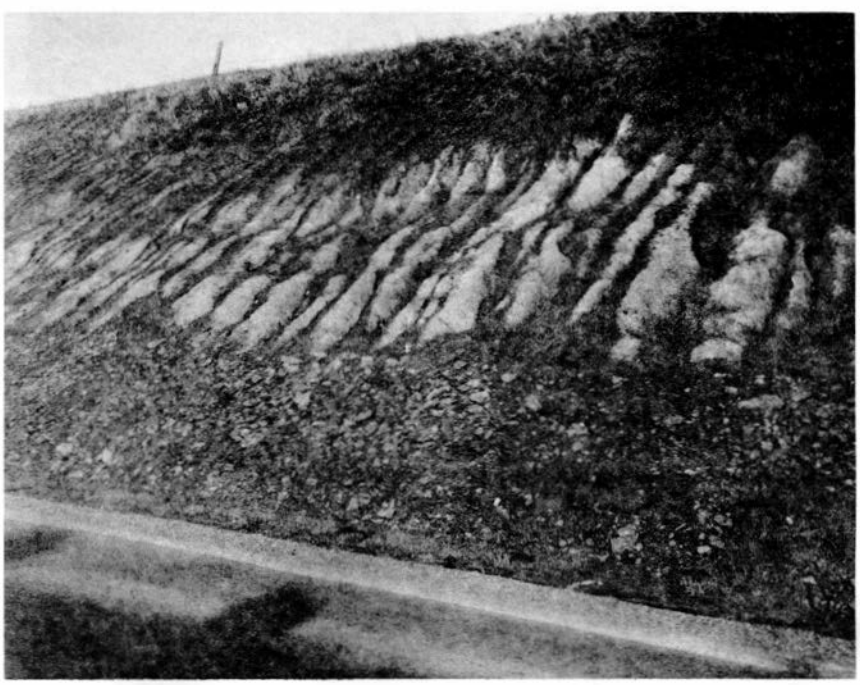


Figure 16. Helvetia Formation overlying Columbia River Basalt at Cornelius Pass.

Tualatin Mountains the formation is locally present, but not mapped, up to about 1,000 feet elevation beneath the upland silt. The Helvetia Formation is also found southeast of Sherwood on the northeast flank of ParrettMountain and on the lower east slopes of theRed Hills of Dundee. This formation is overlain at the valley margins (± 250 to 300 feet elevation) by the Willamette Silt and at higher elevations by upland silt. In the subsurface of the Tualatin Valley, data from water wells indicate that the formation may be overlain by the Troutdale Formation.

The Helvetia Formation is variable within the project area but generally consists of weathered, reddish-brown and light-brown clayey silt or sandy silt. The writers have found one outcrop where Helvetia parent material can be seen weathering to typical reddish-brown Helvetia soil. This locality is on the north flank of Chehalem Mountains, sec. 27, T. 1 S., R. 2 W., at the base of a cut on Iowa Hill Road, where the formation is composed of mottled, brownish-gray siltstone which hasweathered upward into a reddish-brown silty clay. Information from nearby water wells indicates that the siltstone lies above Columbia River Basalt.

Some 48 soil samples were obtained from localities of Helvetia outcrops around the valley and were washed and screened for study of the mineral content by a binocular and a petrographic microscope. All samples contained angular quartz and muscovite, which are foreign to material derived from the Columbia River Basalt. Other minerals identified were: feldspars, pyroxene, amphibole, zircon, tourmaline, opal, magnetite, and gibbsite nodules. Diatoms were also observed in some samples.

The upper few feet of the Helvetia Formation commonly weathers to a mottled gray-and-buff silt which has been leached by downward percolation of ground water.

The formation is considered to be correlative with the earliest Troutdale Formation sediments because of its stratigraphic position and occurrence in deep borings, and because its lithology includes granite, quartzite, muscovite, quartz, and minerals foreign to the weathered lava. The age of the Helvetia Formation is probably early Pliocene.

Figure 17. Troutdale Formation exposed in Willamette River at Newberg.

Troutdale Formation

The name Troutdale Formation as used in this report refers to the general concept of Hodge (1938) and Trimble (1957), and includes the Troutdale and Sandy River Mudstone named by Trimble (1963).

The Troutdale Formation is exposed in the east-central portion of the project area; north, east, and southeast of Beaverton; and in the bottom of steep ravines in the Newberg and Wilsonville valleys. It also crops out in patches along the Willamette River from near Newberg to Wilsonville and in two isolated localities northwest of Six Corners (figures 17, 18, and 19). Subsurface information indicates that the Troutdale underlies most of the Tualatin, Newberg, and Wilsonville valleys at a depth of approximately 50 feet.

The formation in the study area is composed largely of poorly indurated, fine-grained sedimentary material. In outcrops along the Willamette River and in adjacent ravines it consists predominantly of weathered gray and brown mudstone and mottled yellow and reddish-brown, fine, silty sandstone with occasional pebble conglomerate beds and lenses. Typical boring-log sections at Beaverton, Hillsboro, Newberg, Tualatin, and Forest Grove (figure 20) provide detailed information on the lithology of the upper portion of the formation in these localities. Information from deep water wells in the Tualatin Valley indicates that the formation is composed largely of silt and clay with occasional beds of fine sand and rare gravel. The formation reaches its maximum thickness of about 1,500 feet in the center of the Tualatin Valley near Hillsboro and tapers to a thin edge where it finally pinches out on the slopes of the surrounding hills. Further information on the thickness of the Troutdale Formation appears in a geologic section (plate 2).

The Troutdale is considered to be early Pliocene in age (Trimble, 1957). The writers regard the Troutdale Formation of the study area to be deposited under variable fluvial and lacustrine conditions in a slowly subsiding basin. The base of the Troutdale Formation, therefore, is probably closely parallel to the deformed surface of the underlying Columbia River Basalt. The upper portion of the formation appears to have had little or no folding.

Boring Lava

The Boring Lava, named by Treasher (1942), occurs along the west edge of the Tualatin Mountains generally above 200 feet elevation in scattered outcrops and extensively in the foothills of the northern Cascade Mountains of Oregon. In the Tualatin Mountains the Boring Lava erupted from local vents such as Mount Sylvania in secs. 31 and 32, T. 1 S., R. 1 E., and Swede Hills in the NW$\frac{1}{4}$ sec. 1, T. 1 S., R. 1 W. The lavas crop out in road cuts and stream canyons from West Slope east of Beaverton northwesterly for about 3 miles (figure 21). From information obtained from water wells they are also known to underlie the foothill areas between N.W. Laidlaw Road and Old Germantown Road. The lavas are mostly covered with a veneer of upland loessal silt which ranges from a foot or so in thickness in the Cedar Hills area to more than 50 feet in the Springville Road locality (sec. 17, T. 1 N., R. 1 W.). The lavas overlie an irregular erosional surface of the Troutdale Formation.

The Boring Lava is principally a gray, olivine basalt having an expanded texture. It is weathered from the surface to depths as much as 15 feet and along joint fractures. The jointing is blocky and an abundance of large, spheroidally weathered boulders occurs at the surface. Associated with the lava adjacent to the vents are pyroclastics composed of lapilli tuff, breccia, and cinders.

The Boring Lava within the project area ranges from a few feet in thickness in the Cedar Hills district to more than 150 feet as indicated by water wells near the Springville Road in sec. 17, T. 1 N., R. 1 W.

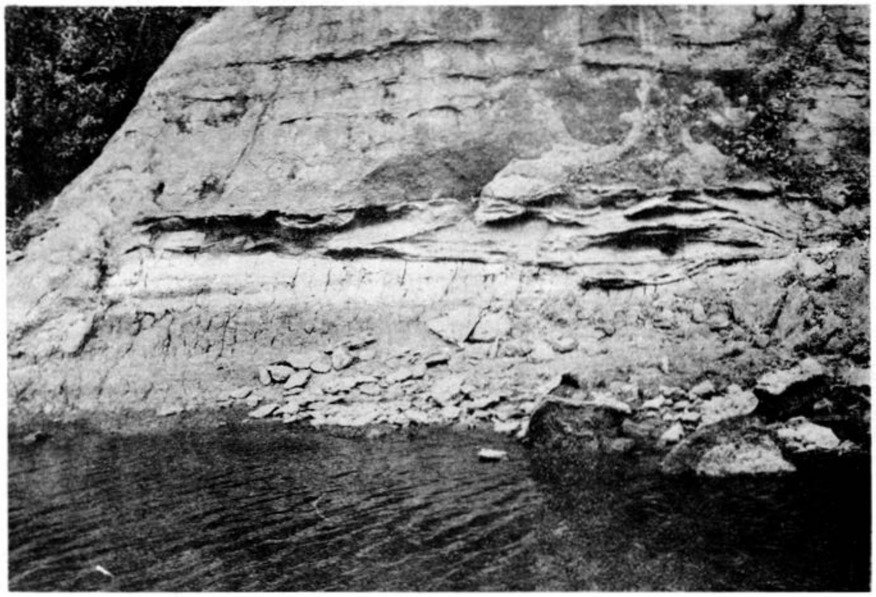


Figure 18. Troutdale Formation mudstones in bank of Yamhill River near Dayton.

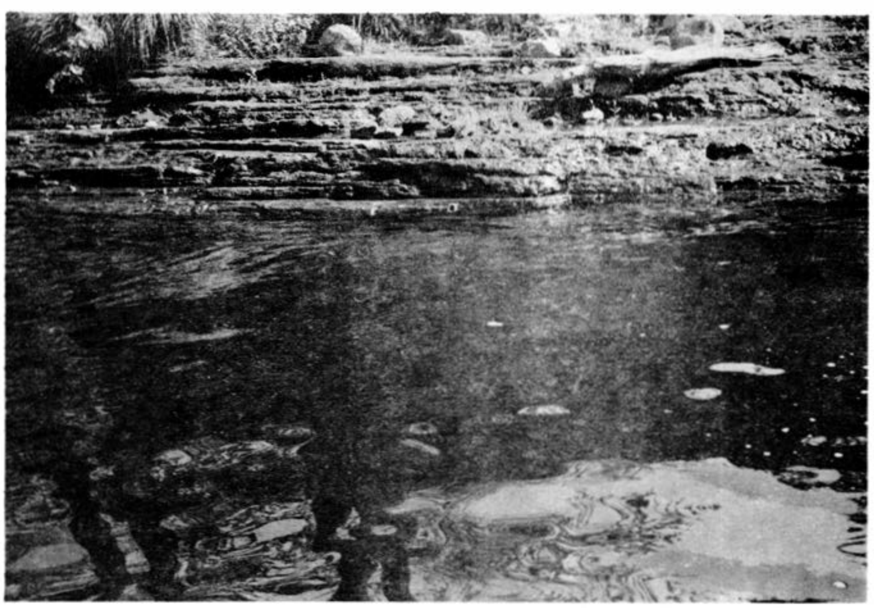


Figure 19. Troutdale bedded mudstones in bank of Willamette River east of Wilsonville.

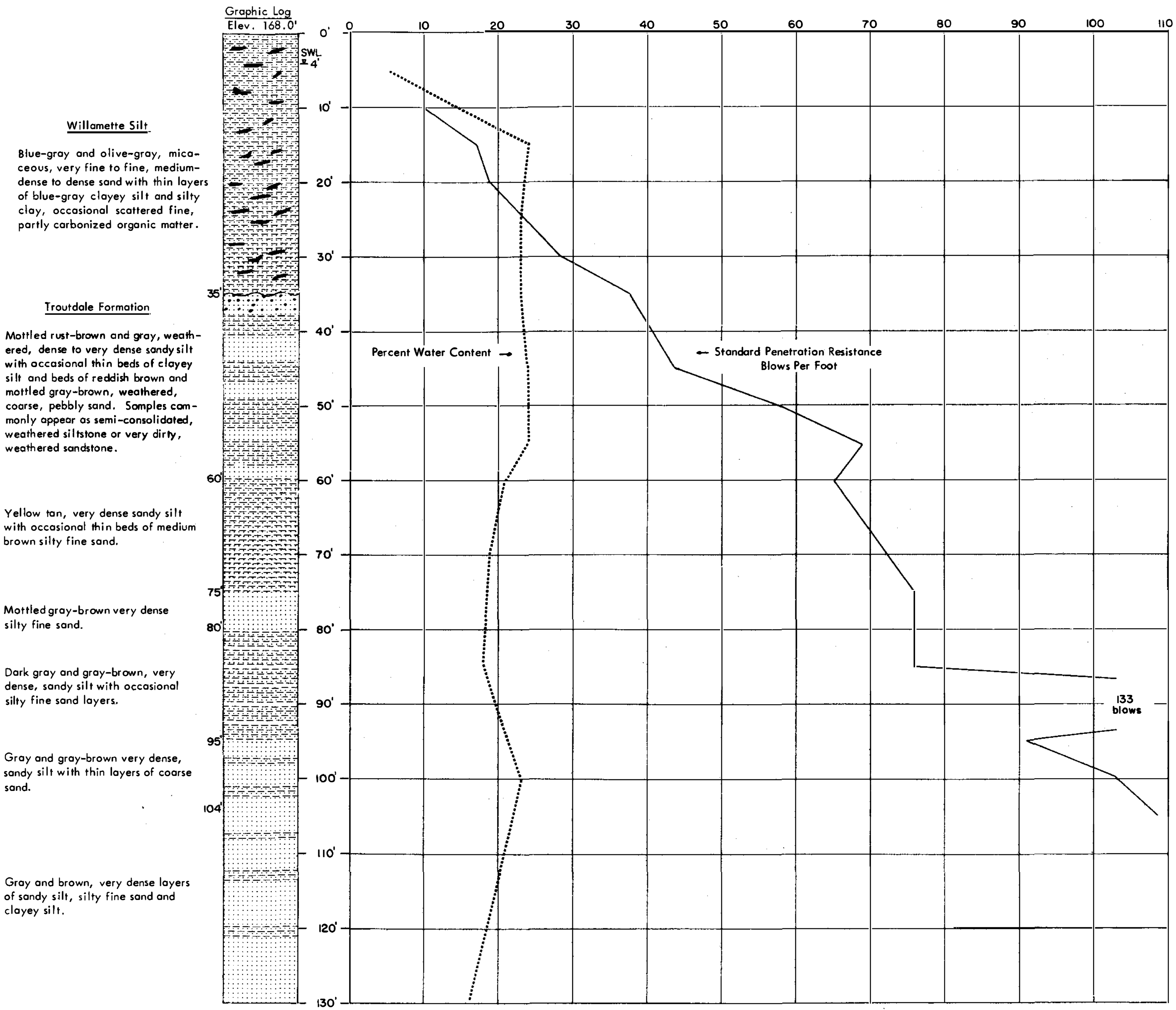


Figure 20a. Typical boring log of the Beaverton area (data from Northwest Testing Laboratories).

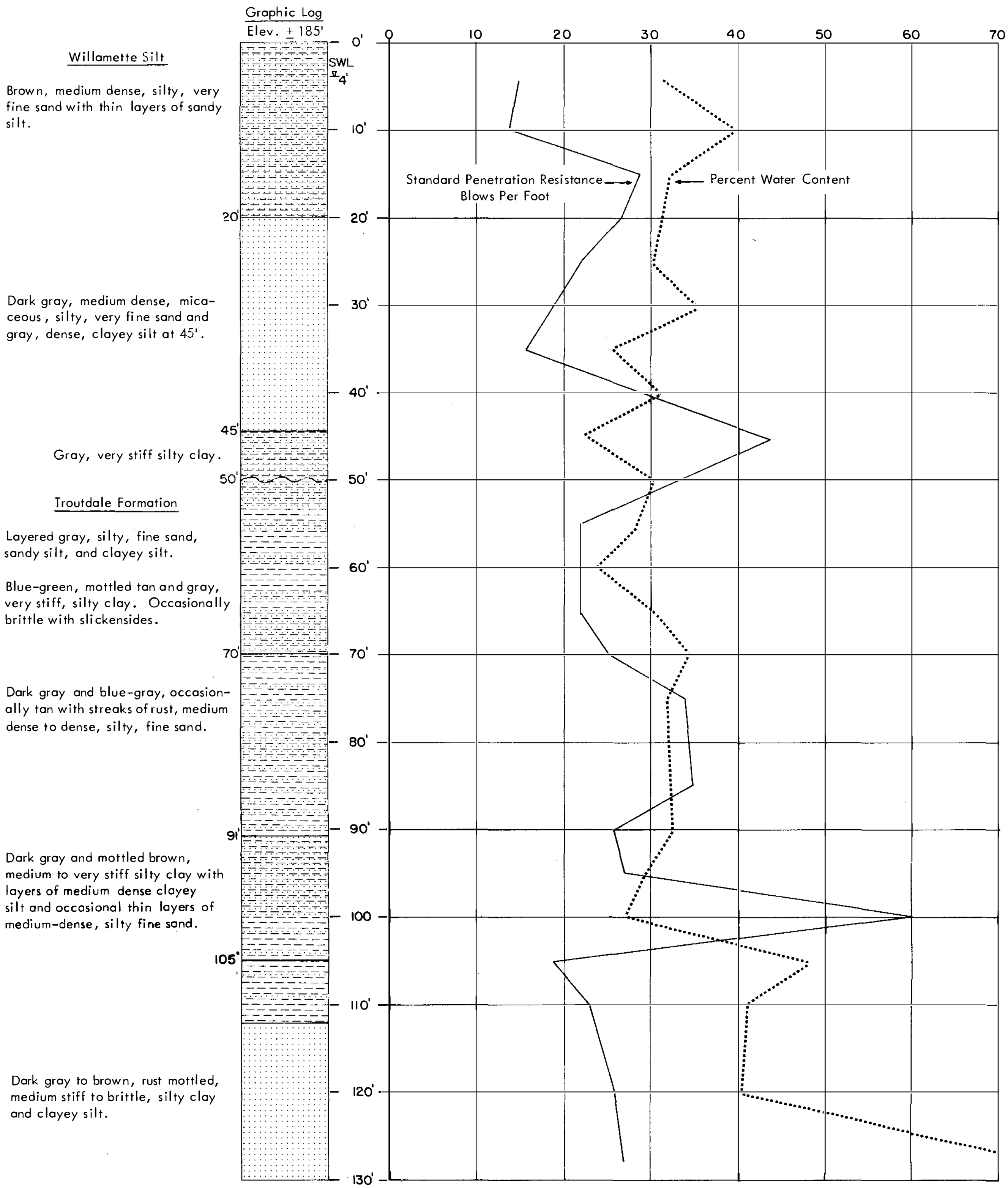


Figure 20b. Typical boring log of the Hillsboro area (data from Shannon & Wilson, Inc.).

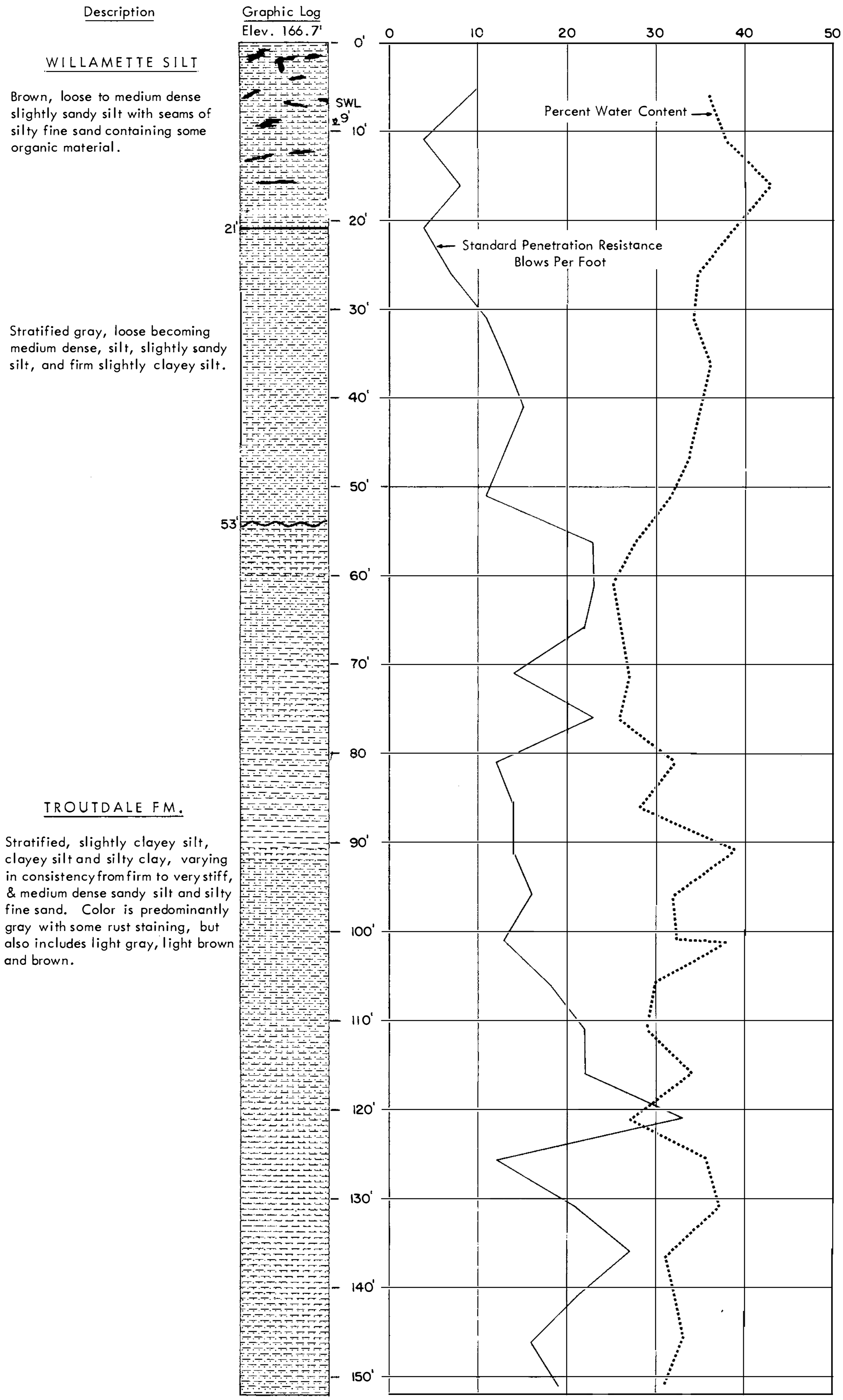


Figure 20c. Typical boring log of the Newberg basin (data from Shannon & Wilson, Inc.).

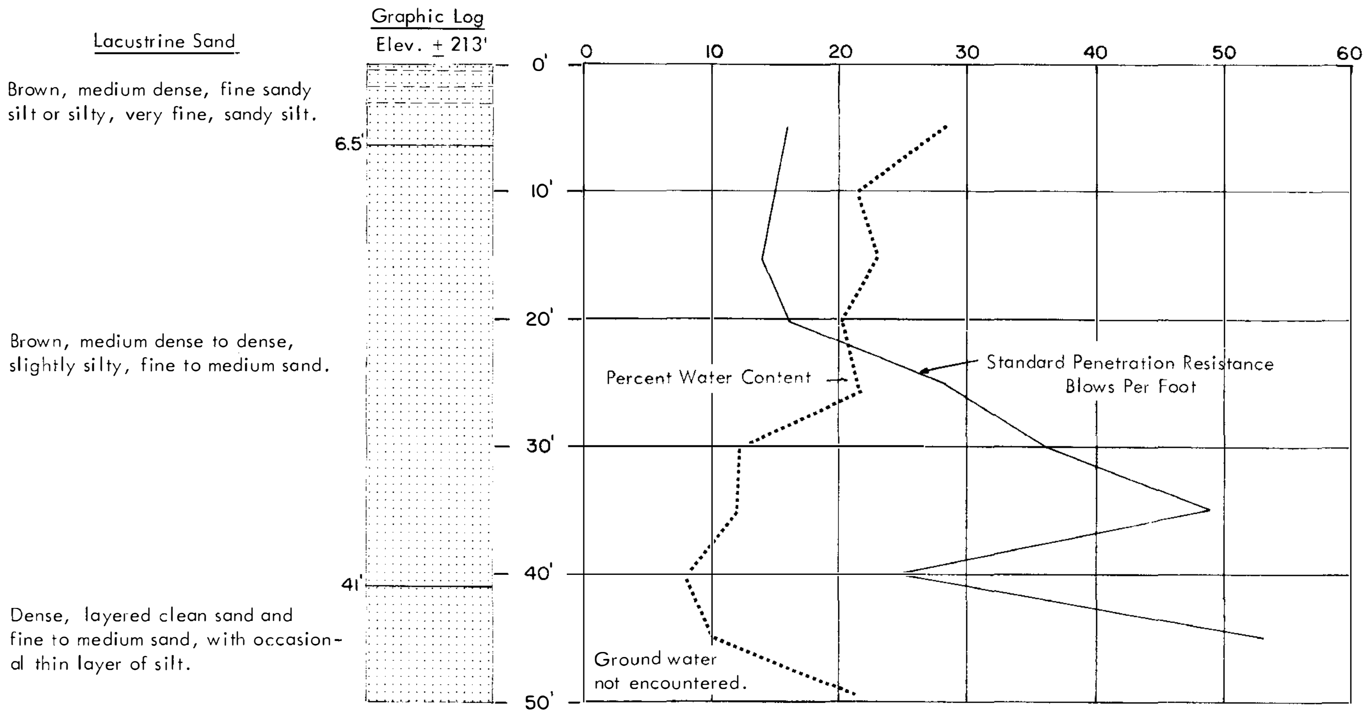


Figure 20d. Typical boring log of the Tualatin area (data from Shannon & Wilson, Inc.).

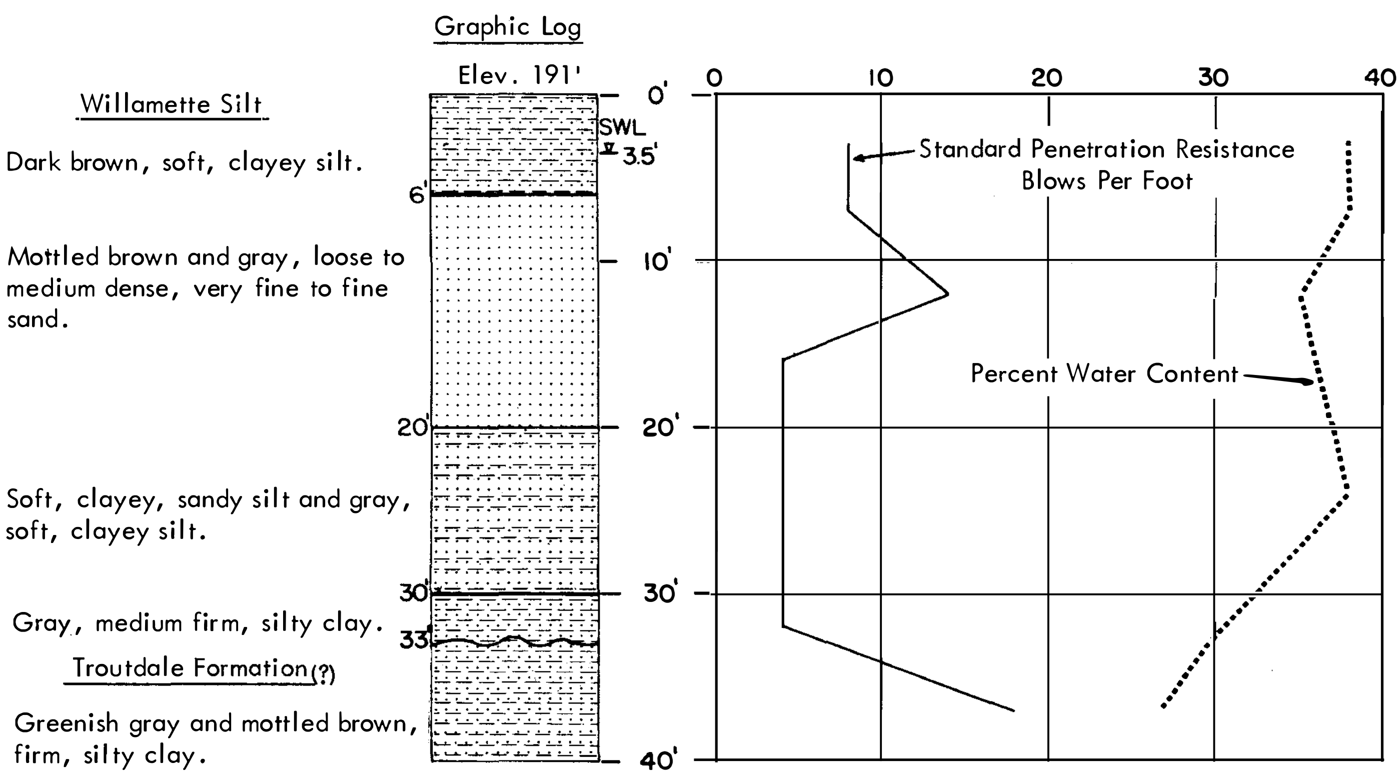


Figure 20e. Typical boring log of the Forest Grove area (adapted from Dames & Moore, boring log for Pacific University).

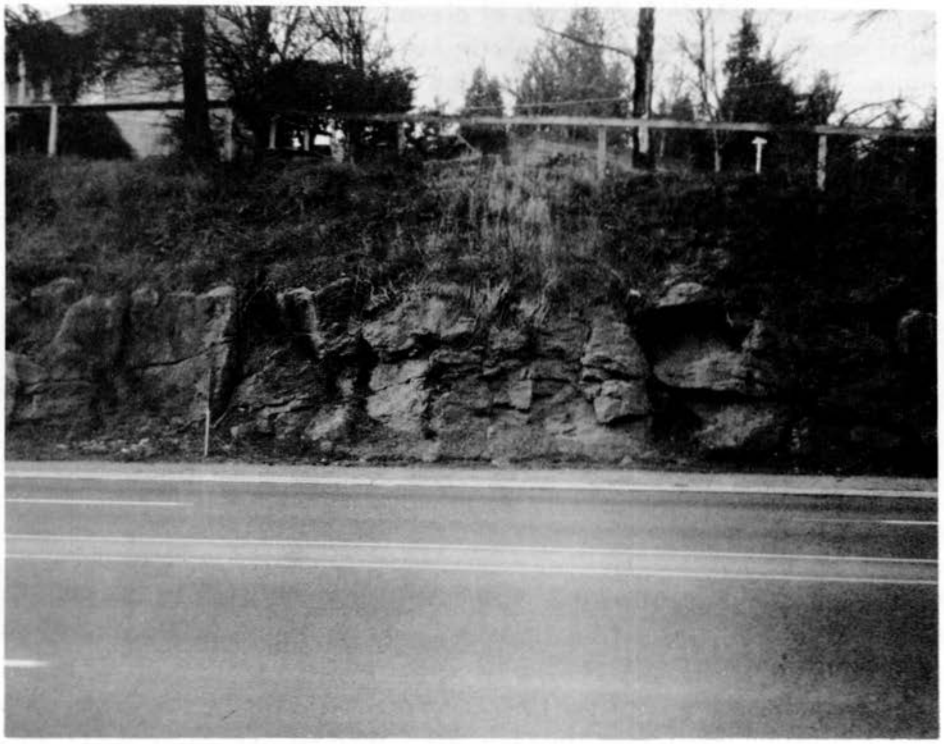


Figure 21. Boring Lava exposed in road cut on S. W. Canyon Road near West Slope.

Figure 22. Willamette Silt exposed in bank of Willamette River south of Newberg.

Upland Silt

Silt overlies the older rocks in the uplands at elevations generally from 250 feet to the summits. It caps ridges, spurs, and flatter parts of the Tualatin Mountains, Cooper and Bull Mountains, and the Chehalem Mountains, where it overlies variously the Columbia River Basalt, Helvetia Formation, Troutdale Formation, and Boring Lava. It is extensive east of Portland and Oregon City (Trimble, 1963).

The silt is consistently uniform in appearance, texture, and mineralogy over its entire outcrop area. It consists typically of massive and structureless, yellow-brown to buff, micaceous sandy silt and clayey silt with occasional well-rounded basalt pebbles. The silt and sand fractions of the deposit are composed principally of quartz and feldspars.

Composition of the silt was determined by Lowry and Baldwin (1952) as containing muscovite, biotite, feldspar, quartz, augite, hypersthene, hornblende, magnetite, tourmaline, garnet, apatite, tremolite, volcanic glass, sponge spicules, and diatoms. X-ray analysis of the silt reported by Trimble (1963) indicated the clay minerals are kaolinite, illite, and perhaps montmorillonite and chlorite.

Earlier writers refer to this material as being loessal, fluvial, and part of each (Diller, 1896), (Darton, 1909), (Ruzek, 1922), (Treasher, 1942), (Libbey, Lowry, and Mason, 1945), (Lowry and Baldwin, 1952), (Theisen, 1958), and (Trimble, 1963). The descriptions of the outcrops and mineral content are frequently in agreement even though the interpretations are widely divergent.

The silt has been previously called the Portland Hills silt member of the lacustrine Troutdale Formation by Lowry and Baldwin, loess-like soil parent material by Theisen, and Quaternary loess by Trimble.

The mineralogy of the upland silt, the Helvetia Formation, and the Willamette Silt is similar. This is indicative that all three formations have had the Columbia River drainage as their source, with the possibility that some of the upland silt was derived from the Willamette Silt as windblown material.

The writers believe that the Portland Hills silt member of the Troutdale Formation (Lowry and Baldwin, 1952) includes both the Helvetia and upland silt unit. This paper used the term "upland silt" for the loessal silts which are similar and undistinguishable from the Willamette Silt except for their occurrence at elevations above 250 feet. The red-brown Troutdale of Lowry and Baldwin and the Helvetia Formation (this report) have been previously considered to be residual basalt soil. Although residual basalt soil occurs locally, the writers do not believe that it is widespread. Much of the so-called laterized basalt is now interpreted to be in reality the laterized Helvetia Formation.

Since the Boring Lava is considered to be late Pliocene-early Pleistocene in age, the overlying silt can be no older; it is probably partly equivalent to the earliest Willamette Silt.

Willamette Silt

The Willamette Silt underlies nearly all of the lowlands within the project area. It generally extends onto the surrounding uplands to an approximate average elevation of 250 feet, where it occurs on sloping terraces. The Willamette Silt lies on the erosional surfaces of all the older bedrock units.

The unit is composed of unconsolidated beds and lenses of fine sand, silt, and clay. Stratification is commonly in the order of 4- to 6-inch beds; 3- to 4-foot beds are locally present; and in many areas the silt is massive with indistinct stratification (figure 22). Lenses of pebbly, fine to medium sand with scattered cobbles of granite and quartzite occur in some of the outcrops. The silt is usually light brown to buff in color, and occasionally light gray where granular soils predominate.

The upper surface of the silt has undergone leaching by percolating ground water, which has locally concentrated clayey soils at a shallow depth beneath the silt. Clays have also been concentrated in poorly drained, shallow depressions on the surface of the Willamette Silt. The clay phase of the Willamette Silt, where observed, has been indicated on the geologic map.

The Willamette Silt within the project area ranges from a few feet to about 50 feet in thickness. In the Tualatin Valley it is generally 20 to 50 feet thick and thins rapidly along the margins of the valley. In the Newberg and Wilsonville districts it ranges from a 5- to 10-foot thickness on the higher elevations to about 50 feet adjacent to the Willamette River. In the Yamhill Valley the

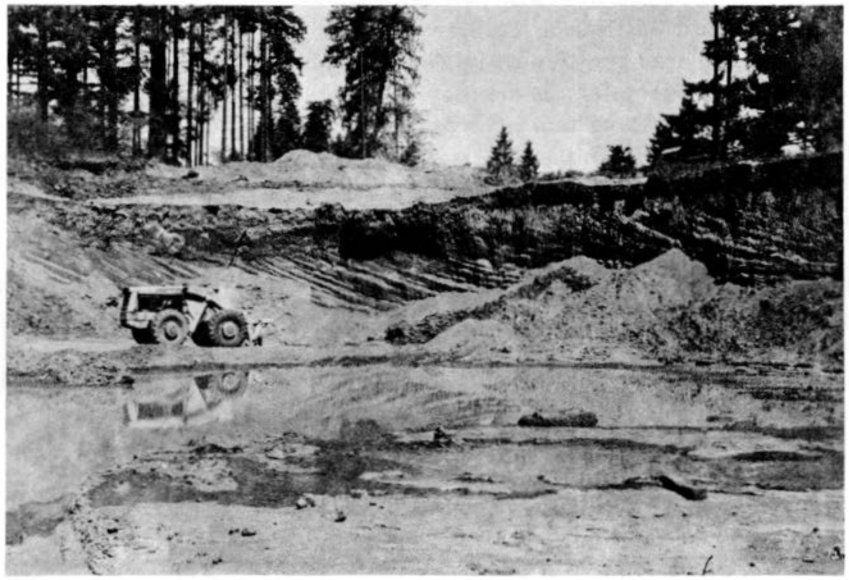


Figure 23. Torrential bedding in sand pits near Onion Flat.

Figure 24. Coarse sand with pebbles and cobbles in pits at Onion Flat.

silt is generally less than 40 feet thick. Boring-log sections (figure 20) at Newberg, Beaverton, Hillsboro, and Forest Grove show the thickness and character of the Willamette Silt in these localities.

The Willamette Silt is correlative with widespread lacustrine deposits of similar composition which mantle almost the entire Willamette Valley up to an elevation of about 250 feet from Portland to Eugene, Oregon. The silt has been studied by Allison (1933, 1935, 1936) and Glenn (1965) south of the project area. The study by Glenn is the most recent on the origin and history of the Willamette Silt. Glenn provides data to indicate that silt was deposited during at least 40 large Columbia River floods into the Willamette Valley. Carbon-14 dates reported by Glenn indicate that the silt was deposited from 19,000 years (B.P.) to 34,410 ± 3,450 years (B.P.)

Elephant bones have been found at the base of the Willamette Silt on the surface of Troutdale sediments in the map area and at other localities in the Willamette Valley. Within the map area, the bones have been found at Garden Home, NE$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 1 S., R. 1 E., on the surface of Troutdale sediments, and on the north bank of the Willamette River across from Clark's Marina, sec. 29, T. 3 S., R. 1 W., at the contact of Willamette Silt and the Troutdale Formation (Glenn, 1965). Glenn also found bones at the contact of the Willamette Silt and the Molalla Formation (probably Troutdale equivalent, at Needy (sec. 6, T. 5 S., R. 1 E., east of map area).

Lacustrine Deposits

Sand

Torrential flood deposits of cross-bedded sands are contained within an east-west outcrop belt, about 3 miles wide, extending from Tualatin in the southeast portion of the project area westerly to about 3 miles northwest of Six Corners on U.S. Highway 99 W. The surface of the deposits is locally highly irregular, containing numerous low ridges and small closed depressions.

The sands are well exposed in several pit excavations located a short distance north and east of Onion Flat (figures 23, 24, and 25). Here the sands are at least 50 feet thick and are medium to coarse grained. Thin pebbly lenses are present. They contain scattered cobbles of basalt and rare cobbles of granite and quartzite. The granite and quartzite clasts are redeposited erratics from the upper Columbia River drainage.

Deltaic bedding with moderately dipping foresets is common. The sands are clean and, with the exception of the pebble and cobble lenses, are well sorted. Lithic volcanic clasts, some quartz, and feldspar predominate.

Gravels

Gravel deposits near Durham and Cipole, and near Wilsonville in the southeast portion of the project area are considered to be of lacustrine origin and to have been deposited during torrential floods. Trimble (1963) mapped the deposits at Durham as an extension of widespread Pleistocene lacustrine deposits in the east Portland area. The writers consider that gravels near Cipole and at Wilsonville are also part of this sequence.

The gravels at Durham and Wilsonville are of like composition and gradation; they consist of cross-bedded, bouldery pebble and cobble gravel in a matrix of silt and medium to coarse sand (figures 26 and 27). Boulders in the gravel are as much as 5 feet in diameter. The gravels are principally basalt with scattered granitic, metamorphic, and limonite clasts (figure 28). Most of the basalt clasts have been derived from the Boring Lava and Columbia River Basalt in the Tualatin Mountains adjacent to Lake Oswego. Quartzite and granite cobbles are from gravel deposits of southeast Portland opposite the east end of Lake Oswego. Limonite cobbles probably have their source in an iron deposit at Lake Oswego.

Composition of the gravels and the structure of the deposit and its orientation give credence to the occurrence of a gigantic flood during the late Pleistocene. Flood waters poured through the gap, eroding out the present Lake Oswego, and washing gravels and blocks of basalt through the Tualatin Mountains to deposit them in the fan-shaped delta at Durham. Glenn (1965), Trimble (1963), Bretz (1925, 1928), and Allison (1933, 1935, 1936) discuss the evidence and mechanism for such a flood.

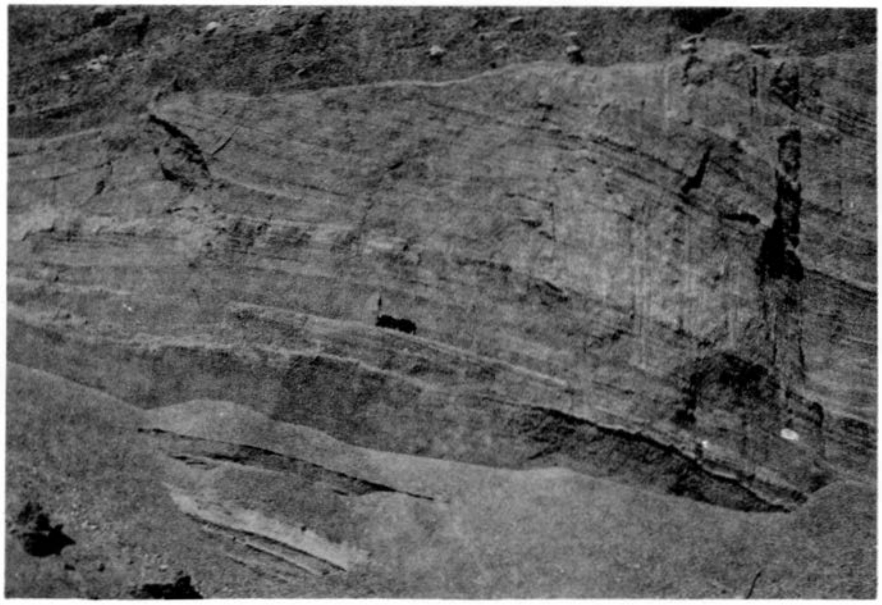


Figure 25. Cross-bedded sand in pit at Onion Flat; sun glasses give scale.

Figure 26. Deltaic bedding in gravel pit at Durham.

Figure 27. Unsorted silty gravels overlying torrentially bedded gravels at Durham pit.

Figure 28. Limonite cobble in gravels at Durham pit.

The lacustrine deposits appear to overlie and/or truncate Willamette Silt west of Tualatin. The lacustrine deposits overlie Columbia River Basalt south of Tualatin, and at Wilsonville the gravel phase of the deposits overlies the Troutdale Formation and underlies silts that may be a late phase of the Willamette Silt. The deposits range in thickness from a few feet to more than 50 feet.

Terrace Gravel

Gravel deposits are present in a former valley plain within and along the sides of the present flood plain of Gales Creek in the northwest part of the map area. The gravel terraces are 10 to 15 feet thick and rest on Eocene volcanics and sediments. They are composed of slightly weathered pebble gravel, with occasional cobbles, containing a silty, fine-to-medium sand. The pebble and cobble clasts are largely basalt and gabbro with a small percentage of sandstone and siltstone.

Terrace gravels were deposited during an earlier period of alluviation of the Gales Creek valley. The deposits are probably early Recent or late Pleistocene in age.

Young Alluvium

Young alluvium predominates in the flood plains of the Willamette River, Tualatin River, and Yamhill River. It also covers significant areas in the flood plains of Gales Creek, East Fork of Dairy Creek, and McKay Creek. It is present in the channels of all of the main streams and in most of the smaller tributaries.

The composition of the young alluvium is mainly silty clay, clayey silt, and fine sand, with local areas of peat and organic clay. Gravels are being deposited only in the upper reaches of Gales Creek and in the Willamette River at Ash Island.

Clayey soils cover most of the flood-plain areas of the Yamhill River and adjacent tributaries and the flood plains of East and West Dairy Creek and McKay Creek. Clayey soils are also present at numerous localities in the Tualatin River flood plain, especially in areas where waters may be ponded during wet periods of the year. The development of natural levees often causes ponding of flood water, and the settling out of clays in these quiet ponds is probably responsible for most of the clay phase of the young alluvial soils.

In areas where drainage is poor and the water table remains at the surface for most of the year, abundant vegetation produces peat or organic clay soils. The principal areas of organic soils are Wapato Lake, Carlton Lake, Strohmeyer Canyon, and Onion Flat. The many small occurrences of organic soils and peat suggest that these deposits are probably much more abundant than is shown on the map (plate 1). Peat has been reported at the Interstate 5 crossing of the Tualatin River, at the junction of the Sunset Highway with the Wilson River Highway east of Banks, and in Seely Ditch just west of Mulloy.

The young alluvium has been deposited in channels and flood plains in areas underlain by Willamette Silt, Troutdale Formation, Columbia River Basalt, and Oligocene and Eocene marine sediments and volcanics. In general, the thickness of the young alluvium ranges from 5 to 15 feet over areas of Miocene and older rocks. Over areas of Troutdale Formation and Willamette Silt in the Tualatin Valley, it is 20 to 30 feet thick. Young alluvium is much thicker in Wapato Lake valley where drilling logs indicate about 60 feet of organic clay.

Structural Framework

The predominant structural framework of the project area is expressed by the northwest-trending anticlinal ridges of the Tualatin Mountains, Cooper Mountain-Bull Mountain, and Parrett Mountain-Chehalem Mountains separated by the broad synclinal areas of the Tualatin, Newberg, and Wilsonville valleys. In the southwest portion of the project area, the beds of the east flank of the Coast Range dip primarily northeasterly to form a monoclinal structure. Major faults with displacements greater than 1,000 feet are common in the bedrock units of the project area.

Tualatin Mountains Anticlinal System

The Tualatin Mountains are developed in Columbia River Basalt and form a broad, nearly symmetrical northwest-trending anticlinal system that has been oversteepened on each flank by faulting parallel to the mountain front. The primary anticlinal axis is believed to be located at the crest of the mountains; however, smaller linear folds are also present parallel to the main axis. A major normal fault, mapped on the east flank of the mountains, is part of a regional 50- to 60-mile fault trend that extends at least 30 miles northwest of the map area and 20 miles to the southeast up the Clackamas River (Schlicker and others, 1964). The fault on the north flank of the mountains near Cornelius Pass is probably also normal but may extend beyond what is shown on the map.

Cooper-Bull Mountains Anticlines

These anticlines are apparently separate structural features that form domal uplands of basalt in the southeast portion of the Tualatin Valley. A cross fault separates the two structures, and subsurface information indicates the presence of other faults on the northeast and southwest flanks of Cooper Mountain. The Cooper-Bull Mountain anticlines are nearly symmetrical structures whose flanks dip toward the valley.

Parrett Mountain-Chehalem Mountains System

The Parrett Mountain-Chehalem Mountains system is a complex, northwest-trending structural feature that probably developed originally as a broad anticline, but that has been so modified by subsequent faulting and erosion that its present principal structure is obscure. Parrett Mountain is separated from the Chehalem Mountains by a major cross fault that may continue to the southwest into the Grand Ronde area and to the northeast through the Oswego Gap and beyond. Parrett Mountain appears to be a south-plunging anticlinal nose that has been cut by a series of northwest-trending normal faults having small displacements.

Several dip reversals and the presence of Columbia River Basalt on the southwest flank of the Chehalem Mountains indicate that the feature may be a northwest-trending anticline that has been modified by faulting. While detailed information is lacking, it is possible that the scarp along the southwest edge of the mountain has been produced by faulting and erosion. The scarp may also have been formed by southwest movement of major landslide blocks. The primary structure of the Chehalem Mountains is monoclinal, with low northeast dips into the Tualatin Valley and local steep southwest dips into the Newberg valley.

Coast Range

The structure in bedrock units of the east flank of the Coast Range is basically a northeast-dipping monocline with a well-developed system of rectangular faults. Faults which show stratigraphic displacement of several hundred to more than 1,000 feet include the southeast-trending fault in Gales Creek valley and probably the faults in the valleys of Scoggin Creek and the Tualatin River. These faults also continue for many miles northwesterly into and possibly across the entire Coast Range. The northeast-trending cross faults appear to be of less magnitude.

Valley Structural Systems

The Tualatin, Wilsonville, and Newberg valleys are the result of broad regional downwarping that has produced synclinal structures. The Tualatin Valley is a bowl-shaped syncline that is underlain by Columbia River Basalt with a fluvial and lacustrine filling of Troutdale sediments and Willamette Silt. The basalt surface has been depressed to an elevation of about 1,300 feet below sea level in the center of the valley. The Wilsonville and Newberg areas are smaller synclines, with filling comparable to that of the Tualatin basin. They plunge southerly into the structural basin of the Willamette Valley.

Economic Minerals

Nonmetallic Minerals

Nonmetallic mineral deposits which are currently being exploited in the region include basalt, sand and gravel, and clay. Basalt quarries and sand and gravel deposits are discussed in detail under "Construction Materials" in the engineering section of this report. Location of the quarries and pits is shown on the geologic map (plate 1).

Drain tile is being manufactured commercially by the Scholls Tile Co., located near Scholls, and by the Forest Grove Clay Products Co. at Forest Grove. The Scholls Tile Co. obtains raw material from the clay phase of young alluvium deposits of the Tualatin River and the Forest Grove Clay Products Co. utilizes clay soils from the Willamette Silt.

Peat deposits are present in the area, but no commercial use has yet been made of them.

Oil and Gas

Major oil companies have been interested in the oil and gas possibilities of the region since the early 1940's. Two deep tests were drilled in 1946 to explore the marine formations which underlie the area. One test was drilled by Texaco, Inc., to a depth of 9,263 feet on Cooper Mountain (sec. 25, T. 1 S., R. 2 W.). The other was drilled by Richfield Oil Co. to a depth of 7,885 feet on the Tualatin Mountains in sec. 23, T. 1 N., R. 1 W., Multnomah County. Neither test found significant shows of oil or gas, although the Texaco well recovered salt water on a drill-stem test at a measured rate of 750 B/D. A block of approximately 15,000 acres of oil and gas leases is presently held by Atlantic-Richfield in the Gaston area (Northwest Oil Report, 1965).

Ferruginous Bauxite

Deposits of ferruginous bauxite were discovered by the Oregon Department of Geology and Mineral Industries in 1944 along the lower slopes of the Tualatin Mountains north and west of Helvetia (Libbey, Lowry, and Mason, 1945). The ores are generally oolitic or pisolitic and magnetic, and occur in flat-lying beds as much as 30 feet thick under the silty clay of the Helvetia Formation. The ore is of lateritic origin and was apparently formed by the weathering of the Columbia River Basalt during late Miocene and early Pliocene time prior to the folding and accompanying uplift of the region. Deposition of the overlying Helvetia Formation is believed to have preserved the bauxite horizon before natural erosional processes removed all of the upper surfaces of the weathered basalts.

An exploration drilling program in Washington County by the Department indicated more than 5 million long tons of ferruginous bauxite in two localities. An arithmetical average of samples obtained by auger-hole drilling of deposits in these localities is 34.7 percent alumina, 23.1 percent iron, 9.5 percent silica, 4.9 percent titania, and 0.176 percent phosphorus.

During the period from 1945 to 1950, the Aluminum Co. of America extensively explored the bauxite deposits in Washington and Columbia Counties, Oregon, and in Cowlitz County, Wash. Most of the known deposits are now owned by Alcoa as a result of its drilling exploration program.

The Oregon-Washington laterites are relatively low in alumina as compared with high-grade bauxite in other parts of the world, but they have advantages which partially, at least, compensate for this disparity. The high iron content could make a commercial by-product, either pig iron or ferrotitanium. It has been reported authoritatively that there are no metallurgical obstacles to treatment of the ore either by the Bayer or Pedersen processes. The physical characteristics of the deposits are favorable for cheap surface mining, and there are excellent transportation facilities to the lower Columbia River area where aluminum reduction plants are operating.

APPLICATION OF GEOLOGY TO ENGINEERING PROBLEMS

This section of the report is based on the geology of the area, as described previously and shown on the geologic map (plate 1) and cross sections (plate 2). It discusses (1) the engineering characteristics of the various soil and rock units, (2) geologic hazards, (3) construction materials, (4) ground-water resources, and (5) pollution problems, and summarizes these topics for each of the four geologic provinces. While this information is not intended to serve as a substitute for a site investigation, it will be of considerable aid to engineers and planners working in the Tualatin Valley. Aspects of primary applicability are:

1. Preliminary site evaluation of soil and foundation characteristics for industrial, commercial, and residential properties.

2. Evaluation of geologic and soil conditions for location of roads, pipelines, and other surface and subsurface installations.

3. Evaluation of response of soils to erosion, compaction of embankments, slope stability, and internal drainage.

4. Location of geologic hazards such as areas of flooding, natural slope failure (landslides), and near-surface ground-water table.

5. Determination of response of soil and rock units to earthquake forces.

6. Location of construction materials including rock quarries and sand and gravel deposits.

7. Evaluation of ground-water potential for water-supply systems.

Engineering Characteristics of Geologic Units

Each of the various soil and rock units within the area has fairly distinctive characteristics when used as supporting horizons for structures, as sources of materials for earthwork construction, as media for disposal of sanitary wastes, and in other engineering applications. A summary of soil classification, laboratory tests, and soil performance data for each sedimentary formation is presented in table 1. The following paragraphs describe in general terms the engineering properties of the individual units. The intent of this section is to furnish guidance in reconnaissance, planning, and preliminary estimates of engineering projects; the importance of a specific site investigation for the design phase of a project cannot be overstressed.

Eocene Volcanics and Sediments and Yamhill Formation

The unnamed Eocene volcanics and sediments and the Yamhill Formation are discussed together because the soils developed on these units are similar in composition and engineering characteristics. These sediments, laid down in a shallow marine environment, crop out along the western edge of the map area in a belt 2 to 8 miles wide.

The surface of the Yamhill Formation is composed of deeply weathered thin-bedded marine shales and minor amounts of basaltic sandstone. The unnamed volcanics and sediments are composed of deeply weathered, Yamhill-type sediments which in some places are intercalated with basalt flows and intruded by gabbroic and basaltic rocks.

The soil developed on these units is a heavy, impermeable plastic clay having engineering characteristics similar to those of the more weathered clay soils derived from the Oligocene marine sediments described later. The soil horizon is frequently very shallow, often less than one foot thick, above weathered bedrock.

Soil classifications and laboratory data on Yamhill Formation soils are given below.

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-7-6 (15)	E-8	CH

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
91.2	47.2	44.0	50	23	26.2	94.6

The weathered part of the bedrock is usually quite firm, and road cuts stand on a 1½ horizontal to 1 vertical slope. Where the bedding dips into the cut, difficulties may be experienced in maintaining slopes in bedrock. Ravelling from the thin-bedded shales frequently fills roadside ditches and impedes drainage. Landslides of considerable size are prevalent on steep slopes, particularly in areas of high relief (plate 3).

Material excavated from the Yamhill Formation breaks down to its original clay or silt constituents under the action of construction equipment. Fills made with this material present the construction-control problems of silt or clay, rather than of rock.

The Yamhill and older sediments are impermeable; consequently, roads require adequately designed rock base for drainage and load distribution. The relatively unweathered rock will support moderate to heavy structures. The deeply weathered and softened bedrock may be poor foundation material for structures which are either very heavy or intolerant to settlement.

The shales and associated clays are generally unsatisfactory for drain field installations.

Spencer Formation

The Spencer Formation crops out in a narrow band about half a mile wide and 20 miles long, bordering the eastern edge of the Yamhill Formation. This discussion is limited to the sandstone phase of the formation. Although the sandstone is sometimes sufficiently cemented to retain its character as rock (upon excavation), it usually breaks down to its soil constituents. These are classified as follows:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-4 (8)	E-6	SP

Sieve Analysis by State of Oregon Highway Department

		Sieve Analysis - Passing Tyler Screen Sizes						MM Size - Hydrometer Analysis Size in MM				
Lab. No.	Location	10	20	40	60	140	200	.053	.038	.024	.007	.005
617749	Sec. 32, T. 1 S., R. 4 W.	100.0	99.8	99.4	95.4	23.4	15.4	10.0	6.0	6.0	2.0	2.0
617747	Sec. 1, T. 2 S., R. 4 W.	100.0	98.8	98.6	98.0	41.6	27.8	20.0	16.0	12.0	4.0	2.0
617748	Sec. 15, T. 2 S., R. 4 W.	100.0	99.8	96.2	67.4	23.0	17.6	12.0	8.0	8.0	3.0	2.0
617744	Sec. 30, T. 3 S., R. 3 W.	100.0	99.8	99.4	97.2	39.8	31.2	28.0	22.0	16.0	4.0	2.1
617745	Sec. 24, T. 3 S., R. 4 W.	100.0	99.8	99.6	99.2	35.0	22.8	16.0	12.0	12.0	4.0	4.0
617746	Sec. 7, T. 3 S., R. 3 W.	100.0	99.8	99.6	92.8	32.2	24.4	24.0	20.0	18.0	13.0	10.1

The Spencer sand is poorly graded. Approximately 68 to 80 percent is fine sand (.08-0.25 in.). The 15 to 31 percent passing the 200-mesh screen is chiefly silt.

Permeability varies from good to fair, depending upon silt and clay content, and drainage ranges from fair to poor.

Much of the Spencer sandstone crops out on steep topography. Landslides have occurred where streams have cut deep channels through this material, such as on Woodland Loop Road. The poorly cemented portions of the formation will stand vertically for heights of 10 or 12 feet. The better cemented portions have been observed to stand vertically to heights of 30 feet.

Spencer sand lends itself to construction of embankments of high strength, low compressibility, and low-to-moderate permeability. Compaction may be achieved by routing of loaded hauling equipment, rubber-tired rollers, and vibratory rollers. Compaction is aided by addition of some moisture; however, construction operations cannot be carried on in heavy or continuous rain. New embankments must be protected immediately against surface erosion.

Table 1. Soil Classification and Laboratory Test and Performance Data for Geologic Units in the Tualatin Valley Region.

	Formation or Soil	Young Alluvium (Qya)			Willamette Silt (Qws)	
	Soil Phase	Silt	Clay	Organic	Silt	Clay
	Number of Samples	6	3	5	5	4
Soil Classification	A.A.S.H.O	A-4(8)	A-7-6(12)	A-8	A-4(8)	A-7-6(11)
	F.A.A.	E-6	E-7		E-6	E-7
	Unified	ML	CL	OH-PT	ML	CL
	Textural	Silt loam	Clay loam	Organic mat'l	Silt loam	Clay loam
Hydrometer Analysis	Percent Sand	12-24	3-17	43-62	9-35	4-30
	Silt	41-74	36-71	42-58	46-61	36-58
	Clay	7-39	25-47	15-29	12-31	24-47
Screen Analysis	Passing No. 10	94-99.9	99.7-99.9	92-100	93.2-97.6	94-99.9
	40	92.5-99.8	96.5-99.4	89-99	92.1-97.0	86-99.5
	60	89.5-99.6	95.1-98.8	85-98	90.9-96.4	84-99.3
	200	81.8-94.7	92.1-96.4	65-91	80.2-94.4	77-95.9
Shear Strength	Angle of internal friction	Variable	Low	Low	Mod.-high	Low-mod.
	Cohesion P.S.I.	Moderate	High	Low	Low	Mod.-high
Atterburg Limits	Liquid limit	24-32	40-53	41-153	23-30	29-49
	Plastic index	0-8	14-27	0-23	0-6	11-27
Proctor Density	Optimum moisture	17-22	20-26		15-22	20-22
	Dry density	99-109	96-104		100-110	102-105
Modified from Casagrande Soil Charts	Foundation rating	Fair to poor	Fair to poor	Very poor	Fair-poor	Fair-poor
	Frost potential	Med. to high	Med. to high	Slight	Med.-high	Med.-high
	Shrinkage-expansion	Slight-med.	Medium	Very high	Slight-med.	Medium
	Internal drainage	Fair-poor	Impervious	Fair-poor	Fair-poor	Impervious
	Dry strength	Slight-med.	Med.-high	None	Slight-med.	Med.-high
	C.B.R. Wet-compacted	6-25	4-15	None	6-25	4-15

Table 1, Continued.

Upland Silt (Qs)	Troutdale (Tpt)	Helvetia (Tph)	Oligocene Undiff. (Tos)	Spencer (Tes)	Yamhill (Tey)
2	33	3	2	6	1
A-4(8) E-6 ML Silt	A-6(10)-A-7-6(18) E-6 to E-8 ML-CL-CH Silty & inorganic clay	A-6(10) E-7 ML-CL Silty clay	A-7-6(12) E-7 CL Inorganic clay	A-2 E-3 SP Fine sand	A-7-6(15) E-8 CH Inorganic clay
10-18 58-73 16-21	2-32 50-62 19-36	8-18 44-69 23-40	25-30 41-61 25-56	69-85 13-29 2-4	9 47 44
99.8-100 96.4-97.8 96.2-96.8 90.2-93.4	99.7-100 91.7-99.2 89.9-99.2 84.7-98.2	99.3-100 91.8-97.5 85.8-96.8 74.2-92.7	99.6-100 98.4-99.5 98.6 - 74.5-96.9	100 98.6-99.6 95.4-99.2 15.4-27.8	100 99 97 91
Moderate Low	Low to moderate Mod. to high	Low to mod. Moderate	Low to mod. Variable	High None	Low to moderate Mod.-high
26-29 0-6	29-61 8-35	35-40 10-16	38-63 13-24	None	50 23
16-18 106-109	16-22 103-113	22-24 102-104	18-25 98-107		26 95
Fair-poor Med.-high Slight-med. Fair-poor Slight-med. 6-25	Fair-very poor Med.-high Med.-high Impervious Med.-high 0-15	Fair-poor Med.-high Slight-med. Fair-poor Slight-med. 6-25	Fair-poor Med.-high Medium Impervious Med.-high 4-15	Fair-good Slight-med. None-low Fair-poor Slight-med. 8-30	Poor-very poor Medium High Impervious High 0-6

A proposed damsite on Scoggin Creek just west of Stimson Mill is located on the Spencer sand. The abutments are sandstone, while the main dam will rest on impervious alluvial soils of the stream valley. The presence of a semi-pervious formation within the dam abutment may have a far-reaching influence on stability of the valley walls downstream from the dam. Existing landslides in the proposed reservoir area also suggest aggravation of slide activity from reservoir fluctuations.

Oligocene Marine Sediments Undifferentiated

The Oligocene marine sediments crop out in the eastern part of the southwest quarter of the mapped area. The sediments include indurated tuffaceous and basaltic sandstone, massive siltstone, shale, and occasional conglomerate beds. Bedding ranges from 2 feet in thickness to less than 3 inches. The rock is deeply weathered, often to 15 feet or more. An exception is the well-indurated lime-cemented sandstone exposed in the quarries on Scoggin Creek and in Patton Valley.

The soils derived from these sediments range from clayey sands to highly plastic clays, depending upon the composition of the parent material. The tuffs alter to a light-colored plastic clay and the shales to a silty clay of moderate plasticity. The sandstones weather to a clayey sand.

Landslides are common in areas of moderate to steep slopes. Because of low permeability and high moisture capacity, the weathered shales remain wet much of the year. The clay developed along bedding planes provides sliding surfaces wherever the direction of dip coincides with the surface slope. Dislocations in roads, fences, and buildings on old landslides serve as indicators of slide movement.

Soils developed from the Oligocene marine sediments have good shear strength when dry; however, shear strength decreases rapidly with increase in moisture content. Bentonitic clays developed from weathering of tuffaceous sandstone frequently swell or shrink with changes in moisture content and, therefore, can be troublesome as foundation material. When used as borrow, these materials tend to break down to their textural constituents. Sampling and testing available to this study do not indicate all of the variations within each of the sedimentary rock types. The following tables summarize the known properties of the materials.

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-6 (9)	E-7	ML
A-7-5 (18)	E-10	MH
A-7-6 (12)	E-7	CL
A-7-6 (10)	E-7	CL

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
74.5	47.8	26.8	38	13	24	98
96.9	41	60	63	24	38.3	--
96.6	61	36	41	21	22	--
87	61	26	40	15	27	--

Columbia River Basalt

The Columbia River Basalt crops out on the Red Hills of Dundee and the mountains surrounding the Tualatin Valley. It also crops out in Bull and Cooper Mountains and in smaller prominences in the Tualatin Valley.

In the areas underlain by Columbia River Basalt, the topography is mountainous with slopes ranging from moderate to steep. Numerous steep-sided canyons have been cut into the basalt.

On canyon walls, erosion has stripped the overlying silt and weathered basalt exposing hard, unweathered rocks. On high ridges the soil cover is occasionally very thin, with hard rock only a few feet beneath the surface. In flatter areas the basalt is deeply weathered and buried by a thick cover of silt and clay.

Although the Columbia River Basalt is normally excellent foundation material, the slope and thickness of the rock, nature of the overlying and underlying formations, geologic structure, and degree of weathering and jointing at the site must be considered.

Unweathered basalt surfaces are usually jointed or fractured to such an extent that surface water gains access to the ground; frequently, however, a clay or weathered silt zone lying on the basalt forms an impermeable blanket. Disposal of sewage by septic tanks may offer serious difficulties when the effluent drains either directly into the ground-water supply or when it breaks out on steep hillsides a short distance downhill from the drain field.

In most cases the basalt surface dips downslope. The construction of roads and the leveling of the ground for building sites usually involve making a cut into the hillside and placing the excavated material downslope. The leveled area is then part cut and part fill. Attention must be given to the possibilities of uneven settlement and adverse effects on general stability. Unless appropriate steps are taken to insure stability of the cut slope, a failure may ensue.

Excavation in the weathered basalt requires ripping of the weathered rock and removal of large, unweathered blocks of basalt. Excavation of fresh basalt requires the use of explosives.

Columbia River Basalt is the most widely used crushed rock in the area. The rock is usually sound, shoots small enough to be handled by standard-size jaw or cone crushers, and it is brittle enough to break easily. Laboratory test data by the Oregon State Highway Department are given in table 4, in the section of this report on Construction Materials.

Although much of the area on the geologic map has been shown to be basalt lava, the economical quarry sites are limited by a number of considerations, first of which are the distance to market and local competition. Other important considerations are rock quality, stripping of overburden, and accessibility. A quarry site must have ample room for plant and stockpile and be relatively remote from population centers. Today's uneconomical rock sources may be tomorrow's quarry sites.

Helvetia Formation

The Helvetia Formation crops out in patches at the lower elevations in the mountains surrounding the Tualatin Valley. The formation is composed of poorly indurated sand, silt, and clay and is the oldest sediment resting on the Columbia River Basalt. The Helvetia Formation has been laterized in places to a deep, red-brown, clayey silt. Although firm when in a dry state, the material from this formation disintegrates to its basic soil constituents when saturated in water or disturbed by construction equipment. The laboratory tests available on random samples give the following range of classifications:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-6 (8) to A-6 (10)	E-6 to E-7	ML to CL

Figure 29. Helvetia Formation standing in vertical cut.

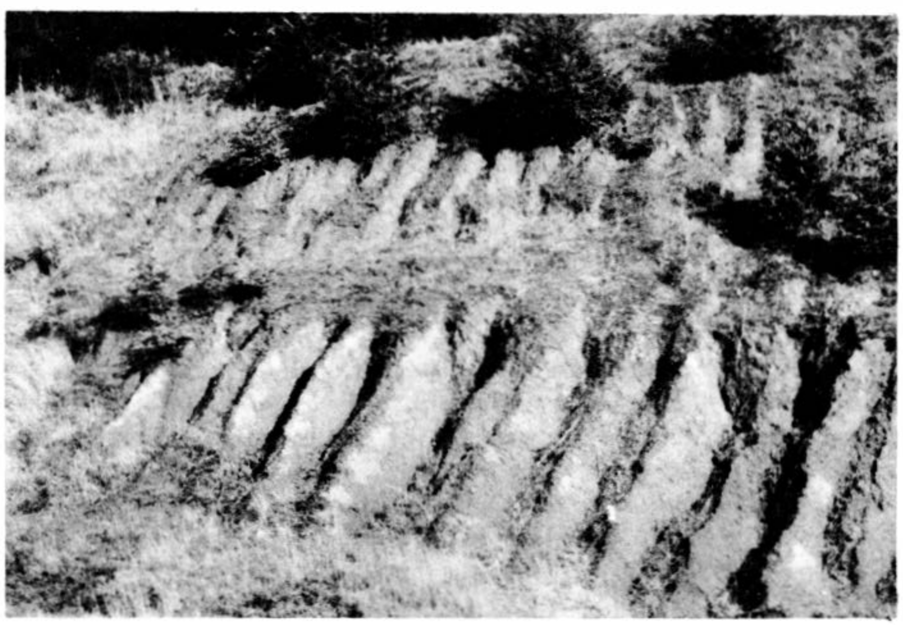


Figure 30. Severe gullying in Helvetia Formation occurs where cut at 1 to $1\frac{1}{2}$ slope.

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu.ft.
74-92	44-69	23-40	35-40	10-16	22-24	102-104

Soil data are insufficient to define adequately the engineering characteristics of this unit because of variations throughout the area. Previous studies have failed to recognize that the Helvetia Formation is separate from laterized basalt; careful examination is needed to identify the two units.

Available tests show that soil from the Helvetia Formation is moderately plastic. Road cuts are stable and will stand vertically to heights of 10 or 15 feet; but in cut slopes of 1 to 1 or 1½ to 1, erosion by gullying is common (figures 29 and 30). The undisturbed material can adequately support light structures. When soil taken from the formation is reworked for embankment construction, a fill of low to moderate compressibility, permeability, and shear strength will result. Although low fills may be constructed without difficulty, very high fills should be undertaken only upon full consideration of the effects of stability and compressibility.

The formation is of low permeability in situ; attempts to dispose of septic tank effluents by tile drain fields may not be successful, particularly for large installations.

Troutdale Formation

The Troutdale Formation is exposed intermittently and slightly above water level in the Willamette River channel between Newberg and the Wilsonville area. It crops out in the deeper stream canyons north of the river from Newberg to east of Wilsonville. It is found in the Tualatin Mountains along the eastern margin of the Tualatin Valley north of Tigard, where it occurs in scattered patches capped in places by Boring Lava. Several small outcrop areas of Troutdale are exposed north and west of Six Corners. The Troutdale occurs at shallow depth beneath the Willamette Silt throughout most of the Tualatin Valley. The depth to the Troutdale is 15 to 30 feet at Beaverton and about 50 feet at Hillsboro and Newberg.

The Troutdale Formation in the map area is predominantly clay, silt, and fine sand, with occasional lenses of gravel. Although the material is somewhat indurated in situ, it breaks down to its particle constituents upon excavation. Laboratory data and classification for the Troutdale Formation soils are as follows:

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
85-97	50-70	18-36	32-62*	10-36*	16-23	103-113

* Isolated samples - LL = 78, Pi = 39 — 105' depth at Hillsboro
LL = 97, Pi = 58 — 128' depth at Hillsboro

These two samples are indicative of variations which can be encountered in the Troutdale Formation.

Classification Based on Selected Test Boring Data

Location (Sec., T., R.)	Depth (Feet)	A.A.S.H.O.	F.A.A.	Unified System	% Natural Moisture
15, 1 S., 1 W.	30	A-6 (9)	E-7	ML	30.4
	35	A-6 (10)	E-7	CL	- -
	38	A-6 (10)	E-7	CL	23.7
	57	A-7-6 (15)	E-7	CL	- -
22, 1 S., 1 W.	3	A-6 (9)	E-7	CL	24
15, 1 S., 1 W.	35	A-6 (9)	E-7	CL	27.2
	45	A-4 (8)	E-6	ML	19.5
	55	A-7-6 (20)	E-10	CH	30
	130	A-5 (10)	E-7	ML	16
20, 3 S., 2 W.	55	A-7-6 (15)	E-8	CH	28
	145	A-7-6 (13)	E-7	CL	33
32, 1 N., 2 W.	60	A-7-6 (20)	E-8	CH	24
	105	A-7-5 (20)	E-11	MH	48
	120	A-7-6 (19)	E-8	CH	41
	129	A-7 (20)	E-12	CH	65

Troutdale soils range from moderately to highly plastic. Penetration tests in the fine, granular material indicate relative densities varying from medium dense to dense. Consistencies of the clays range from firm to stiff, and occasionally brittle, with slickensides. Presence of the impervious Troutdale Formation at very shallow depth beneath the Willamette Silt may prevent satisfactory disposal of effluent from septic tanks.

The Troutdale mudstones can be used for embankment construction under favorable conditions, where strength and compressibility are not critical factors.

The Troutdale Formation is a competent bearing horizon for important structures in which little or no settlement can be tolerated.

Deep borings indicate that the Troutdale will be the foundation for most of the larger engineering structures in many localities in the Tualatin Valley area. In typical boring logs, figure 20, the densities are indicated by Standard Penetration Tests.

Boring Lava

The Boring Lava occurs in scattered outcrops on the western slope of the Tualatin Mountains. Usually, the lava is overlain by varying thicknesses of silt.

The lavas have a wide joint pattern; consequently, weathering produces large residual boulders, many of which are more than 5 feet in diameter. These boulders present special excavation and disposal problems if they occur at or above grade. One solution often used is to dig a hole next to the boulder and bury it on the site. Where the lava is relatively unweathered, excavation may require explosives. This breaks the rock along joints to produce large, unwieldy boulders which call for the employment of heavy equipment for removal.

The Boring Lava generally provides a solid foundation for heavy structures if it occurs at or near the surface. In Cedar Hills, for example, at the east end of the shopping center the Boring Lava occurs 7 to 14 feet below the surface and can be utilized for founding heavy structures.

Few quarries for crushed rock have been developed in the Boring Lava. The quality of Boring rock products is good, but because of the blocky jointing, secondary blasting may make the cost of producing crushed rock prohibitive.

Upland Silt

The upland silt caps the flatter areas above 250 feet elevation on the Tualatin Mountains and on Bull and Cooper Mountains and Chehalem Mountains. It ranges from a foot or so in thickness to a maximum of about 55 feet, and consists primarily of unindurated sandy silt and clayey silt. Soil classifications and available laboratory data for the upland silt are as follows:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-4 (8)	E-6	ML

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
90-94	58-74	17-21	26-32	6-12	16-18	106-109

The upland silt is a nearly homogeneous and structureless material of low plasticity. At low moisture content it is stable, but it is unstable and spongy at moisture contents much above the plastic limit. It has low permeability, is subject to high capillary rise, and therefore is frost susceptible.

The upland silt may be used for support of light to moderate structures by means of spread footings at shallow depth, provided that a small amount of settlement can be tolerated in the structure. Heavy structural loads, or those in which no settlement can be tolerated, cannot be supported in this unit. In many locations, the ground water is able to rise to the surface of the upland silt, thereby seriously weakening heavily stressed foundations and earth slopes. Mud flows and slumps have been observed in many areas where the slope of the ground surface is in the order of 15 to 20 percent. It is apparent that considerable care should be exercised in increasing the stresses within an earth slope either through excavating of the toe or filling at the top. Loss of stability in this soil unit frequently occurs where the upland silt is underlain by bedrock whose surface slopes with the ground contour.

Although it is occasionally possible to construct a septic tank drain field in the upland silt, this formation should be considered as marginal at best for this purpose. Attempts to construct septic tank drain fields for large installations such as schools or shopping centers would, in all probability, meet with serious difficulty.

The material from the upland silt unit can be compacted into fills of moderate strength and compressibility. Construction operations are usually suspended in prolonged periods of wet weather because of difficulty in maintaining the close moisture control necessary to achieve adequate compaction in this material. As a rule, 2 to 3 percentage points above or below optimum moisture content will result either in unsatisfactory compaction or in a completely unworkable fill. Compaction of embankments made from the upland silt can be achieved by routing of loaded hauling equipment, heavy rubber-tired rollers, and sheepsfoot rollers.

Willamette Silt

The Willamette Silt is the most extensive soil occurring in the lowlands and on the sides of the valleys to about 250 feet elevation.

Certain areas in the Willamette Silt contain appreciable amounts of plastic clays, while in other areas the soil is almost entirely silt of low plasticity. Where information was available on the clayey areas, they have been mapped. Areas not mapped as claymay have clay layers and lenses in the subsurface.

The uppermost part of the Willamette Silt has been modified by weathering, leaching, and mixing with organic matter. Deep borings have penetrated clay lenses at variable depths throughout the Willamette Silt. The presence of these clayey soils at or near the surface has a considerable effect on the permeability and affects the engineering aspects of the soil. The clay phase of the unit is discussed later. Classification of Willamette Silt soils and available laboratory data are given as follows:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-4 (8)	E-6	ML

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/Cu. Ft.
80-94	46-61	12-31	23-30	0-6	16-19	103-109

The Willamette Silt soils are fine-grained, sandy, clayey silts having little or no plasticity. The consistency ranges from soft to medium firm. Dry strength ranges from slight to moderate; in the natural state, the silts are relatively weak and moderately compressible.

Willamette Silt can be used as the supporting horizon for light to moderate structural loads for which some settlement can be tolerated. Heavy loads or extremely critical structural loads must be transferred to more competent formations beneath the Willamette Silt by means of piers or piling.

Disposal of effluents from septic tanks of single-family dwelling units is possible in the Willamette Silt where not precluded by the presence of a high ground-water table during the winter months. In areas where the ground-water table rises to or near the surface, or in cases where a large quantity of effluent is to be discharged as for a school or shopping center, conventional septic tank and drainfield construction may not be feasible.

The Willamette Silt can be used as embankment material for projects in which a fill of moderate strength and moderate compressibility is acceptable. Particular difficulties may be encountered in constructing embankments from this material when the natural water content exceeds the optimum moisture content by more than 2 or 3 percent. The moisture content may be reduced to an acceptable percentage in favorable weather by aeration. Compaction of this material can be accomplished by routing of loaded hauling units, rubber-tired rollers, or sheepsfoot rollers.

Willamette Silt clay phase

The clay phase of the Willamette Silt has developed principally in areas of poor drainage. Soils of this phase have moderate to high plastic and liquid limits. Dry strength is moderate to high; in-situ strength is low to moderate.

Soil classification and available laboratory data on the clay phase are as follows:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-7-6 (16)	E-7	CL

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
77-96	36-59	24-47	34-46	11-27	19-26	102-105

The clay phase of the Willamette Silt can be used as a supporting horizon for extremely light structures in which some settlement can be tolerated. The time rate of settlement is restricted by the escape of pore water through the comparatively impervious soil structure; consequently, settlement of a given structure may be protracted over a considerable period of time, depending on size of loaded area, thickness of clay, and drainage layers within the clay.

Disposal of sanitary effluent in the clay is at best marginal and generally not possible for schools or shopping centers.

Where no other soils are available, the clay may be used in embankment construction; however, this should be attempted only where a compressible embankment is acceptable, and during dry weather. Compaction of the clay may be accomplished by routing of loaded hauling equipment, rubber-tired rollers, or sheepsfoot rollers.

Lacustrine Deposits

The lacustrine deposits of sand and gravel are of principal interest as sources for aggregate and select borrow materials. The gravel deposits at Durham and Wilsonville have been utilized extensively for road construction. Gravel deposits near Cipole have not been exploited at this date. The sand phase of the lacustrine deposits has been used extensively for high-quality fill materials.

Soils developed on both the sand and gravel phases have high permeabilities. The gravels are dense and will support heavy building loads with minor settlement. Standard Penetration Tests conducted in these sands at a site south of Tualatin indicate that the sands are predominantly medium dense but that they range locally from loose to dense.

These materials are particularly valuable as borrow for site preparation in projects located on less favorable formations. Properly compacted and controlled embankments may be used to support very heavy structures without harmful settlement, provided that adequate steps are taken to guard against settlement of the supporting soil formation. Compaction of these materials may be achieved by routing of loaded hauling units, rubber-tired rollers, or vibratory rollers. The best units of the formation may be worked in all kinds of weather.

Young Alluvium

The youngest materials in the area are those being deposited by the present-day streams along their channels and on the adjacent flood plains. These deposits are variable and include granular, non-plastic soils, plastic clay soils, and highly compressible organic clays. These units have been indicated on the geologic map by separate patterns.

The modern stream channels transgress the older soils and bedrock. The young alluvium overlying the older soils and bedrock is usually not more than 30 feet thick. In some instances these soils may be stratified and have clay, organic soil, and silt in a vertical section.

Silt phase

Soil classification and laboratory data for the silt phase of the young alluvium are as follows:

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-4 (8)	E-6	ML

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
82-95	44-74	8-32	24-32	0-8	17-32	99-109

The silt-phase soils are fine grained, with little or no plasticity. The soils have a consistency ranging from very soft to soft. Dry strength ranges from low to moderate; in situ the soils are weak and moderately compressible.

Heavy structural loads or light loads which can tolerate little or no settlement should not be placed on this material. Piling or piers can usually be used to transmit the loads for such engineering structures to the more competent underlying Troutdale Formation.

The high ground-water table, which exists during much of the year at the low elevations, occupied by these soils precludes the disposal of effluents from septic tanks.

The young alluvium should not be used in embankments except as a last resort and only where low strength and moderate to high compressibility can be tolerated. The saturated condition of the young alluvium poses special problems in reducing the moisture content to the required optimum.

Clay phase

The clay-phase soils occur in poorly drained areas within the stream channels and recent flood plains. Classification and laboratory data are given on the following page.

Soil Classifications

A.A.S.H.O.	F.A.A.	Unified System
A-7-6 (10), A-7-6 (17)	E-7, E-8	CH, CL

Laboratory Data Summary

Gradation			Atterburg Limits		Proctor Density (Harvard Miniature)	
% Passing 200	% Silt	% Clay	Liquid Limit	Plasticity Index	Optimum Moisture	Dry Density Lb/cu. ft.
92-96	36-71	25-46	40-53	14-27	20-25	97-104

The recent clay soils have moderate plasticity and moderate-to-high liquid limits. They have moderate-to-high dry strengths; in the natural state the strength is low to very low. As foundation material these soils can be used to support only very light structures and some settlement can be expected. Since the material has high compressibility and is practically impervious, settlement can take place over a long period of time. Embankments may be constructed from this soil only during the dry season and if compressibility can be tolerated. Compaction can be accomplished by sheepsfoot rollers and equipment traffic.

Disposal of effluents from septic tanks is generally not practical because of low permeability and high ground-water table.

Geologic Hazards

Geologic hazards are considered here as earth problems which have special significance to man and his building activities. In the study area the problems include landslides and unstable slopes, near-surface ground water, annual or cyclic floods, soft and highly compressible organic soils, and saline ground water. An assessment is also made of earthquake history and areas which may be particularly sensitive to damage of structures from seismic ground motion. The location of these particular problem areas is shown on the geologic hazards map (plate 3).

Landslides and Unstable Slopes

Major landslides are located primarily in the southwest portion of the map in areas of relatively steep topography underlain by marine sedimentary rocks. Most of the slides have occurred on sides of stream valleys where the fine-grained phases of the marine rocks have been deeply weathered and slopes oversteepened by erosion (figures 31 and 32). Because all of these landslides have moved under natural circumstances, they emphasize the precarious condition of slopes in this area. Man-made changes in moisture conditions and slope declivities may reactivate old landslides or create new ones (figures 33 and 34).

Significant slope failure has occurred locally on the southwest flank of the Chehalem Mountains, and a few small areas of landslides are present in the Red Hills of Dundee, on Parrett Mountain, and in the Tualatin Mountains. Numerous landslides have taken place in the densely populated part of the Tualatin Mountains east of the map area where upland silt and residual clay soils have failed through oversteepening of slopes and removal of lateral support. Similar soil conditions are present in the Tualatin Mountains of the map area and with increased population slope failure may also be anticipated unless precaution is taken (Schlicker, 1956). The Chehalem Mountains likewise contain silt and clay soils above the Columbia River Basalt which may be subject to slope failure if hillsides are artificially oversteepened.

Numerous landslides have occurred on steep slopes adjacent to the Willamette River, but they are too small to be shown on the map in true scale. Most landslides in the banks of the river have occurred as a result of undercutting of slopes.

Near-surface Ground Water

Ground water occurs at near-surface elevations over a large part of the Tualatin Valley as indicated on the map (plate 3). In several areas, such as in the vicinity of Hillsboro, Aloha, and Forest Grove, ground water rises to surface elevations. Hydrographs (figure 35) show the annual variation in the ground-water table in several wells in the Tualatin Valley. The near-surface ground-water table requires that special precaution be taken to protect basements of houses and other buildings from water infiltration. Either the basement floor slab must be designed to withstand hydrostatic uplift pressures, or water levels must be controlled. Hydrostatic uplift can also produce damage in swimming pools unless water is retained in the pools during the high ground-water season or unless the structure is designed to withstand uplift pressures. Within the high ground-water areas, it should be anticipated that any shallow excavation will encounter ground water and special precautions may be required to protect excavated slopes.

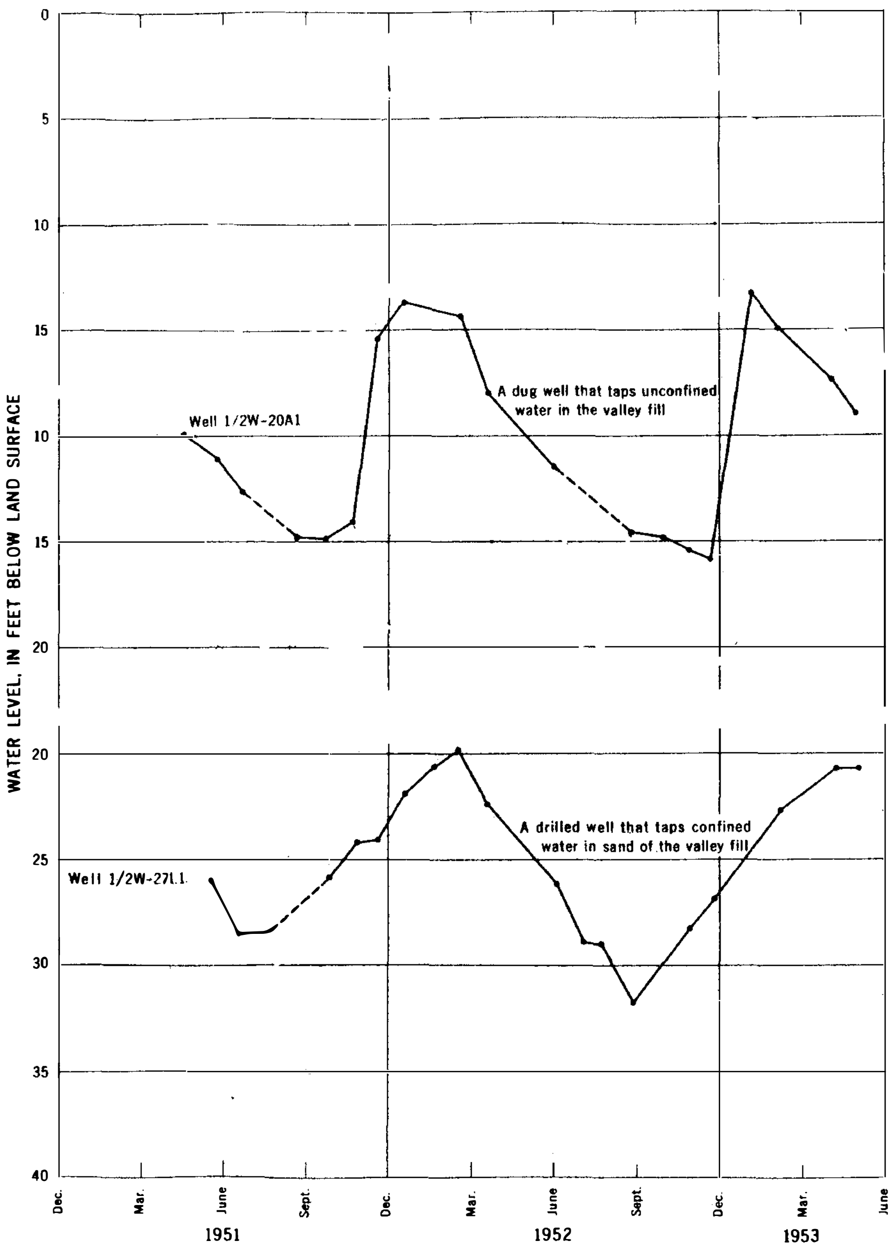
The high ground-water table of the Tualatin Valley is a particularly annoying hazard to septic

Figure 31. Slump topography on Patton Valley northwest of Gaston.

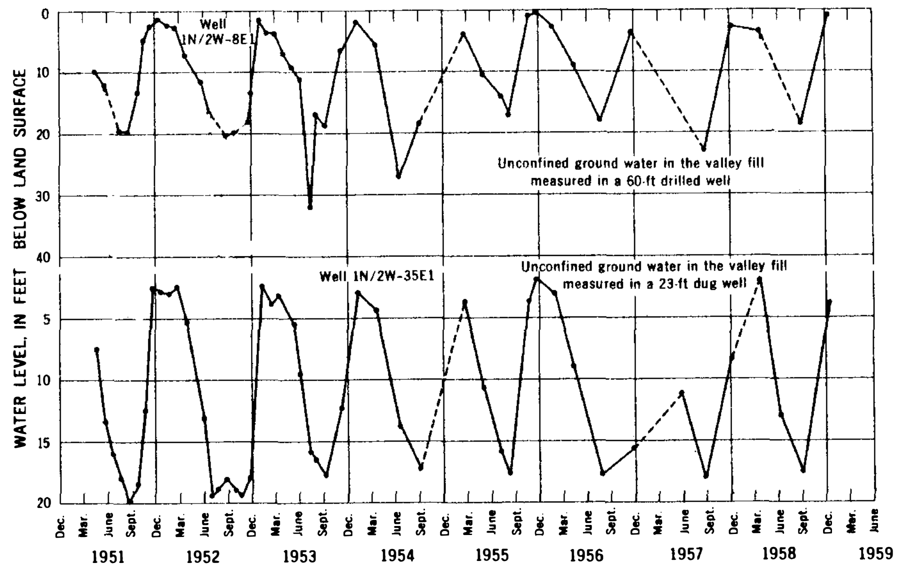
Figure 32. Slump topography in Yamhill Formation west of Stimson mill on Scoggin Creek.

Figure 33. Landslide in weathered Oligocene rocks at reservoir west of Dilley is due partly to excavation of material from edge of reservoir and partly to fluctuation in reservoir level.

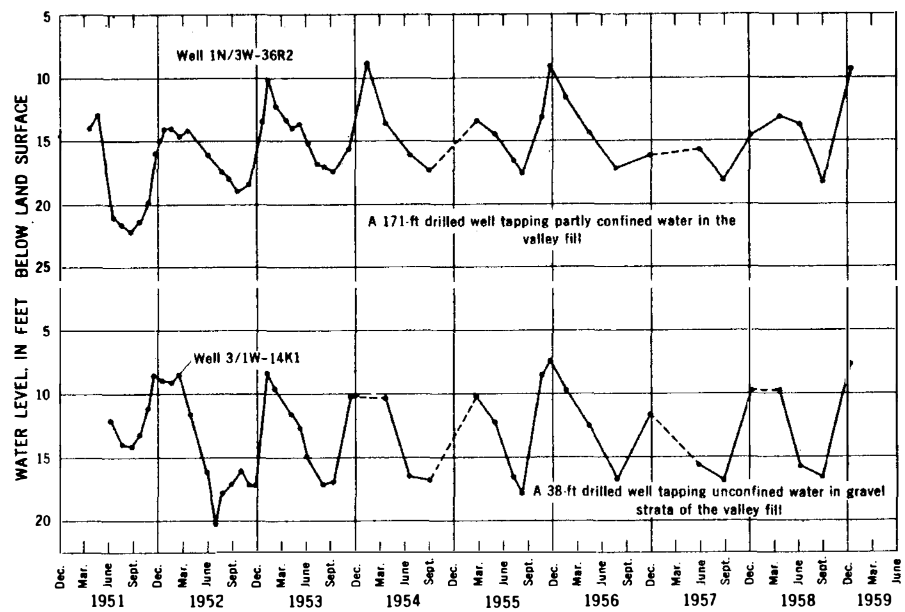
Figure 34. Landslide in Oligocene sediments west of Forest Grove.



Graphs of water levels measured in four wells showing seasonal recharge.

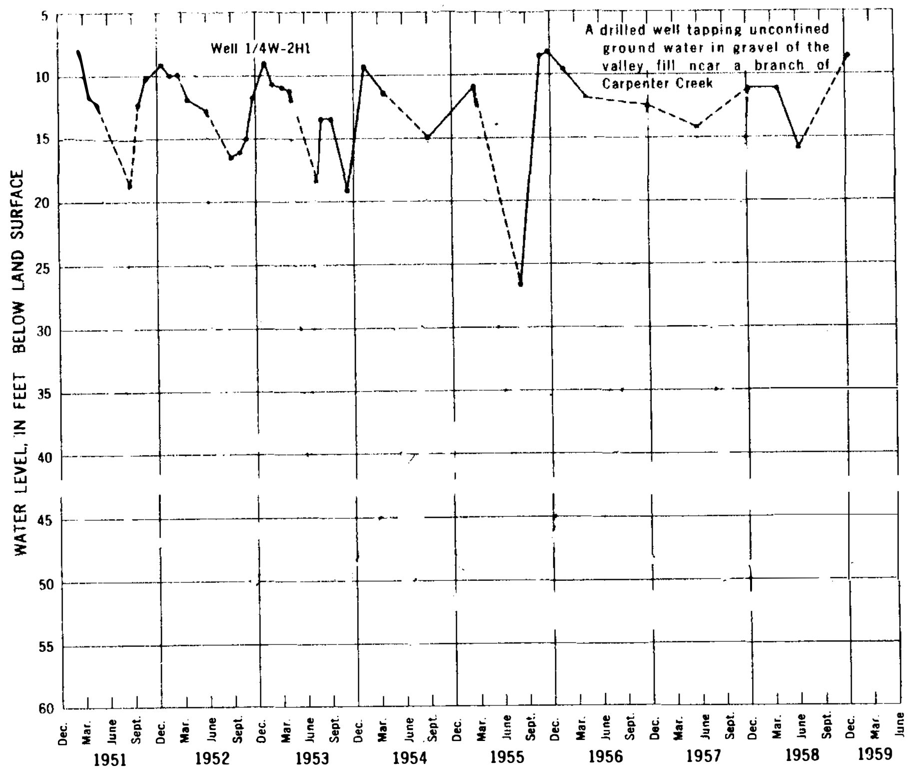


Graphs of water levels in two wells tapping water in the valley fill, showing effects of seasonal recharge.

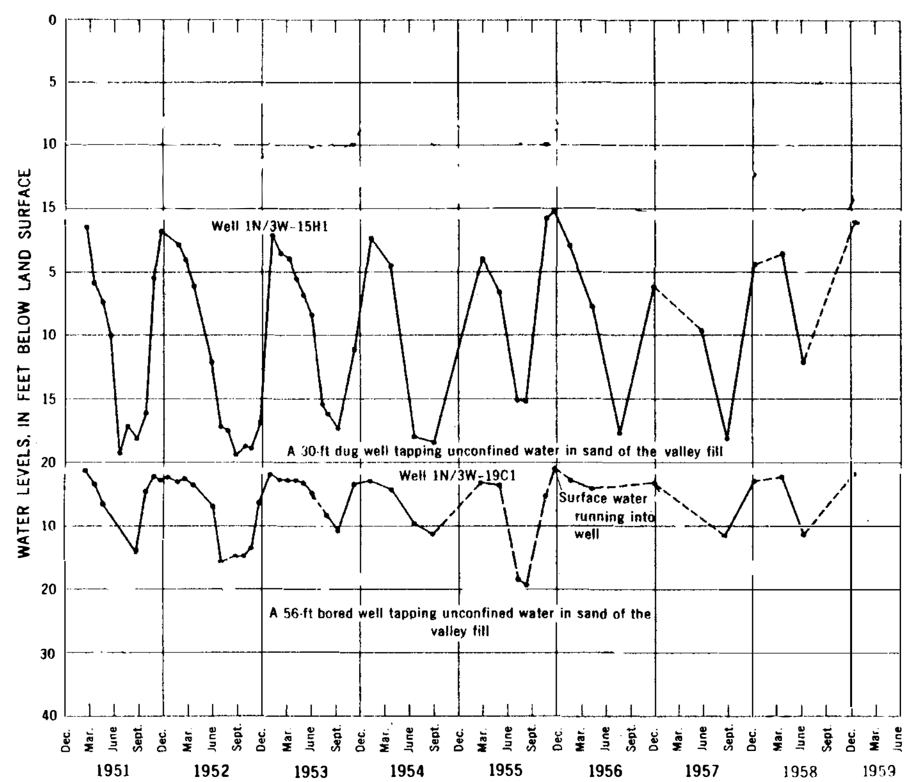


Graphs of water levels measured in two wells, showing annual variations in the amount of seasonal recharge.

Figure 35. Hydrographs of ground-water levels in the Tualatin Valley (adapted from Hart and Newcomb, 1965).



Graphs of levels of ground water in two wells, showing seasonal fluctuations.



Graphs showing the magnitude and timing of seasonal recharge.

Figure 35 (continued). Hydrographs of ground-water levels in the Tualatin Valley (adapted from Hart and Newcomb, 1965).

Figure 36. Willamette River during the December 1964 flood. Newberg and Bald Peak in the distance.

tank drainage. Either the entire system will simply fail to function and will back up into feeder lines, or the effluent will break out to the ground surface and escape above ground. In either case, the condition is unpleasant and potentially dangerous.

Ground-water data are incomplete for the Yamhill, Newberg, and Wilsonville valleys. Present information indicates that these valleys are also subject to high ground-water conditions, particularly during flood periods when river levels approach ground surface elevations.

Flooding

Flooding occurs in the Willamette Basin primarily during winter months. It is caused by high discharge rates of streams flowing from the Cascade Mountains and Coast Range into the flat valley areas which are already fully saturated with water. The sinuous and meandering courses of major streams temporarily detain sudden runoff and flooding results. In the Tualatin Valley system the Tualatin River and its major tributaries, which originate in the Coast Range to the west of the map area, discharge their high-velocity runoff near Gaston and Forest Grove. The river then follows an approximately 45-mile, meandering channel which descends only 20 feet before meeting a bedrock reef 4 miles north of the town of Willamette (east of the map area), where it drops 40 feet in 4 miles and empties into the Willamette River. Seida (1965) discusses the nature of the flood problem on the Tualatin River: "The adverse effects of flooding upon the social and economic well-being of the people in the Tualatin Valley basin have long been a matter of much concern. During the past 50 years flood damage has increased greatly in the Tualatin Valley; however, one must not be misled by the fact that increased flooding is due to climatological changes. Rather, the increased magnitude of flood damage is primarily the result of unimpeded encroachments by man upon the flood plains of the Tualatin Valley streams."

In December 1964 and January 1965, major floods occurred in all stream courses of the project area. The Willamette River experienced what is considered to be a "100-year flood" (figures 36, 37, and 38) (U.S. Corps of Engineers, July 1966) and the Yamhill River and the Tualatin and its tributaries a "50-year flood." The Tualatin River and tributaries and the Yamhill River experience some flooding on an annual basis, but not to the extent of the major flood periods (plate 3).

The hazards map shows limits of the December 1964 flood in major stream courses where information was available, and also the flood limits in the Tualatin River and tributaries during a similar major flood which occurred in December of 1933. Records also indicate that major floods occurred in the Tualatin Valley (U.S. Corps of Engineers, 1953) in February 1890, November 1904, January 1905,

Figure 37. Willamette River west of Wilsonville during the 1964 flood. Champoeg State Park at first sharp bend in river.

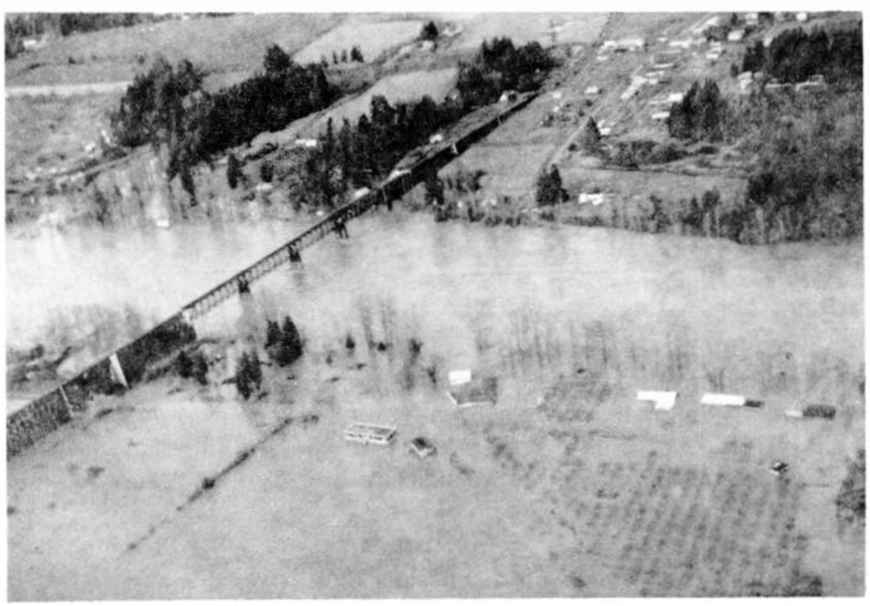


Figure 38. South bank of Willamette River at Wilsonville during 1964 flood.

January 1914, and December 1937, which were smaller than the 1933 flood. In the lower Willamette River basin (Oregon State Water Resources Board, June 1965) an average of one and a half to two floods takes place in a given season, with severe floods occurring on the average of about once in 10 years. Basin-wide floods on the Willamette River occurred in 1890, 1923, 1945, and in December 1964.

Seven upstream reservoirs in the Willamette River system provide 1,200,000 acre-feet of storage and three more under construction will bring upstream reservoir capacity up to 2,000,000 acre-feet of flood-control space. This is almost 70 percent more than was available in December 1964, when the flood inundated more than 600 square miles in the entire Willamette Basin (U.S. Corps of Engineers, 1966).

The U.S. Corps of Engineers (1953) prepared a report on water resource development in the Tualatin River basin. The report recommended channel changes in the Tualatin River and upstream storage reservoir dams on the river above Gaston and on Gales Creek and McKay Creek. The U. S. Bureau of Reclamation (1955) made studies for a dam on Scoggin Creek, which was subsequently authorized. Funds for construction have not yet been made available. In a recent news report, the U.S. Department of Agriculture, Soil Conservation Service, announced that funds had been authorized for final studies and construction for dams at McKay Creek and Rock Creek. Construction for these dams is scheduled for 1967.

Areas of Soft and Compressible Clay and Organic Soils

These areas have been shown on the hazards map by special patterns for each soil type. Soft and compressible clay soils are found primarily within flood plains of the major stream courses and in several localities within the Willamette Silt. Organic soils with significant areal extent occur exclusively in areas of young alluvium and are found at several localities within the flood plains of the Tualatin River and its northern tributaries, at Wapato Lake, and in the Carlton Lake area of the Yamhill River.

Soft and compressible clay and organic soils represent hazards to certain types of construction. Since these soils are generally located within flood plains of streams and not where building is likely to occur, construction problems are primarily associated with placement of road embankments. Special embankment design and construction procedure must be adopted in order to place roads successfully across these areas.

Clayey soils developed on the surface of the Willamette Silt present special design problems for buildings with heavy loads and particularly difficult problems in the operation of septic tanks, because of poor drainage.

Saline Ground Water

A number of wells drilled in the Troutdale Formation and Columbia River Basalt in the Tualatin and Newberg valleys have encountered water containing high concentrations of calcium chloride and sodium chloride. Wells drilled in marine sedimentary rocks in the southwest portion of the map area commonly encounter saline ground water. Locations of salt-water wells are shown on the hazards map, plate 3.

The occurrence of salt water in the Tualatin and Newberg valleys is not completely understood, but since marine sedimentary rocks containing connate saline waters underlie each of the basins it is assumed that saline waters have migrated upward to the younger rocks through the pore, fracture, and joint systems. Wells yielding salt water in the Tualatin Valley can generally be associated with steep flexures in the Columbia River Basalt, which probably indicates faulting. In some cases salt-water wells are found along trends of faulting mapped in surface exposures. Hart and Newcomb (1965) discuss several ways in which saline waters may have entered Troutdale and Columbia River Basalt aquifers. Saline waters obtained in wells drilled into marine sedimentary rocks are from indigenous connate aquifers within the marine sequence.

Earthquake Probability

Oregon is a tectonically active state within the circum-Pacific belt of crustal instability, in company with California, Washington, British Columbia, and Alaska. All of the states and provinces which border the Pacific Ocean have received violent earthquake shocks in recent years. Oregon has received fewer earthquakes than either of the neighboring states but the total, and particularly of those recorded in the Portland area, is impressive. Since 1841, the state has experienced 167 earthquakes ranging from Mercalli intensities II to VII and 47 of these quakes were centered in the Portland vicinity. A list of earthquakes whose epicenters were located in and around Portland is shown in Table 2.

Earthquakes are caused primarily by deep-seated movements in the earth's crust which generally can be associated with the surface expression of major fault systems. In some cases, such as the San Andreas system in California, earthquake movement is expressed in surface displacement of soil and rock and in offsetting of roads, streams, and buildings. Recent studies of the November 5, 1962, earthquake at Portland by Dehlinger and Berg (1962); by W. H. Westphal (1962); and by Dehlinger, Bowen, Chiburis, and Westphal (1963) indicate that the earthquake was probably associated with a major fault which parallels the northeast flank of the Tualatin Mountains. The earthquake was assigned a Mercalli rating of VII (see map at end of earthquake discussion). No terrain effects such as ground displacement or landslides were noted.

The geologic structure of the project area includes several other major faults, in addition to the one on the northeast flank of the Tualatin Mountains, which could provide the locus for propagation of earthquake seismic waves. Major faults occur on the flanks of the Coast Range in the valleys of Gales Creek, Carpenter Creek, Scoggin Creek, and across the Tualatin Valley west of Gaston. A

Table 2. Earthquakes with Epicenters in the Portland Vicinity, 1846-1963.

Year	Epicenter	Mercoli Intensity	Year	Epicenter	Mercoli Intensity
1846	Oregon City		1921	Portland	II-III
1877	Cascades	VIII	1921	Portland	IV
1877	Portland	III	1922	Portland	IV
1879	Portland	IV	1930	Perrydale	III
1883	Portland		1930	Perrydale	VI
1884	Portland	IV	1932	Portland	IV
1885	Portland	II-III	1933	Portland	III
1891	Salem	IV	1937	Dallas	IV
1892	Portland	VI	1939	Portland	III
1892	Oregon City		1939	Portland	III
1896	McMinnville	VI	1941	Portland	III
1897	Forest Grove	III	1941	Tigard	IV
1898	Portland	IV	1941	Portland	VI
1898	Portland	III	1942	Portland	V
1904	Portland	IV	1951	Portland	II
1904	Portland		1953	Portland	VI
1904	Portland		1954	Canby	
1904	Portland		1954	Portland	IV
1907	Portland	III	1957	Salem	VI
1909	Portland		1957	Portland	III
1910	Portland		1958	Portland	II
1910	Portland	IV	1958	Gresham	III
1910	Portland	6.8 mag.	1959	Portland	III
1914	Portland	IV	1961	Albany	III-IV
1914	Portland	III	1961	Portland	V
1915	Portland	V	1961	Portland	IV
1918	Portland	III	1961	Scappoose	III
1920	Portland	III	1962	Portland	VII
			1963	Portland	V

major fault with a possible 50-mile northeast-southwest trend separates Parrett Mountain and the Chehalem Mountains.

The relationship between earthquake damage and geology in Portland and vicinity east of the map area is discussed by Schlicker and others (1964). Since many of the same geologic units are present within the area of this study, some general comparisons may be made. Schlicker and others (1964) describe five of the most important types of reactions a geologic formation experiences in earthquake vibrations. These include: (1) elastic, (2) fluid, (3) brittle, (4) viscous or visco-elastic, and (5) granular.

In the project area, geologic units are present that will respond to each of the major types.

Elastic response

Elastic response to vibrations occurs in bedrock formations in which damping does not play an important part and in which the component particles maintain the same relative position. Geologic units which may be expected to respond elastically to earthquake ground motion include the undifferentiated Eocene volcanics and sediments, marine sediments of the Yamhill and Spencer Formations, Oligocene marine sediments, Columbia River Basalt, Boring Lava, and probably the semiconsolidated Troutdale and Helvetia Formations. These formations constitute the bedrock units of the area and are generally considered as "good ground." Reports on previous earthquakes in this and other areas indicate that structures founded in bedrock are not severely disturbed by quakes whose epicenters are more than 50 miles distant. In the event of an extremely violent earthquake in the near vicinity, however, the maximum lateral accelerations may be unleashed on structures founded on competent bedrock.

Fluid response

Fluid-reacting formations are those which undergo a total loss of strength upon repeated application of forces. Examples of fluid reaction in the Alaska Good Friday earthquake, March 27, 1964, include the Turnagain slide and the slide at the Seward waterfront. Soils which are capable of fluid response are usually saturated and range in texture from clay to coarse sand and gravel. Formations in the study area which may be expected to respond in a fluid manner to earthquake vibrations include all of the unconsolidated deposits of the valleys and, if saturated, the upland silt. If a liquified soil is confined laterally in all directions the structures may simply sink into it; if it is not confined, then the soil may flow toward the unconfined side in a mass movement.

Brittle response

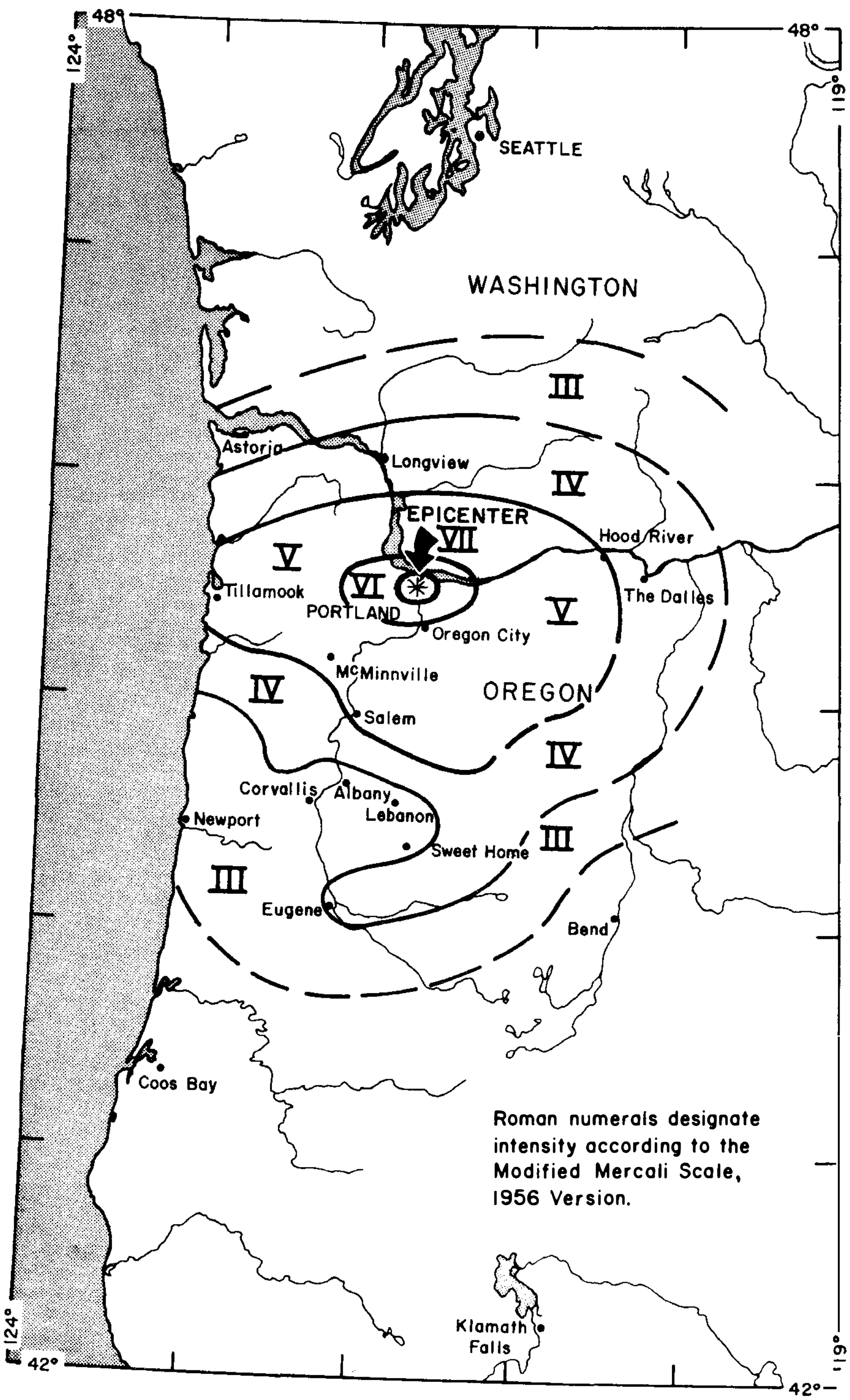
Brittle response occurs where relatively competent units occupy precarious positions on hillsides or mountain tops and are detached during ground motion. Ordinarily the masses of material detached are of small magnitude, but velocities can be great and potential damage high if structures are located at lower elevations than detached masses. Units in the project area which have potential for brittle response include the Helvetia Formation, upland loessal silt, marine bedrock units, and deeplyweathered areas of the Columbia River Basalt. In all instances the danger is the greater where permanently high shear stresses are present because of steep slopes, as in the case of high, vertical cliffs of bedrock.

Viscous or visco-elastic response

This type of earthquake response is characteristic of masses of cohesive materials having the following general properties: (1) low mobility of pore water; (2) ability to deform plastically under shear stresses of low to moderate order; (3) inability to undergo sudden changes in volume; and (4) a "rubber-like" response to dynamic loads. Most existing landslide areas in which earth movements have been in more or less continuous progress for many years will exhibit a viscous or visco-elastic response to earthquake stresses. Geologic units in the map area which may respond to this type of action include the clay phases of the Willamette Silt and young alluvium of the valley area, the landslides which are composed of cohesive soils, and possibly fine-grained phases of the Troutdale Formation.

Granular response

Geologic units which may respond in this way to earthquake vibrations include thick beds of loose, cohesionless soils which tend to densify under vibratory loading. Structures founded in these soils are subject to damage principally by differential settlement. Geologic units in the map area which may be susceptible to a granular response include the sands and gravels of the lacustrine deposits and the granular phases of soils in the flood plains of the major stream courses.



Isoseismal Map of the Portland Earthquake November 5, 1962.

Reprinted from Dehlinger and Berg, 1962

Construction Materials

Crushed basalt, gravel, and sand used in portland cement concrete, in asphaltic concrete, and for rock base and fill material are produced from quarries and gravel pits in the map area. Most of the sand and gravel used in the Tualatin Valley, however, comes from the Portland metropolitan area to the east.

The location of operating and non-operating quarries and gravel pits are shown on the geologic map by symbols and numbers. The numbers correspond to those in table 3, which lists the quarries and gravel pits. Some areas that are considered as prospects for basalt quarries are also indicated on the map. The prospect areas listed have been determined by Oregon State Highway Department geologists through combinations of geologic surface inspection, bulldozer trenching, and in some cases by subsurface investigations by core drilling. Table 4 shows test results of rock from a number of quarries and gravel pits located throughout the project area.

Basalt

Basalt is quarried from sills, dikes, and lava flows ranging in age from Eocene through Pliocene. The most desirable rock quarried for crushing is the Columbia River Basalt. It is the most extensive lava sequence in the map area. The rock is commonly weathered and vesicular at the top of flows, but it is dense and of good quality between the weathered zones. The rock crushes cleanly because of its brittleness and close jointing. Laboratory tests of the Columbia River Basalt are shown in table 4. Some of the typical quarries in Columbia River Basalt are shown in figures 39, 40, 41, 42, and 43. Quarries in Boring Lava are limited in extent within the mapped area and therefore are of minor consequence.

Eocene volcanics and sediments in the western part of the map area include basaltic lava flows, interbedded pillow basalt, and breccia indicative of extrusion in a marine environment. These rocks can be extremely variable in quality, with excellent rock containing pods of extremely poor rock. Quarrying must be selective in order to produce good quality rock (figure 44). Thick overburden usually limits the extent to which a deposit can be utilized.

Several quarries have been developed in basaltic dikes and sills which intrude the Yamhill Formation and Oligocene sediments in the southwest portion of the map area. The rock bodies are generally of limited size, and overburden can be a significant deterrent factor as quarry operations proceed into a hillside.

Dikes and sills composed of blocky, coarse-grained gabbro intrude Eocene volcanics and sediments. Blasting produces a high percentage of large blocks which make crushing difficult and expensive. High abrasion in some of the rock makes it unsatisfactory for road metal.

The intrusive rocks in the map area generally have considerable overburden. Most of the quarries are small and are not economical for commercial operations. They have had utility in the past and may have value in the future for use in a specific local project where large quantities of rock are not required and where hauling costs can be reduced.

Sand and Gravel

Sand and gravel deposits of commercial significance are located at Durham, Wilsonville, in the

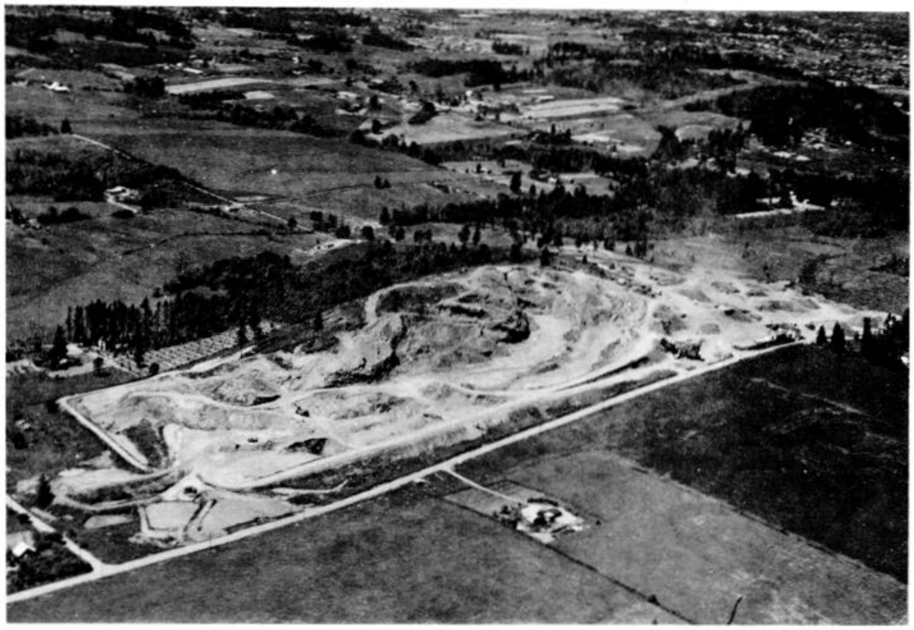


Figure 39. Cobb quarry in Columbia River Basalt at Sexton Mountain south of Beaverton.

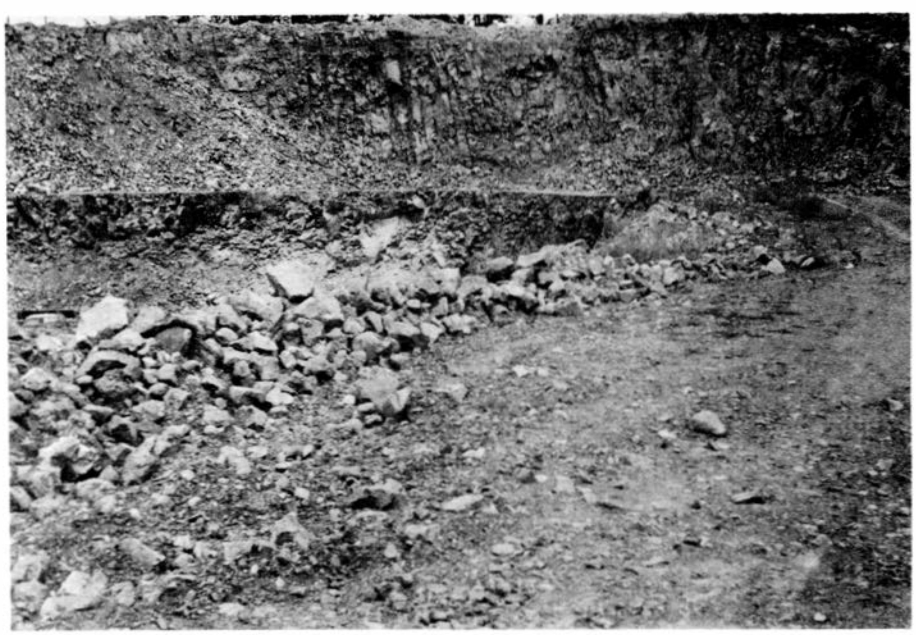


Figure 40. Beaverton quarry on Cooper Mountain. Columbia River Basalt shows columnar and cubic jointing.

Figure 41. Krueger quarry in Columbia River Basalt. Layer of blocky-jointed basalt overlies cubic-jointed basalt.

Figure 42. Aerial view of Baker and Quality Rock Products quarries on Cooper Mountain.

Figure 43. Baker quarry in Columbia River Basalt on Cooper Mountain.

Figure 44. Vanaken quarry on Carpenter Creek in variably jointed basalt of Eocene age.

Table 3. Rock Quarries and Sand and Gravel Pits

1. Alecs Butte Prospect: SE$\frac{1}{4}$ sec. 9, T. 3 S., R. 4 W., and NW$\frac{1}{4}$ sec. 15, T. 3 S., R. 4 W.
A poorly exposed intrusion of fresh, dense basalt, possibly a dike. Needs more prospecting to determine quantities and feasibility of quarrying.

* 2. Baker Quarry: Center N$\frac{1}{2}$ sec. 26, T. 1 S., R. 2 W.
Commercial quarry in Columbia River Basalt.

3. Baker Tualatin Quarry: SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 2, T. 3 S., R. 1 W.
Commercial quarry in Columbia River Basalt.

4. Bald Peak Quarries: SE$\frac{1}{4}$ sec. 26, T. 2 S., R. 3 W., and
5. NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 31, T. 2 S., R. 2 W.
Abandoned quarries located on south scarp of Chehalem Mountains along Bald Peak Road in Columbia River Basalt.

6. Barnford Quarry: NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 16, T. 1 N., R. 4 W.
Abandoned quarry in Columbia River Basalt.

* 7. Bearce Quarry: SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 6, T. 3 S., R. 2 W.
Small roadside quarry in Columbia River Basalt. Basalt resting on tuffaceous marine shales.

* 8. Beaverton Quarry: SE$\frac{1}{4}$ sec. 26, T. 1 S., R. 2 W.
Commercial quarry operated by L. C. Cobb. Rock is Columbia River Basalt.

9. Beef Bend Quarry: SE$\frac{1}{4}$ sec. 9, T. 2 S., R. 1 W.
Abandoned quarry adjacent to Beef Bend Road, in Columbia River Basalt.

10. Berger Quarry: NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 7, T. 1 N., R. 1 W.
Abandoned quarry in Columbia River Basalt.

*11. Burkhalter Quarry: NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 30, T. 1 S., R. 2 W.
Abandoned quarry in Columbia River Basalt adjacent to Burkhalter Road.

12. Cedar Hills Quarry Prospect: SW$\frac{1}{4}$ sec. 27, T. 1 N., R. 1 W.
Basalt outcrop prospect in Boring Lava. Willamette Silt overlies Boring Lavas on flatter areas.

13. Chehalem Creek Quarry: SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 2 S., R. 3 W.
Abandoned quarry in fine-grained basalt intrusive.

14. Cherry Grove Quarry: NE corner sec. 36, T. 1 S., R. 5 W.
Abandoned quarry in basalt intruding Eocene marine sediments. Quantity small, quality of rock questionable.

15. Cipole Sand Pit: SE$\frac{1}{4}$ sec. 21, T. 2 S., R. 1 W.
Abandoned pit in lacustrine sand.

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* Laboratory data in Table 4.

Table 3. Rock Quarries and Sand and Gravel Pits, Continued

*16. Cobb Quarry: SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 29, T. 1 S., R. 1 W.
Commercial quarry on Sexton Mountain, in Columbia River Basalt.

17. Crabtree Quarry: SE$\frac{1}{4}$ sec. 28, T. 3 S., R. 3 W.
Commercial quarry in Columbia River Basalt.

18. Cutbank Quarry Prospect: NW$\frac{1}{4}$ sec. 22, T. 1 S., R. 1 W.
Quarry prospect in Columbia River Basalt outcrop.

19. Daniels Quarry Prospect: SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 3, T. 1 S., R. 1 W.
Quarry prospect in Boring Lava outcrop.

20. Dober Quarry Prospect: NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 34, T. 1 S., R. 3 W.
Columbia River Basalt outcrop.

*21. Dugdale Quarry Prospect: SE$\frac{1}{4}$ sec. 36, T. 2 N., R. 5 W.
Quarry prospect in sill-like body intruding Oligocene marine sediments.

22. Elliot Quarry: NW. corner sec. 10, T. 1 S., R. 4 W.
No information.

23. Ewing Young Marker Abandoned Quarry: NW$\frac{1}{4}$ sec. 15, T. 3 S., R. 3 W.
Columbia River Basalt quarry.

*24. Fuegy Quarry: NE. corner sec. 12, T. 1 N., R. 2 W.
Abandoned quarry in Columbia River Basalt.

*25. Gales Creek Gravels: NW$\frac{1}{4}$ sec. 8, T. 1 N., R. 4 W.
Gravels 6 to 10 feet thick overlying marine sediments in Gales Creek valley.

26. Garrish Valley Abandoned Quarry: NE$\frac{1}{4}$ sec. 19, T. 2 S., R. 4 W.
Altered basalt of questionable quality. Probably flow or sill.

*27. Groner Quarry: SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 2, T. 2 S., R. 2 W.
Abandoned quarry in Columbia River Basalt.

28. Gun Club Prospect: Center of sec. 33, T. 2 S., R. 1 W.
Columbia River Basalt in channel of Rock Creek.

*29. Herget Quarry: NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 20, T. 1 S., R. 3 W.
Columbia River Basalt. Considerable overburden of red weathered basalt and silt.

30. Hess Creek Quarry: SE$\frac{1}{4}$ sec. 27, T. 3 S., R. 3 W.
Commercial quarry in Columbia River Basalt.

31. Hill Prospect: NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 2, T. 1 N., R. 2 W.
Columbia River Basalt.

32. Huffman Quarry Prospect: SW$\frac{1}{4}$ sec. 35, T. 2 S., R. 3 W.
Columbia River Basalt above Oligocene marine sediments.

Table 3. Rock Quarries and Sand and Gravel Pits, Continued

33. Hutchinson Quarry: SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 3 S., R. 2 W.
Columbia River Basalt exposed in hill surrounded by alluvium.

*34. Jackson Creek Quarry: NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 33, T. 2 N., R. 2 W.
County quarry in Columbia River Basalt.

*35. James Gravel Pit: SE$\frac{1}{4}$ sec. 5, T. 1 N., R. 4 W.
Gravel 8 to 10 feet thick overlying marine sediments in Gales Creek valley.

36. James Quarry Prospect: SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 1, T. 1 N., R. 2 W.
Columbia River Basalt outcrop.

37. Johnson Quarry Prospect: SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 23, T. 1 S., R. 3 W.
Columbia River Basalt outcrop.

*38. Kinton Quarry: Center NE$\frac{1}{4}$ sec. 5, T. 2 S., R. 1 W.
Large quarry face of Columbia River Basalt exposed on Scholls Ferry Road.

39. Krueger Quarry: SE$\frac{1}{4}$ sec. 36, T. 2 N., R. 2 W.
State-owned quarry in Columbia River Basalt.
Quarry has zones of poor rock.

*40. Kuhns Quarry Prospect: SE$\frac{1}{4}$ sec. 5, T. 3 S., R. 2 W.
Near Oliver Springs. Columbia River Basalt.

41. Lambert Quarry Prospect: NW$\frac{1}{4}$ sec. 31, T. 3 S., R. 4 W.
Basalt sill in Eocene marine sediments. Prospected by Oregon State Highway Department with test pits.

*42. Laurel Quarry: NE$\frac{1}{4}$ sec. 11, T. 2 S., R. 3 W.
Abandoned quarry in Columbia River Basalt.

43. Laurelwood Quarry: NE$\frac{1}{4}$ sec. 17, T. 2 S., R. 3 W.
Columbia River Basalt quarry owned by Laurelwood Academy and operated by C. Meisel.

*44. Leffler Quarry Prospect: NW$\frac{1}{4}$ sec. 1, T. 3 S., R. 3 W.
Columbia River Basalt outcrop.

45. Millican Creek Quarry: Center sec. 31, T. 3 S., R. 3 W.
Small quarry in basalt dike.

46. Mount Richmond Quarry Prospect: NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 1, T. 2 S., R. 5 W.
Basalt dike intruding Eocene shales.

47. Oldenburg Quarry: Center sec. 19, T. 3 S., R. 4 W.
Gabbro sill intruded in Eocene shale.

48. Onion Flat Sand Pits: N$\frac{1}{2}$ secs. 21, 22, T. 2 S., R. 1 W.
Coarse sand deposited by flood waters. Several operators selling from individual pits for selected fill material.

Table 3. Rock Quarries and Sand and Gravel Pits, Continued

49. Patton Valley Abandoned Sandstone Quarry: SW$\frac{1}{4}$ sec. 27, T. 1 S., R. 4 W.
Hard, fossiliferous sandstone of Oligocene age. Building stone or base rock source.

50. Perrine Quarry Prospect: NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 27, T. 1 N., R. 1 W.
Probably Boring Lava.

51. Peters Gravel Pit: Center sec. 36, T. 2 N., R. 5 W.
Gravel 8 to 10 feet thick in Gales Creek valley.

52. Pike Gravel Pit: NW$\frac{1}{4}$ sec. 25, T. 3 S., R. 5 W.
Abandoned gravel pit. Small quantity. No information.

53. Pike Quarry: NW$\frac{1}{4}$ sec. 26, T. 3 S., R. 5 W. (Not on map list.)
One mile west of Pike Gravel Pit. Commercially operated.

54. Pioneer Quarry: NW$\frac{1}{4}$ sec. 13, T. 1 N., R. 1 W.
Commercially operated quarry in Columbia River Basalt.

*55. Quality Rock Quarry: SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 1 S., R. 2 W.
Commercial quarry in Columbia River Basalt.

*56. Reddings Quarry: NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 2, T. 3 S., R. 1 W.
Columbia River Basalt quarry.

*57. Renne Quarry: SE$\frac{1}{4}$ sec. 22, T. 3 S., R. 2 W.
Commercial quarry in Columbia River Basalt.

58. Rex Hill Quarry: NE$\frac{1}{4}$ sec. 15, T. 3 S., R. 2 W.
Columbia River Basalt quarry operated by C. Meisel.

59. Rogers Sherwood Quarry: SE corner sec. 33, T. 2 S., R. 1 W.
Quarry in Columbia River Basalt.

60. Sanders Quarry Prospect: NW$\frac{1}{4}$ sec. 11, T. 3 S., R. 2 W.
Columbia River Basalt outcrop.

*61. Scoggin Creek Sandstone Quarry: NW$\frac{1}{4}$ sec. 27, T. 1 S., R. 4 W.
Hard, fossiliferous Oligocene sandstone. For use as building stone or base rock.

62. Sudal Quarry Prospect: NW. corner sec. 3, T. 3 S., R. 1 W.
Columbia River Basalt outcrop. Thin overburden.

*63. Tigard Sand & Gravel Pit: Center sec. 13, T. 2 S., R. 1 W.
Located in lacustrine gravels.

64. Tonquin Quarry Prospect: NW$\frac{1}{4}$ sec. 34, T. 2 S., R. 1 W.
Columbia River Basalt outcrop. Thin overburden.

65. Trappist Abbey Abandoned Quarries: NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 29, T. 3 S., R. 3 W., and
66. NE. corner sec. 31, T. 3 S., R. 3 W.
Small quarries in basalt dike intruding marine sediments.

Table 3. Rock Quarries and Sand and Gravel Pits, Continued

67. Tualatin Abandoned Quarry: SE¼NE¼ sec. 24, T. 2 S., R. 1 W.
Small quarry in Boring Lava, a quarter of a mile east of edge of map near Tualatin.

*68. Twin Hills Quarry: NW¼SE¼ sec. 35, T. 3 S., R. 2 W.
Quarry in Columbia River Basalt.

*69. Vaandering Quarry: NE¼NW¼ sec. 10, T. 1 N., R. 4 W.
Commercially operated basalt quarry. Rock is associated with Eocene sediments.

*70. Vanaken Quarry: SW¼NW¼ sec. 10, T. 1 S., R. 4 W.
Commercially operated. Basalt associated with Eocene sediments.

*71. Vanaken Sand & Gravel Pit: SW¼ sec. 27, T. 1 N., R. 4 W.
Gravel 8 to 12 feet thick overlying marine sediments in Gales Creek valley. Commercially operated.

*72. Vandecoevering Quarry: NW corner sec. 29, T. 1 S., R. 2 W.
Quarry in Columbia River Basalt.

*73. Votaw Quarry Prospect: SW¼NW¼ sec. 12, T. 3 S., R. 2 W.
Columbia River Basalt outcrop.

74. Wilsonville Gravel Pit: NW¼SE¼ sec. 23, T. 3 S., R. 1 W.
Lacustrine gravels having appreciable large boulders. State owned.

*75. Zaiger Quarry Prospect: SE¼ sec. 32, T. 1 S., R. 3 W.
Columbia River Basalt outcrop drilled and sampled by Oregon State Highway Department.

Table 4. Laboratory Data for Quarry and Gravel Pits in the Tualatin Valley Region.

No.	Name	Type of Material	Lab. No.	Abrasion % Loss*	Specific Gravity	Na_2SO_4 % Loss**	Asphalt Stripping Test***	Degradation (Hgt.inches)	Remarks
2	Baker Quarry	Basalt	727760	21.8	2.76	3.2	95+	18.7	Lava flow.
7	Bearce Quarry	Basalt	428156	18.1	2.79	--	Fair	28	Lava flow.
8	Beaverton Quarry	Basalt	727762	19.0	2.84	0.9	95-	20.6	Lava flow.
11	Burkhalter Quarry	Basalt	721287	32.7	2.91	3.2	Np	29.8	Lava flow.
16	Cobb Quarry	Basalt	727758	18.1	2.89	0.2	95-	15.8	Lava flow.
21	Dugdale Quarry Prospect	Basalt	721058	63.6	2.97	15.6	95+	44.5	Sill (surface material).
21	Dugdale Quarry Prospect	Basalt	383794	22.7	2.76	12.8	--	--	Horizontal core 1'-45'.
21	Dugdale Quarry Prospect	Basalt	384597	22.7	2.75	6.9	--	--	Horizontal core 46'-61'.
21	Dugdale Quarry Prospect	Basalt	384728	19.0	2.76	9.4	--	--	Horizontal core 0'-55'.
21	Dugdale Quarry Prospect	Overburden	--	--	--	--	--	--	20'-65' thick.
21	Dugdale Quarry Prospect	Basalt	385729	--	2.67	10.3	--	--	Vertical core 21'-26'.
21	Dugdale Quarry Prospect	Basalt	385728	25.4	2.69	22.5	--	--	Vertical core 26'-27'.
24	Fuegy Quarry	Basalt	351065	26.3	2.76	--	Fair	--	
25	Gales Creek Gravels	Gravel	387163	23.6	2.84	--	--	--	Test hole 3'-8½'.
27	Groner Quarry	Basalt	727761	27.2	2.79	2.3	95+	20.4	
29	Herget Quarry	Basalt	721285	15.1	2.84	0.2	95+	16.5	Test on better zone.
34	Jackson Creek Quarry	Basalt	353825	19.0	2.85	--	--	--	County quarry.
35	James Sand & Gravel Pit	Gravel	387927	25.4	2.91	--	--	--	

38	Kinton Quarry	Basalt	727763	16.3	2.72	2.5	95+	19.2	Lava flow.
40	Kuhns Quarry Prospect	Basalt	428157	25.4	2.80	--	--	--	Lava flow.
42	Laurel Quarry	Basalt	721818	20.9	2.93	0.4	95+	14.3	Lava flow.
44	Leffler Quarry Prospect	Basalt	428155	20.0	2.85	--	Good	--	Lava flow.
50	Perrine Quarry	Basalt	354681	32.7	2.79	--	Good	--	
51	Peters Sand & Gravel Pit	Gravel	387537	16.3	2.85	--	--	--	
55	Quality Quarry	Basalt	727759	20.9	2.76	0.6	95+	20.9	Lava flow.
56	Reddings Quarry	Basalt	276174	37.2	2.94	--	--	--	Lava flow.
57	Renne Quarry	Basalt	574811	15.1	2.78	1.1	Fair	20.9	Lava flow.
61	Scoggin Cr. Sandstone Qy.	Sandstone	722743	22.7	2.43	30.0	95+	21.8	Olig. marine sandstone.
63	Tigard Sand & Gravel Pit	Gravel	776565	33.6	2.84	19.8	--	42	Lacustrine gravels.
68	Twin Hills Quarry	Basalt	428154	20.9	2.78	--	Fair	--	Lava flow.
69	Vaandering Quarry	Basalt	721819	13.6	2.93	0.3	95+	12.6	Eocene lava.
70	Vanaken Quarry	Basalt	721820	13.6	2.84	3.6	95+	13.7	
71	Vanaken Sand & Gravel Pit	Gravel	381996	23.2	2.85	--	--	--	
72	Vandecoevering Quarry	Basalt	721288	26.3	2.79	7.4	95+	26.2	
73	Votaw Quarry	Basalt	428152	25.4	2.89	--	--	22	
75	Zaiger Quarry Prospect	Basalt	691310	22.7	2.85	0.4	Good	21.5	Core sample 75'-150'.

* Loss expressed as percentage of original weight of test sample for percent of wear (Resistance to Abrasion of Large Size Coarse Aggregate by Use of the Los Angeles Machine, ASTMC535.)

** Weighted average calculated from loss percentage (Soundness of Aggregates by Use of Sodium Sulfate, ASTM C88).

*** Estimated coated area of aggregate (Coating and Stripping of Bitumen - Aggregate Mixtures, ASTM D 1664).

valley of Gales Creek, at Ash Island, and nearby in the channel of the Willamette River. Gravel resources in the Portland metropolitan area to the east are also available to the Tualatin Valley area and are used almost exclusively as the source of concrete aggregate.

Terrace gravels

Terrace gravels in the valley of Gales Creek are shown on the map as Quaternary terrace gravels. The gravel terraces are about 10 to 15 feet thick and rest upon Tertiary sedimentary bedrock at about stream level. Although some sedimentary pebbles and cobbles of poor quality occur in the gravels, the rock is satisfactory for many construction purposes. Screening and crushing of the oversize cobbles is generally sufficient to eliminate the poor quality sedimentary rock which breaks down to sand and clay and is wasted. Of the several gravel pits on Gales Creek, one is operated intermittently while the others appear to be abandoned. The deposits along Gales Creek are small; however, if rock should become required locally some of these pits could be reactivated.

Gravels in young alluvium

Gravels in young alluvium occur in the channel of the Willamette River at Ash Island and near Wilsonville and are produced by dredge operations. Young gravels of unknown thickness are believed to occur beneath the silt cover on the upstream end of Ash Island. More exploration is needed to determine the extent of these gravels.

Lacustrine gravels

Lacustrine gravels are mapped southeast of Tigard at Durham. This deposit ranges from pebbles up to large boulders 5 feet in diameter. The large boulders are composed mainly of Boring Lava and Columbia River Basalt. The gravel and cobble sized material is mostly basalt but also contains some quartzite, granite, and a few pieces of limonite. The gravel is used locally for concrete aggregate and road construction. Some of the engineering qualities of the gravels determined by laboratory tests are listed in table 4, item No. 63.

Lacustrine sand

Lacustrine sand is shown on the map in several areas of outcrop within a belt about 3 miles wide and 6 miles long between Tualatin and Six Corners. The coarse sands are composed mostly of basalt, but the finer sand is predominantly quartz and chalcedony. Thin lenses of pebbles and cobbles are exposed in the sides of deep excavations.

The sand is widely used for select fill material, but the poorly graded nature of the deposit makes it unsatisfactory for use in concrete.

Future Requirements for Sand, Gravel, and Crushed Rock

The future rock requirements for the Tualatin Valley area can be directly related to the population trends. Calculations relating rock requirements to population have shown that the yearly requirement for each person in an area averages a little more than five tons (Metropolitan Planning Commission, 1964). The Washington County population trend and estimated gravel and crushed rock requirements are tabulated as follows:

Year	Population	Yearly rock requirements (tons) (5 tons/capita)
1965	121,905	610,000
1975	160,000	800,000
1980	190,000	950,000

Gravel resources

Sand and gravel resources, especially for use as concrete aggregate, are severely limited in the project area. Estimates of reserves in the Portland metropolitan region to the east of the project area indicate that these reserves will not be sufficient to last beyond 1985. The Metropolitan Planning Commission "Sand and Gravel Resources Report," of 1964 indicates that the total remaining gravel resources in 1964 were about 100 million tons. The report estimates that slightly less than 100 million tons will be used by 1980, and more than 100 million tons will be used between 1980 and 2000. Total use projections for the Portland metropolitan area alone indicate that more than 200 million tons will be needed by the year 2000. It is, therefore, apparent that since the Tualatin Valley is currently largely dependent on gravel resources of the Portland metropolitan area, the combined need by both areas for this important construction material will result in severe shortages much sooner than 1980.

The reserves of gravels at Durham are presently restricted by urban developments, and it does not appear that this area will be able to supply significant future reserves. Some of the existing pits of Tigard Sand & Gravel have been excavated to depths at which the underlying fine-grained soils of the Troutdale Formation have been encountered. Expansion of the pits must therefore proceed laterally; however, property and zoning restrictions will prevent major reserves from being utilized.

The major sources of sand and gravel for the future are located within the channel of the Willamette River and on gravel bars within and along the sides of the river upstream from Newberg. Gravels also occur in the Willamette River at the mouth of the Molalla River. Utilization of these deposits from the standpoint of barge transportation is not presently feasible because of the restricted size of the locks at the Oregon City dam. Truck hauling would impose additional high cost for delivery to the Portland or Tualatin Valley areas. A reconstruction project was authorized by Congress in 1945 to provide enlargement and modernization of the present Oregon City locks and dam. The total cost of the project was estimated in 1945 to be $11,300,000 of which only $167,800 has been appropriated by Congress. Obviously the cost estimate is now obsolete, and the status of this project is quite uncertain. Until such time that the Oregon City locks are enlarged for economical barge transportation, the upriver gravel resources will not be available for use.

Large reserves of gravel are being developed adjacent to the Columbia River near Scappoose. The material will be dredged and placed on barges for delivery to the Portland metropolitan area in the near future as the market requires. This deposit may be an important source to meet future gravel requirements.

Crushed rock resources from quarries

Adequate reserves of rock for crushed rock products appear to be present in the Tualatin Valley region. Most of the crushed rock utilized in the urban areas of Beaverton and West Portland is obtained from quarries at Sexton Mountain and nearby Cooper Mountain. Crushed rock is also produced in the Red Hills of Dundee between Newburg and McMinnville. Reserves in these quarries appear to be extensive, but encroaching urban developments could create zoning problems that would restrict future exploitation.

Additional reserves of basalt could be developed from quarries presently operative in the Tonquin-Mulloy area, in the Tualatin Mountains northwest of Portland, and in the Chehalem Mountains. Use of this basalt for the Tualatin Valley, however, would present an additional cost factor because of the greater haul distance. Potential quarry prospects are known in the three areas cited above, but extensive detailed field investigations will be required to develop new sources of basalt of adequate quality and quantity.

The amount of overburden, degree of weathering, character of joint systems, and variation of quality between lava flows are all important factors that determine the suitability for quarry operations.

This report recommends that a comprehensive study be made to determine the potential reserves of stone suitable for quarry development and to form guidelines for conservation of lands containing quarries and quarry prospects. It may well be that large percentages of crushed rock products from quarries will be needed in the future to supplement sand and gravel requirements in construction materials.

Ground Water Resources

The major ground-water resources in the project area occur within the Tualatin, Wilsonville, and Newberg valley systems. These valleys provide water supply for domestic consumption, for irrigation, for commercial-industrial purposes, and for municipal use. The upland areas of basalt and areas underlain by marine sedimentary rocks yield highly variable quantities of water of poor to good quality which is used primarily for domestic supply and in a few cases for irrigation of small acreage.

Ground Water from Valley Areas

Ground-water development from stratigraphic units of the Tualatin and Wilsonville valleys has been treated in detail by Hart and Newcomb (1965), and, since similar stratigraphic units are present in the Newberg valley, information given in this report is largely summarized from the work of those authors.

The principal aquifers in the valley areas are within the Willamette Silt, Troutdale Formation, and Columbia River Basalt. Ground water occurs in the Willamette Silt under unconfined conditions, in the Troutdale Formation under unconfined and semiconfined conditions, and in the Columbia River Basalt under artesian pressure in confined aquifers.

Yield from water wells drilled and dug into the Willamette Silt of the valley areas is usually sufficient for domestic purposes, and in rare cases it is ample for irrigation of small acreage. Well yields are generally about 5 gpm, occasionally 10 gpm, and in one known instance as much as 50 gpm (sec. 21, T. 1 N., R. 2 W.). Wells must be completed below the yearly fluctuation of the water table, which has a maximum annual range in the Tualatin Valley of approximately 20 feet. Many of the wells drilled to depths of 40 to 50 feet give a low water yield in the late summer or early fall.

Wells completed in the Troutdale Formation in the valley area range from a common depth of about 100 feet to depths of several hundred feet. Well yields are generally less than 10 gpm, but some wells produce 40 to 50 gpm. One well (sec. 15, T. 1 N., R. 3 W.) will yield 100 gpm with a small amount of drawdown. Most of the aquifers in the Troutdale Formation are fine to very fine sand beds with limited areal extent and rarely gravel beds. Aquifer thickness is generally less than 10 feet. In recent years, wells have been completed by installation of screens and gravel pack, and well yields have been increased in some cases to 100 to 200 gpm for irrigation or commercial use. Wells with sufficient water supply for domestic use, irrigation, and commercial purposes can be developed in most valley areas by performing careful logging of sand horizons and by utilizing special completion methods such as perforated casing, screens, and gravel pack.

Columbia River Basalt is found at depths of several hundred feet in the valley areas. In the Tualatin Valley near Hillsboro the lavas are reached at a maximum depth of about 1,500 feet below ground surface. The lavas provide the principal aquifers for irrigation, industrial-commercial, and municipal water supply. At the present time Tigard, Beaverton, and Aloha obtain all or a portion of their water supply from deep wells drilled into the Columbia River Basalt. Newberg obtains its water supply from springs on the southwest flank of the Chehalem Mountains and from wells completed in gravels of young alluvium in the Willamette River flood plain.

A partial list of water wells drilled into the Columbia River Basalt is shown on table 5. The chart indicates the range of well yields that have been obtained from wells of various diameters drilled into the formation to variable depths. It is apparent that well yield is directly related to well diameter and thickness of basalt penetrated below the water table. Newcomb (1959) states that "One gpm of water for each foot of well penetration below the regional water table is a fair over-all average of the yield obtained by a 10- or 12-inch well when pumped at the common drawdown of 50 to 100 feet." Theoretically, then, a 10- to 12-inch well drilled 200 feet into basalt below the regional water table could expect a well yield of approximately 200 gpm, and one drilled to 1,000 feet approximately 1000 gpm.

Ground water occurs in the Columbia River Basalt in confined aquifers. Hart and Newcomb (1965) indicate that the principal aquifers are interflow zones between basalt flows where breccia zones or "cinders" permit comparatively free movement of water. It is apparent that fracturing attendant with faulting has also been a significant factor in increasing higher water yield.

Wells drilled into the Columbia River Basalt are completed by driving casing through the overlying formation and into the basalt. The well is then advanced open hole into the basalt until a desired quantity of water is obtained or the planned depth is reached. Most domestic wells drilled into the basalt have been 6-inch diameter wells, although in recent years 8-inch wells have become more common. Most irrigation, commercial, and municipal wells are 12 inches in diameter, although some are 14 or 16 inches in diameter.

A map showing the depth of the Columbia River Basalt below ground surface in the Tualatin and Wilsonville valleys appears on plate 4. The map can be used as a guide to determine the approximate depth required for wells to reach ground water in Columbia River Basalt aquifers. Depth of the basalt below ground surface is shown on the map by contours of 100-foot intervals.

Ground Water from Upland Areas

Good water supply can be obtained from basalt in most upland areas. However, deep wells are often required to reach the regional water table whose elevation is approximately that of the valleys. The static water level in these wells may be as low as 550 feet below the surface; expensive pumping equipment is therefore necessary. In higher elevations of the Chehalem Mountains the regional water table may lie below the basalt, and it is therefore necessary to drill to the underlying Oligocene marine sedimentary rocks, from which water yields are erratic.

Perched aquifers in the upland areas can produce adequate supplies for domestic use in some localities; it should be understood, however, that perched water tables are not present in all areas.

Ground Water from Marine Sedimentary Formations

Wells drilled into the marine sedimentary rock sequence for water supply obtain highly variable results both as to quantity and quality. Quantities obtained in 6-inch diameter wells vary from 1 gpm to 50 gpm, but most are less than 10 gpm and commonly less than 5 gpm. Drawdown in wells that yield 10 to 15 gpm is frequently 75 to 100 feet or even more. Water quality is frequently poor, with high iron and sulfur content, and is commonly brackish or highly saline. Most of the water wells are between 100 and 200 feet deep.

Ground Water from Eocene Volcanics and Sediments

Wells drilled into the volcanic-sedimentary rock sequence seldom produce more than 20 gpm; many wells are barely sufficient for domestic requirements. Attempts to obtain sufficient ground-water supplies for irrigation purposes are met with varying results. Although direct information is lacking, well drillers report that water quality in wells is commonly brackish and occasionally highly saline. Carbon dioxide springs are locally present; one spring area is situated in the canyon of Clear Creek in sec. 18, T. 1 N., R. 4 W., and another near Fairdale west of Carlton a few miles west of the boundary of the project area.

Table 5. Well Yield for Columbia River Basalt.

Well location (Sec., T., R.)	Casing diameter (inches)	GPM	Drawdown (feet)	Depth (feet)	Top basalt (feet)	Basalt thickness (feet)
17 P., 1 S., 1 W. of the Willamette M.	14	1089	83	414	11	403
19 E(2), 1 S., 1 W.	6	12	130	211	159	52
19 J(2), 1 S., 1 W.	6	20	30	308	170	138
25 D., 1 S., 1 W.	8	650	142	462	165	297
26 B., 1 S., 1 W.	12-10	500	98	503	168	235
29 A(1), 1 S., 1 W.	12-10	235	400	900	100	800
33 A., 1 S., 1 W.	8- 6	20	235	855	715	140
10 Q., 1 S., 1 W.	6	50	10	813	608	205
11 L., 1 S., 1 W.	10-8	420	-	735	650	85
13 D., 1 S., 1 W.	12	350	240	958	589	369
24 D., 1 S., 1 W.	8	450	-	400	300	100
14 G., 1 S., 1 W.	6	217	388	1090	698	392
26 E., 1 S., 1 W.	12	300	-	162	14	148
2 P., 1 S., 1 W.	8-6	175	68	875	673	202
24 F., 1 S., 1 W.	8	500	-	52	350	150
14 H., 1 S., 1 W.	-	190	250	1080	707	373
21 P., 1 S., 1 W.	16	950	80	800	54	746
31 C., 1 S., 2 W.	6	300	-	715	266	449
23 R., 1 S., 2 W.	12	1250	78	874	5	853
23 G., 1 S., 2 W.	12-10	400	167	805	640	165
24 J., 1 S., 2 W.	16-10	470	162	720	45	649
26 D., 1 S., 2 W.	6	40	35	540	455	85
26 G., 1 S., 2 W.	10-8	232	95	472	3	469
28 A., 1 S., 2 W.	8	150	15	150	105	45
29 P., 1 S., 2 W.	6	600	30	750	450	300
29 Q., 1 S., 2 W.	6	Flow 100 GPM	-	505	445	60
16 E., 1 S., 3 W.	10	260	102	392	55	337
16 G., 1 S., 3 W.	8	550	100	472	245	237
16 J., 1 S., 3 W.	8	Flow 100 GPM	-	742	680	82
21 C(2), 1 S., 3 W.	8-6	80	200	610	300	290
28 E., 1 N., 1 W.	12	230	145	576	470	106
1 G., 1 N., 2 W.	8	100	-	120	20	100
2 N., 1 N., 2 W.	6	80	-	543	250	293
3 R., 1 N., 2 W.	8	110	190	397	160	237
5 R., 1 N., 2 W.	6	300	86	547	342	98
1 M., 1 N., 3 W. (Flows 5 GPM)	6	75	150	440	325	115
3 R., 1 N., 4 W.	6	Flow 25 GPM	-	341	309	32
11 E., 2 S., 1 W.	12	200	-	381	260	121
4 B., 2 S., 1 W.	8	300	-	385	135	250
4 G., 2 S., 1 W.	12	380	153	494	86	408
24 M., 2 S., 1 W.	8	110	35	278	150	128
10 C., 2 S., 1 W.	10	400	90	494	215	279
2 B., 3 S., 1 W.	6	25	0	236	38	198
5 L(2), 3 S., 1 W.	8	60	35	138	74	64
15 L., 3 S., 1 W.	14	2000	-	1000	240	760
16 R., 3 S., 1 W.	14	760	5	1000	340	660
15 E., 3 S., 2 W.	6-5/8	140	54	105	85	20

Water Pollution Problems

Reports from the State Sanitary Authority indicate that streams in the Tualatin Valley are being overused for disposal of waste from sewage-treatment plants. Stream flows of the Tualatin River are highly variable, with flows ranging from nearly zero for about 100 days in the summer months to a maximum of 20,000 cfs in the winter. This has produced a serious pollution problem during the summer months when the flow is inadequate to carry the present effluent load. Pollution is also compounded in the Tualatin Valley by ineffective septic tank drain fields constructed in impervious soils, and in areas where the ground-water table is at or near surface elevation.

Population increases anticipated for the future indicate serious pollution problems unless there is adequate pre-planning for future waste disposal. The State Sanitary Authority has published reports (Oregon State Board of Health, 1965, 1966) in which pollution problems of the Tualatin basin were discussed. The primary purpose of these reports was to point out that direction and organization were needed in order that the Tualatin basin might develop in an orderly way. Their most urgent recommendation was that: "Expansion of existing or construction of newly proposed waste treatment facilities should not be considered until direction is outlined by an over-all basin-wide study."

This study indicates that soil testing should be conducted for drain-field design and construction in urban development areas. The requirements for drain-field soils have been determined and information is available from the local health authorities. The U.S. Department of Health, Education, and Welfare has published a booklet entitled "Manual of Septic Tank Practice," Public Health Service Publication No. 526, available from the U.S. Government Printing Office, Washington, D.C. Also contained in this manual are descriptions of methods which can be used for individual treatment, comparable to that of septic tanks, in areas which will not allow conventional drain fields to be used.

In the project area, drain-field performance can be anticipated by consulting the soil descriptions in the text, the geology and soils map (plate 1), and the geologic hazards map (plate 3). Localities where septic tank installations may prove unsuccessful include fine-grained, low-permeability soils, flood-plain areas of high ground-water table, rock outcrops, and steep slopes.

Summary

The significant geologic, engineering, and hydrologic aspects of the Tualatin Valley region are summarized here by dividing the area into four geologic provinces. In a general way, each province is a topographic entity and contains a characteristic group of soil and bedrock units with fairly distinctive engineering and hydrologic properties. These provinces are: (I) areas underlain by valley fill and semiconsolidated sedimentary rocks; (II) areas underlain by basaltic lavas; (III) areas underlain by marine sedimentary rocks; and (IV) areas underlain by Eocene volcanics and sediments (figure 45).

Areas Underlain by Valley Fill (I)

Areas underlain by valley fill and semiconsolidated sediments include the Tualatin Valley, the Wilsonville, Newberg, and Yamhill valleys, Wapato Lake valley, northern Willamette Valley, and Chehalem valley (figure 45). The topography of the valley areas is characterized by low, rolling hills, long, basinward-sloping terraces, and moderate to steep slopes confining present-day streams.

The surface material of the valley areas includes unconsolidated, fine-grained deposits of the Willamette Silt, lacustrine sand and gravel, and recent flood-plain deposits in present stream courses. These deposits are underlain at variable depths from a few feet to about 50 feet by consolidated marine sedimentary rocks in the Yamhill valley and Wapato Lake valley and by semiconsolidated, fine-grained sediments of the Troutdale Formation in the Newberg, Wilsonville, and Tualatin valleys. Boring-log soil sections encountered in the Newberg and Tualatin valleys appear in figure 20, c and d. These show in considerable detail the types of soil encountered at the location of each section and reflect to some degree the character of soils that may be expected in adjacent areas.

The Willamette Silt is the principal surface soil formation in each of the valley areas. It consists predominantly of sandy silt and slightly clayey silt with clay phases of moderate plasticity. The density of silt, as indicated by Standard Penetration Tests, can be described as loose to medium dense, and the more plastic phases of the silt as soft to moderately firm.

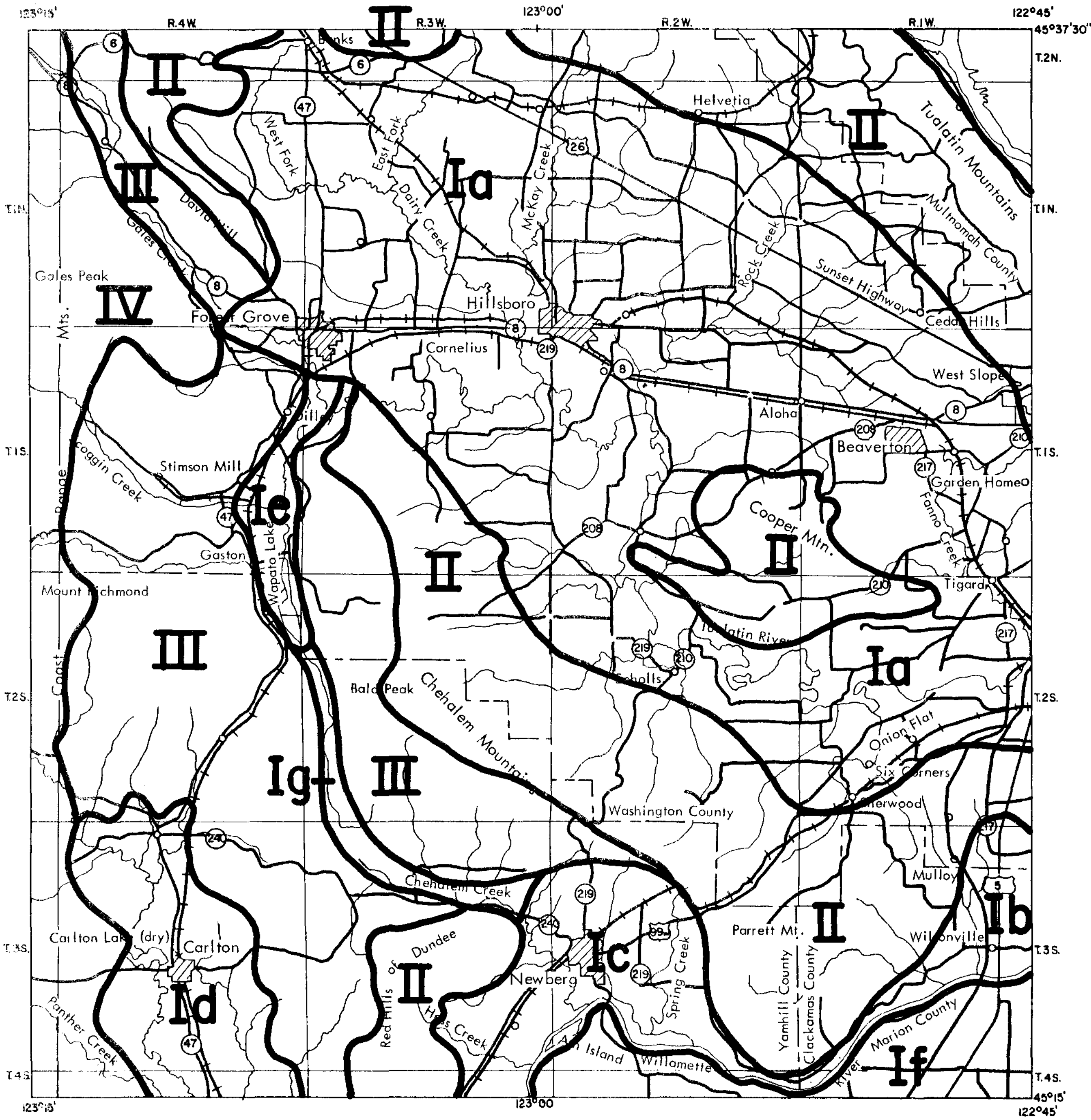
The lacustrine deposits of sand and gravel are restricted to an area of several square miles centering near Tualatin and to one small area near Wilsonville. The gravel phase of this unit consists largely of dense cobble and boulder gravel and the sand phase of medium- to coarse-grained, loose to medium-dense sand.

Deposits in modern flood plains of the Tualatin Valley consist largely of soft, clayey silt and silty clay with significant local areas of highly organic soils. Flood-plain deposits of streams in the Yamhill Valley and Wapato Lake area are predominantly of clay, with varying amounts of organic matter. Recent flood-plain deposits of the Willamette River are principally very fine sand and silt with gravel deposits commencing at the south end of Ash Island near Newberg and extending upstream.

During winter and early spring, unconfined ground water occurs beneath a large portion of the Tualatin Valley at depths of less than 10 feet. In some areas, such as near Aloha, Hillsboro, and Forest Grove, the ground-water table rises to or near the ground surface. Basements of private houses and commercial buildings frequently are filled with water. During the summer and fall months the ground-water table ranges from 15 to 30 feet below the surface.

In the Wilsonville and Newberg valleys the ground-water surface drains to a base elevation established by the Willamette River. During winter flood periods, or times of high-water levels in the Willamette River, the ground-water table in these two valleys can rise to elevations near ground surface.

The ground-water surface in the Yamhill valley adjusts to a base level established by the Yamhill



Explanation

I Areas underlain by valley fill and semiconsolidated sedimentary rocks.

(a) Tualatin Valley; (b) Wilsonville valley; (c) Newberg valley; (d) Yamhill valley; (e) Wapato Lake valley; (f) Northern Willamette Valley; (g) Chehalem valley.

II Areas underlain by basaltic lavas.

III Areas underlain by marine sedimentary rocks.

IV Areas underlain by Eocene volcanic and sedimentary rocks.

Figure 45. Geologic provinces of the Tualatin Valley region.

River, and it also can rise to near-surface elevations during flood periods of the river.

The approximate area of ground-water table in the Tualatin Valley is shown on the geologic hazards map, plate 3. Hydrographs shown in figure 35 provide information on the annual fluctuation of the ground-water table.

Flooding occurs annually in the major stream courses of the Tualatin Valley and less frequently in the Willamette River. Floods are discussed in detail in the section of the report which describes geologic hazards.

Areas Underlain by Basaltic Lavas (II)

This province consists of upland areas underlain at shallow depth by basaltic lavas. These areas include: Red Hills of Dundee, Parrett Mountain-Chehalem Mountains-David Hill trend, Cooper and Bull Mountains and adjacent ridges, and the Tualatin Mountains (figure 45). The uplands are locally steeply dissected by streams flowing to the adjacent valley floors; they rise from the edge of valley terraces at about elevation 250 feet to elevations of more than 1,000 feet. Slopes into the valleys average about 400 feet per mile.

Flows of the Columbia River Basalt and Boring Lava are considered together in this province. These lavas consist chiefly of weathered and unweathered, dense, fine-grained basalt. The Columbia River Basalt generally has a closely spaced joint system and weathers to residual clay soils as much as 20 feet thick. Boring Lava has a blocky to massive joint system and weathering along the joints produces a surface soil containing numerous rounded basalt boulders. Hard and dense basalt is exposed largely in steep slopes of stream canyons and on steep escarpments. Such outcrops are mainly on the northeast flank of the Tualatin Mountains, the southwest flank of the Chehalem Mountains, and the northwest flank of Parrett Mountain.

Silt caps the basalt on spurs, ridges, and summits of the Tualatin Mountains, Cooper and Bull Mountains, and Chehalem Mountains. The silt cover ranges from a few feet to more than 50 feet in thickness. In general, it is greater than 25 feet thick in the Tualatin Mountains and from 5 to 15 feet thick on the other mountains.

Areas underlain by basaltic lavas present special problems for construction practice and land utilization. These problems are related to: (1) steepness of slopes, (2) the degree of weathering, (3) the character of the overlying soil formation, (4) in some cases the character of the underlying formation, and (5) in places the structure of the basalt. In most instances the lava can be considered as excellent foundation support, provided that structures or loads are placed directly on the basalt. Landslides are common in the silts and residual soils overlying the basalt. At places major landslides have developed in the basalt as a result of erosion of underlying formations (plate 3). In areas where the basalt is present at surface elevations, weathering has generally weakened the rock so that shallow excavations of 5 to 8 feet can normally be made with little difficulty. In some areas, however, the basalt is unweathered and sufficiently dense as to require the use of explosives.

The areas underlain by basalt provide the principal source of high-quality stone for production of rock products. Nearly all quarries in this province are located within the Columbia River Basalt.

Ground water in basalt at the higher elevations occurs largely in perched aquifers, in contrast to valley areas where it occurs in both unconfined and confined aquifers.

Good supplies of ground water can be obtained in wells that are drilled in basalt below the regional ground-water table which is present near valley-floor elevations. Such wells are frequently several hundred feet in depth and may require expensive pumping equipment. In some areas, such as in the higher elevations of the Chehalem Mountains, marine sedimentary rocks are present beneath the basalt at elevations above the regional water table, and results obtained are commonly poor, both as to quantity and quality.

Areas Underlain by Marine Sedimentary Rocks (III)

This province lies in the southwest portion of the map area west of Newberg and southwest of Forest Grove (figure 45). The topography varies from rolling hills with moderate relief to areas of relatively steep relief such as on the southwest flanks of the Chehalem Mountains and David Hill and the mountainous topography just north of the Stimson mill on Scoggin Creek. The rocks in this province include the Yamhill Formation, Spencer Formation, and undifferentiated Oligocene marine sediments. They consist largely of consolidated tuffaceous siltstone and shale, occasional lime-cemented shales with some poorly sorted, friable tuffaceous sandstone, basaltic sandstone, and feldspathic sandstone.

Bedrock units are commonly found at or near the ground surface in this province, but in local areas weathering has produced several feet of plastic residual clays and softened bedrock. Weathered materials on moderate to steep slopes have failed, producing extensive slump-type landslides. Where slope failure has not yet occurred, artificial or natural oversteepening may cause landslides. Fine-grained sedimentary rocks dipping in the direction of the slope are also subject to landsliding.

The sequence is locally intruded by basaltic dikes and sills, which may represent prospective sources for stone products, but present information indicates that the intrusives are small and variably weathered.

Ground-water supply from marine sedimentary rocks is similar to that found in the Eocene volcanics and sediments. Quantities obtained in wells vary from a few gallons per minute up to but rarely 40 to 50 gallons per minute. Water is commonly brackish or saline.

Areas Underlain by Eocene Volcanics and Sediments (IV)

The area underlain by Eocene volcanics and consolidated sediments lies along the western edge of the map from its southern boundary to Gales Creek (figure 45). The topography ranges from rolling foothills to steep mountainous terrain. The soils are generally thin, with parent bedrock at or near the surface. Bedrock consists of basalt flows and intrusives intercalated with tuffaceous sandstones and shales. The basalt is weathered but is often found to be very hard and blocky within a few feet of the surface. The intrusives are either basalt dikes or gabbroic sills. The dikes are usually fresh and unweathered, but the sills range from hard and fresh to mechanically disintegrated gabbros which contain scattered boulders in the centers of spheroidally weathered joint blocks.

The sedimentary interbeds in the sequence are locally deeply weathered and produce soils that are largely clay. Where such materials are present on oversteepened hillsides or stream canyons, large landslides have taken place.

Quarries have been developed in a number of localities within this sequence. The quality of stone obtained from these sources is quite variable; some small dikes or sills within quarries produce good quality stone, but generally abrasion test results are high.

Ground-water resources of Eocene volcanics and sediments are highly variable both as to quantity and quality. Most wells yield barely enough water for domestic use, and only occasionally are quantities sufficient for irrigation. Water obtained from wells is commonly saline.

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APPENDIX

A. Moisture Density Curves

The reaction of a limited number of soils to laboratory tests has been plotted on the accompanying graphs to show the relationship of moisture content to degree of possible compaction density and shear strengths (see pages 90, 91, and 92).

Optimum moisture content is the percentage of moisture by weight which will allow the greatest density (dry) of compacted material to be attained with a reasonable effort (that is, in 6-inch layers) by wheel and roller traffic. At lower moisture content than optimum, the friction between the soil particles will resist the compactive effort and maximum dry density will not be attained. With greater than optimum moisture, the water will fill the voids and the soil grains will be held apart by pore-water pressure, thus resisting the compactive effort.

The shear strength of a soil is the sum of the forces exerted by internal friction and cohesion.

"The angle of internal friction is the angle whose tangent is the ratio between the resistance offered to sliding along any plane in the soil and the component of the applied force acting normal to that plane." (Portland Cement Association Soil Primer, 1962).

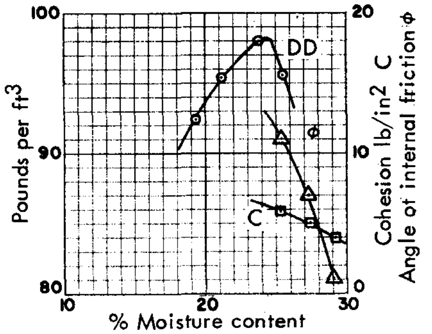
Cohesion is the mutual attraction of particles due to molecular forces and the presence of moisture films. Hence the cohesive force in a particular soil will vary considerably with its moisture content. In this report cohesion is listed in pounds per square inch.

Most of the soils can have a natural moisture content close to 30 percent, which means that they must be dried to optimum before compaction can be adequately accomplished. In addition to compaction, failure can occur in embankments owing to shearing of the soil. At high moisture content the shearing resistance of the soils is shown to be low.

B. Grain Size Distribution Curves

Grain size distribution curves are shown on the accompanying charts for each of the soils described in the engineering section of this report. The data plotted was obtained from sieve and hydrometer tests and is useful for relating the percentages of the various size fractions in the samples from 5 mm down to .001 mm (see pages 93 to 97, inclusive).

MOISTURE DENSITY CURVE *
Oligocene Undiff. (Tos) Lab. No. 624238.

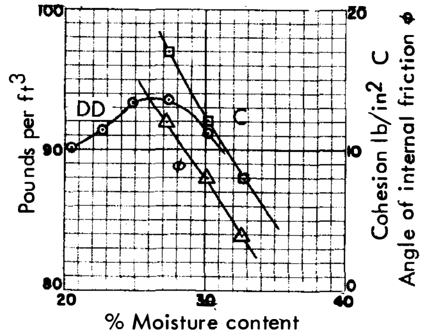


Maximum dry density 98 lb/ft^3
Optimum moisture 24%
Liquid limit 38
Plastic index 13

% Moist.	DD	Φ	C
19.3	92.4		
21.3	95.4		
23.9	98.0		
25.5	95.7	11	6
27.3		7	5
29.1		1	4

A-6(9), E-7, ML
* Harvard Miniature Procedure

MOISTURE DENSITY CURVE*
Yamhill Fm (Tey) Lab. No. 648641.



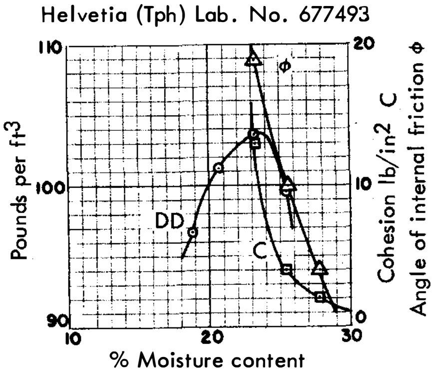
Maximum dry density 94 lb/ft^3
Optimum moisture 26.2%
Liquid limit 50
Plastic index 23

% Moist.	DD	Φ	C
20.5	90.3		
22.8	91.5		
24.9	93.6		
27.5	93.6	12	17
30.2	91.2	8	12
32.9		4	8

A-7-6(15), E-8, CH

* Harvard Minature Procedure

MOISTURE DENSITY CURVE *
Helvetia (Tph) Lab. No. 677493

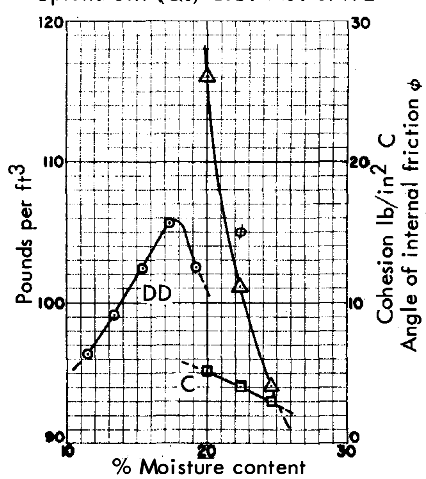


Maximum dry density 103.8 lb/ft^3
Optimum moisture 23.5%
Liquid limit 35
Plastic index 10

% Moist.	DD	Φ	C
18.9	96.9		
20.9	101.1		
23.2	103.7	19	13
25.5	99.6	10	4
27.8		4	2

A-4(8), E-6, ML
* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *
Upland Silt (Qs) Lab. No. 671724

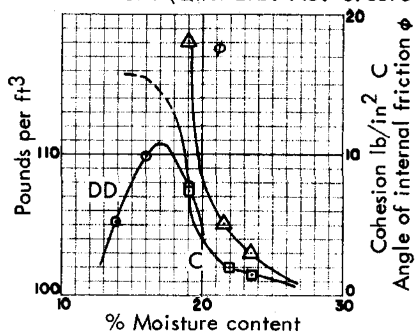


Maximum dry density 106 lb/ft^3
Optimim moisture 18%
Liquid limit 27
Plastic index 6

% Moist.	DD	Φ	C
11.7	96.2		
13.5	99.1		
15.5	102.3		
17.3	105.6		
19.3	102.4		
20.0		26	5
22.4		11	4
24.7		4	3

A-4(8), E-6, ML
* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *
Willamette Silt (Qws) Lab. No. 373578



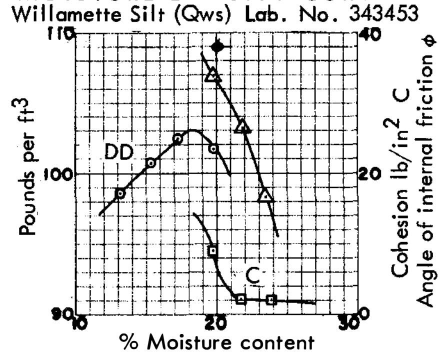
Percent moisture
Dry density 110.6 lb/ft3
Optimum moisture 17.2%
Liquid limit 29
Plastic index 7

% Moist.	DD	φ	C
14.0	105.2		
16.3	109.7		
19.1	107.8	18	7.5
21.8		5	2.0
23.7		3	1.5

A-4(8), E-7, ML

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *
Willamette Silt (Qws) Lab. No. 343453



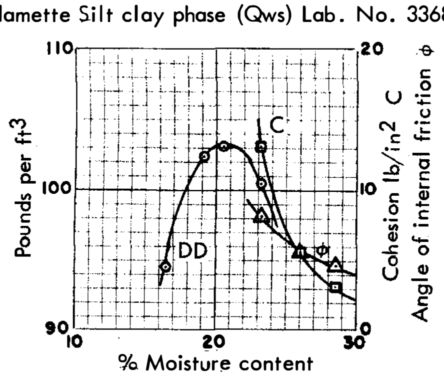
Dry density 103 lb/ft3
Optimum moisture 18.2%
Liquid limit 26
Plastic index 0

% Moist.	DD	φ	C
13.2	98.7		
15.4	100.7		
17.4	102.7		
19.9	101.8	34	4.5
21.8		26	1
23.6		17	1

A-4(8), E-6, ML

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *
Willamette Silt clay phase (Qws) Lab. No. 336894



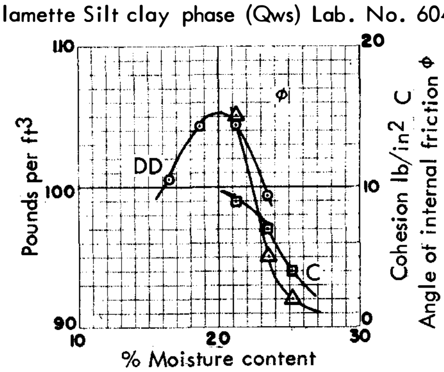
Maximum dry density 103 lb/ft3
Optimum moisture 21%
Liquid limit 46
Plastic index 27

% Moist.	DD	φ	C
16.6	96.4		
19.2	102.2		
20.6	103.0		
23.3	100.2	8	13
26.0		5	5.5
28.8		4	3

A-7-6(14), E-7, CL.

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *
Willamette Silt clay phase (Qws) Lab. No. 604892



Maximum dry density 105.3 lb/ft3
Optimum moisture 20.0%
Liquid limit 37
Plastic index 20

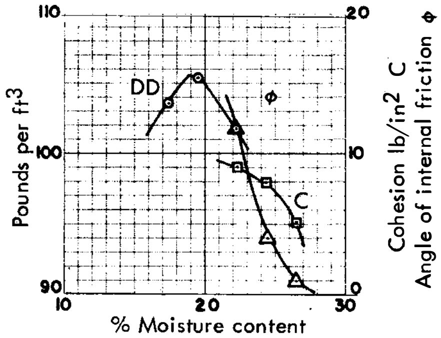
% Moist.	DD	φ	C
16.4	100.4		
18.7	104.1		
21.2	104.2	15	9
23.6	99.3	5	7
25.3		2	4

A-6(11), E-7, CL.

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *

Young Alluvium Silt Phase (Qya) Lab. No. 412053



Dry density 105.8 lb/ft^3
Optimum moisture 19.2%
Liquid limit 32
Plastic index 6

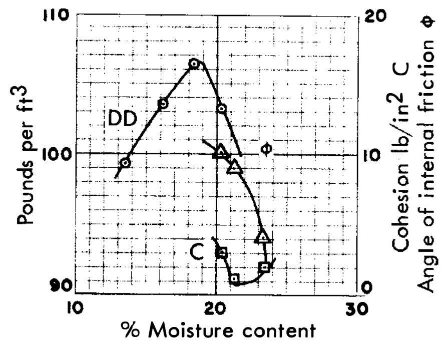
% Moist.	DD	Φ	C
17.8	103.7		
19.7	105.6		
22.1	101.9	12	9
24.3		4	8
26.5		1	5

A-4(8), E-6, ML

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *

Young Alluvium Silt Phase (Qya) Lab. No. 556925



Dry density 106.5 lb/ft^3
Optimum moisture 18.7%
Liquid limit 27
Plastic index 8

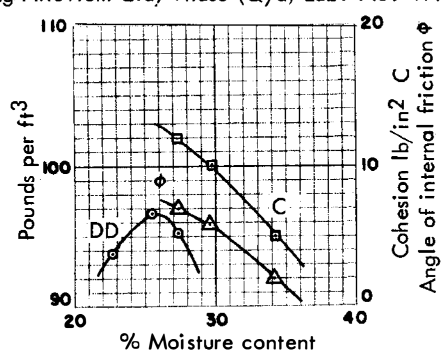
% Moist.	DD	Φ	C
13.6	99.4		
16.2	103.7		
18.6	106.3		
20.3	103.1	10	3
21.4		9	1
22.5		4	2

A-4(8), E-6, ML

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *

Young Alluvium Clay Phase (Qya) Lab. No. 411697



Maximum dry density 96.7 lb/ft^3
Optimim moisture 26%
Liquid limit 53
Plastic index 27

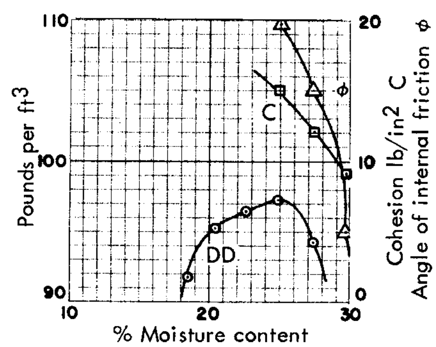
% Moist.	DD	Φ	C
22.9	93.9		
25.5	96.6		
27.3	95.1	7	12
29.8		6	10
34.2		2	5

A-7-6(12), E-7, CL

* Harvard Miniature Procedure

MOISTURE DENSITY CURVE *

Young Alluvium Clay Phase (Qya) Lab. No. 636137

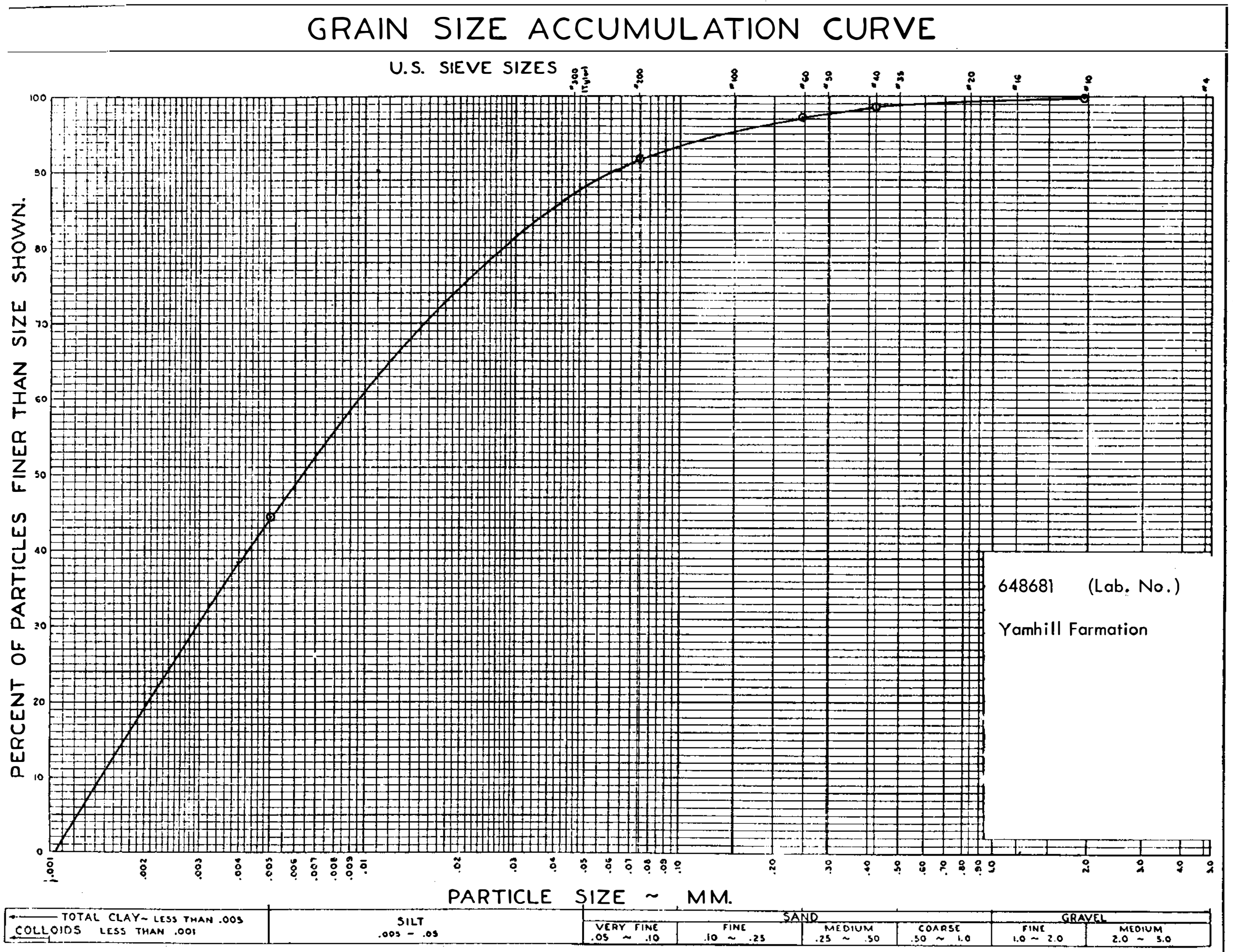


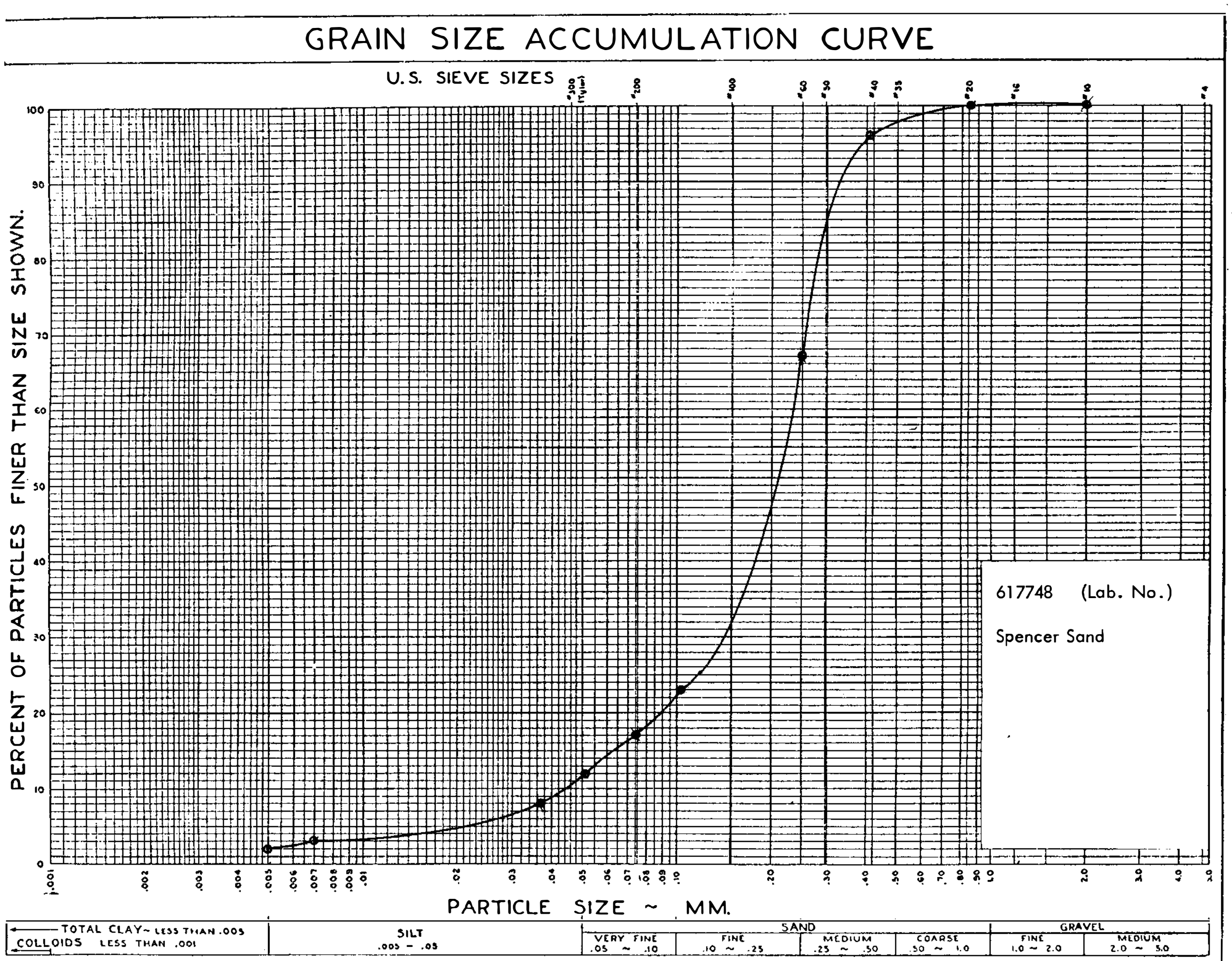
Maximum dry density 97.2 lb/ft^3
Optimum moisture 25.2%
Liquid limit 41
Plastic index 14

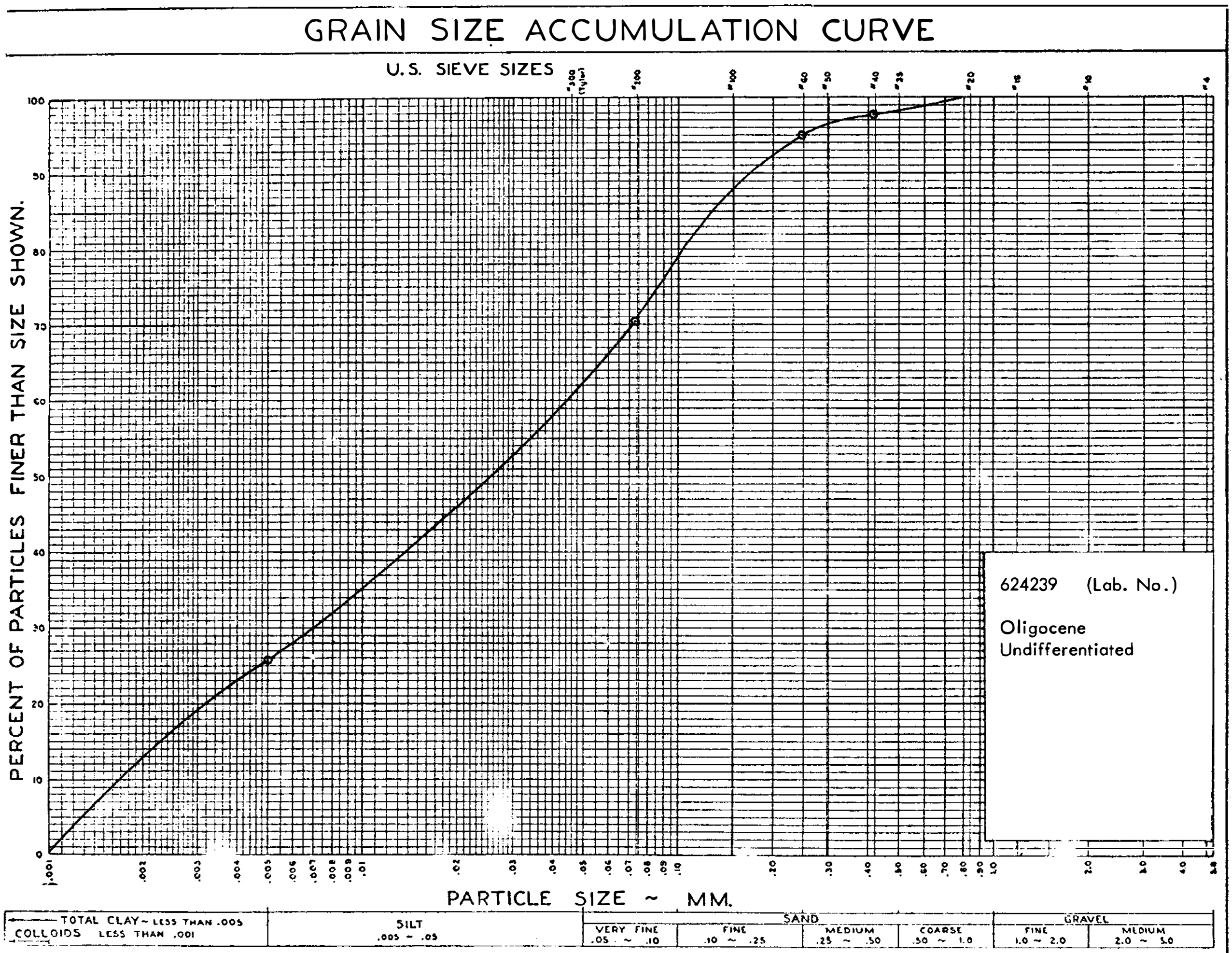
% Moist.	DD	Φ	C
18.6	91.9		
20.5	95.1		
22.8	96.3		
25.0	97.2	20	15
27.3	94.1	15	12
29.9		5	9

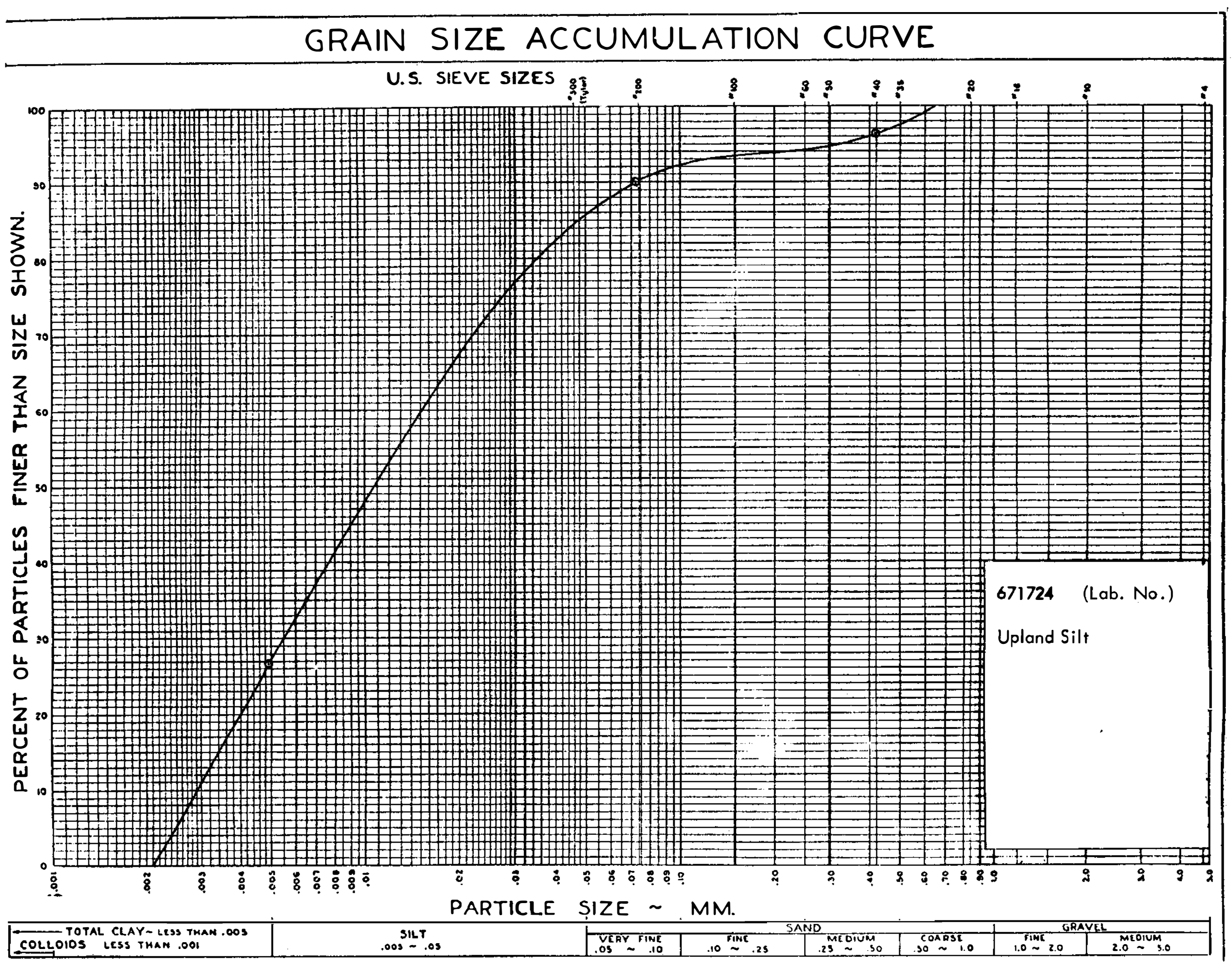
A-7-6(12), E-7, CL

* Harvard Miniature Procedure

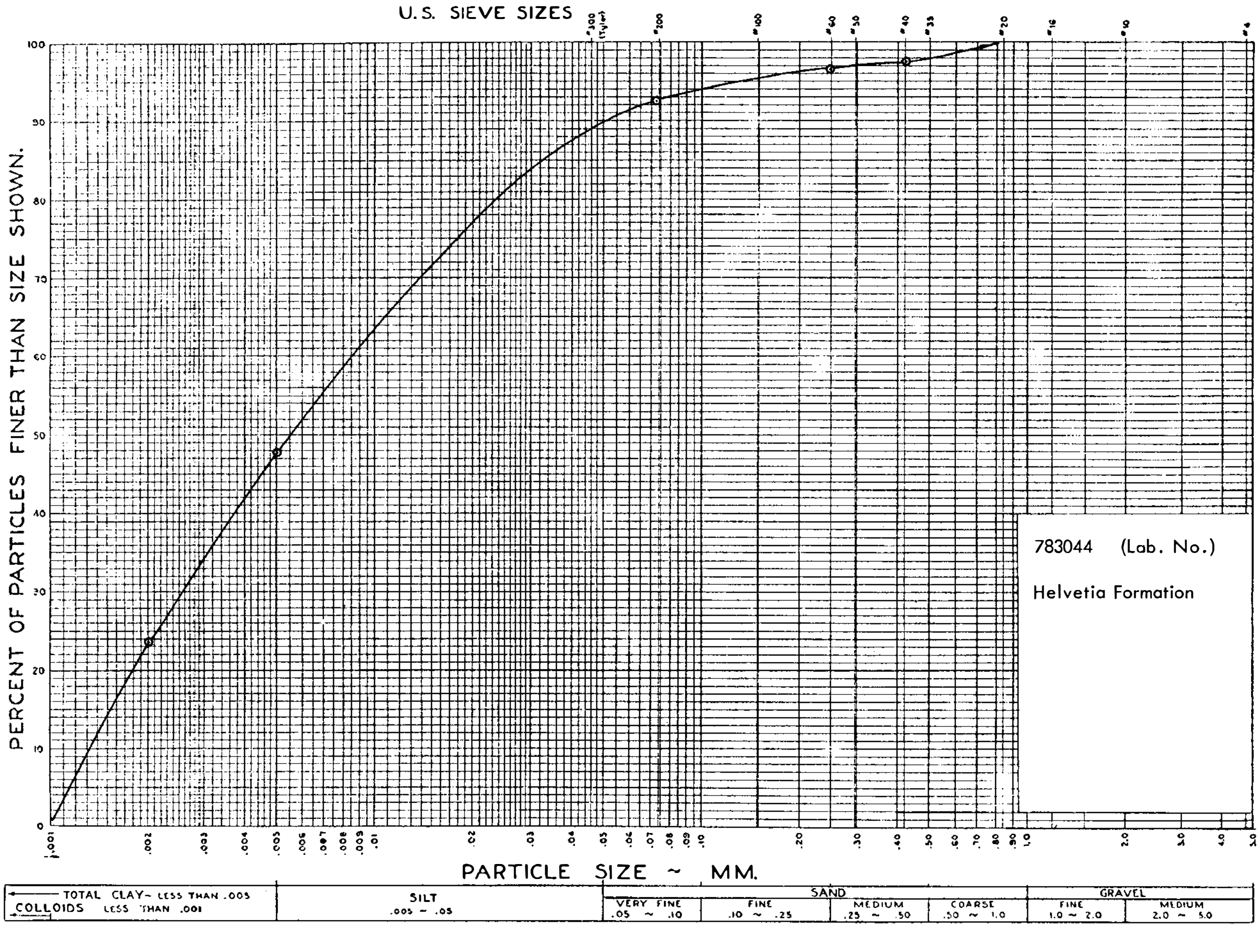

GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
648681 (Lab. No.)
Yamhill Formation
TOTAL CLAY~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 – .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0


GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
617748 (Lab. No.)
Spencer Sand
TOTAL CLAY~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 – .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0

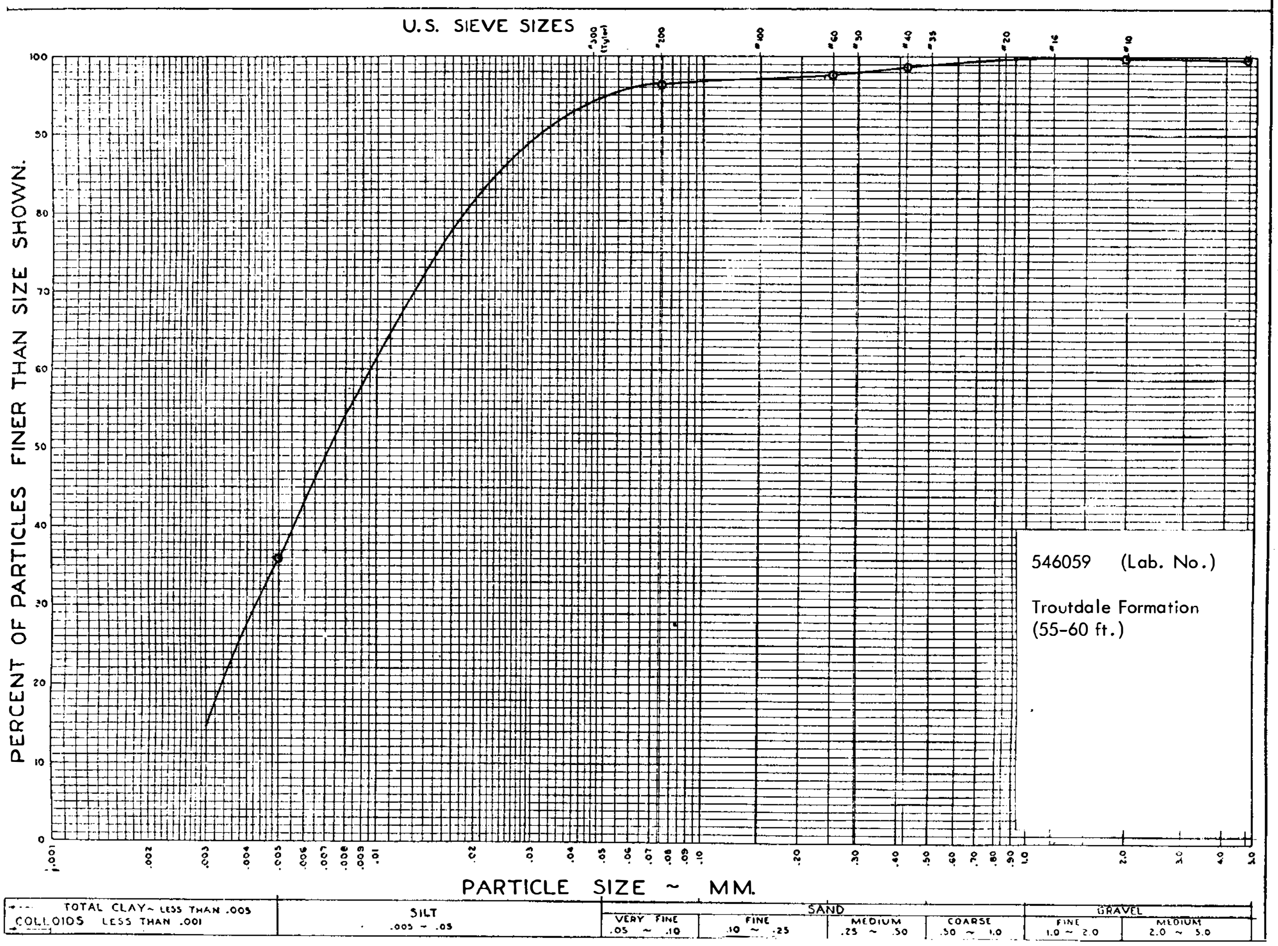

GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
624239 (Lab. No.)
Oligocene
Undifferentiated
TOTAL CLAY~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 ~ .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0

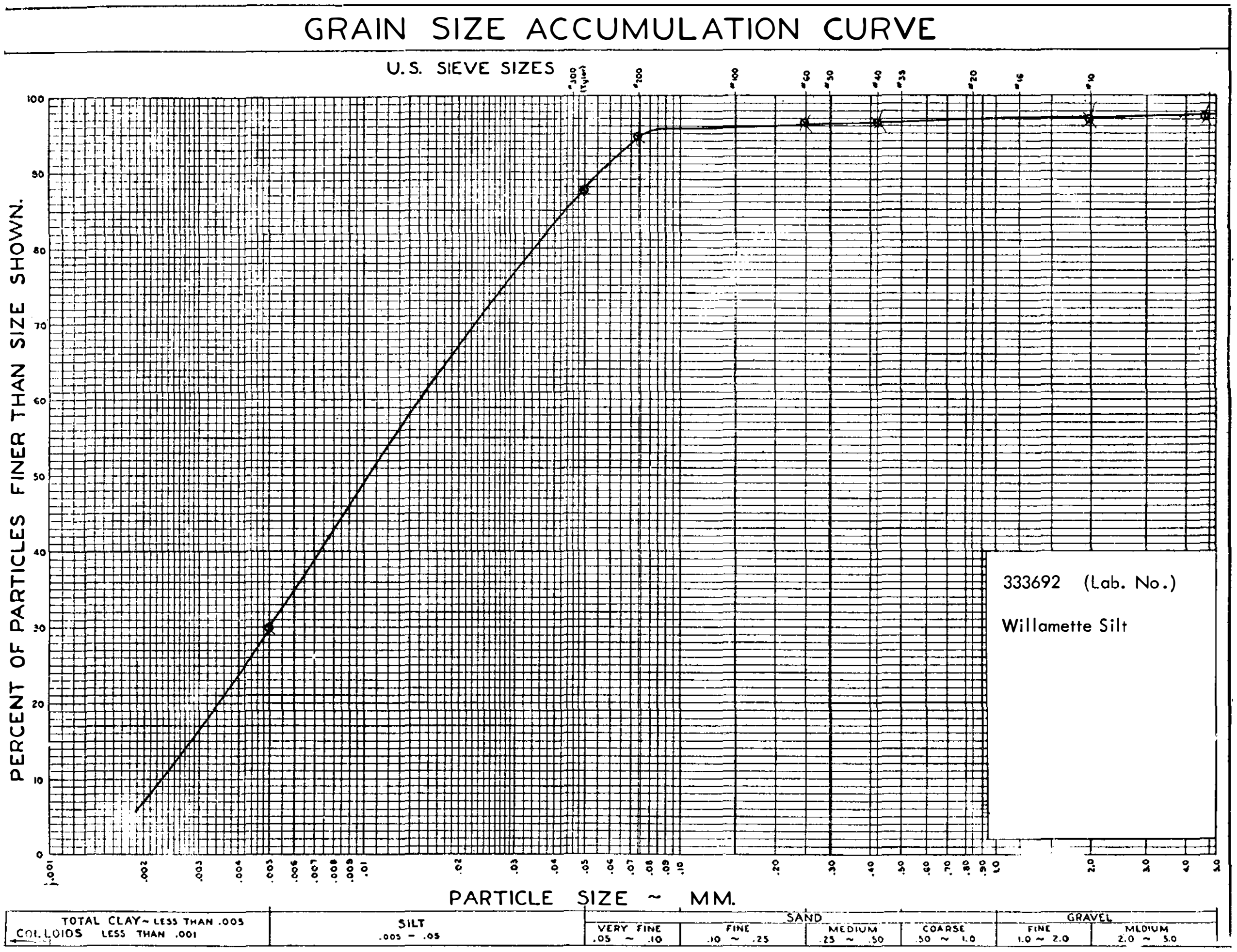

GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
671724 (Lab. No.)
Upland Silt
TOTAL CLAY~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 ~ .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0

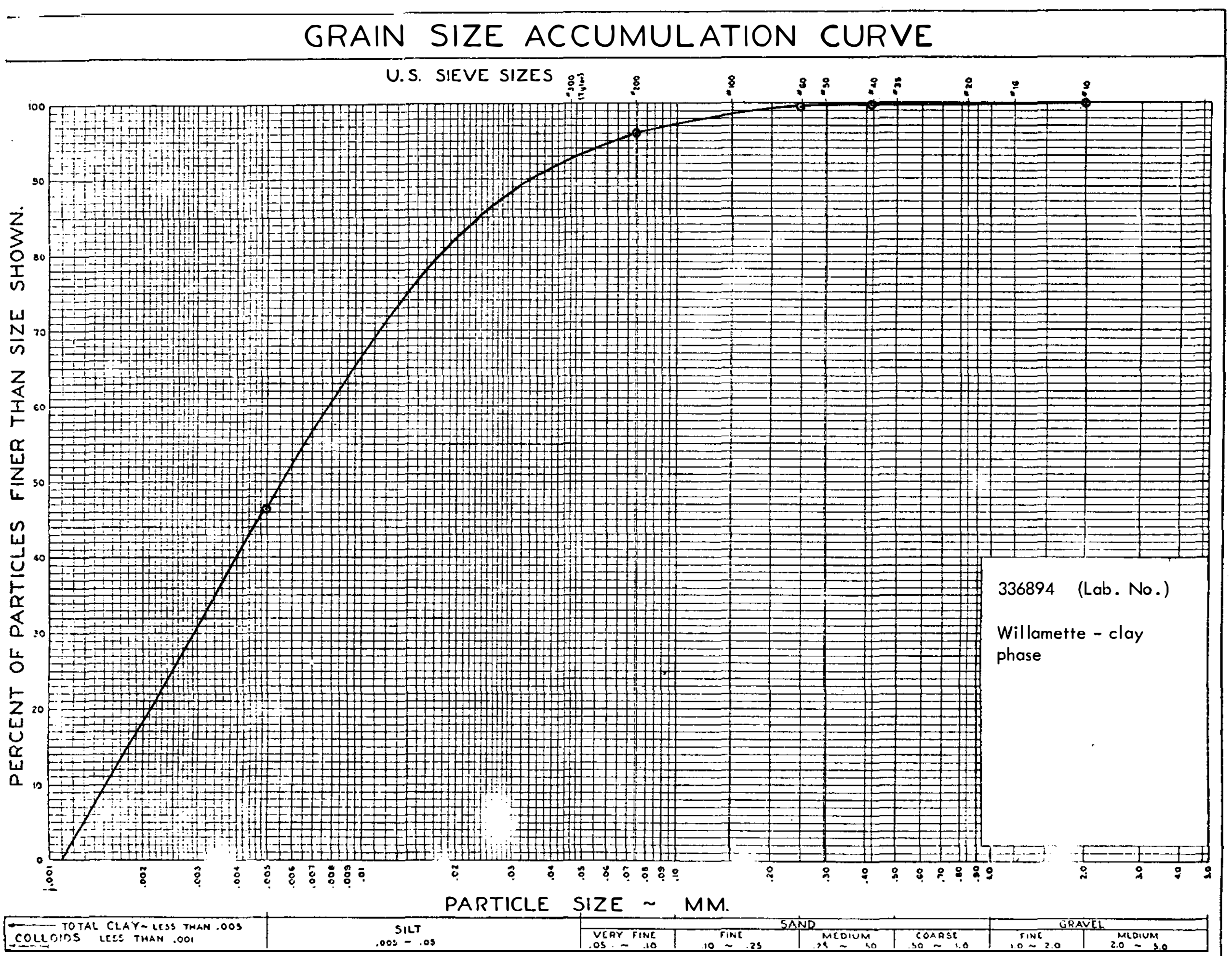
GRAIN SIZE ACCUMULATION CURVE



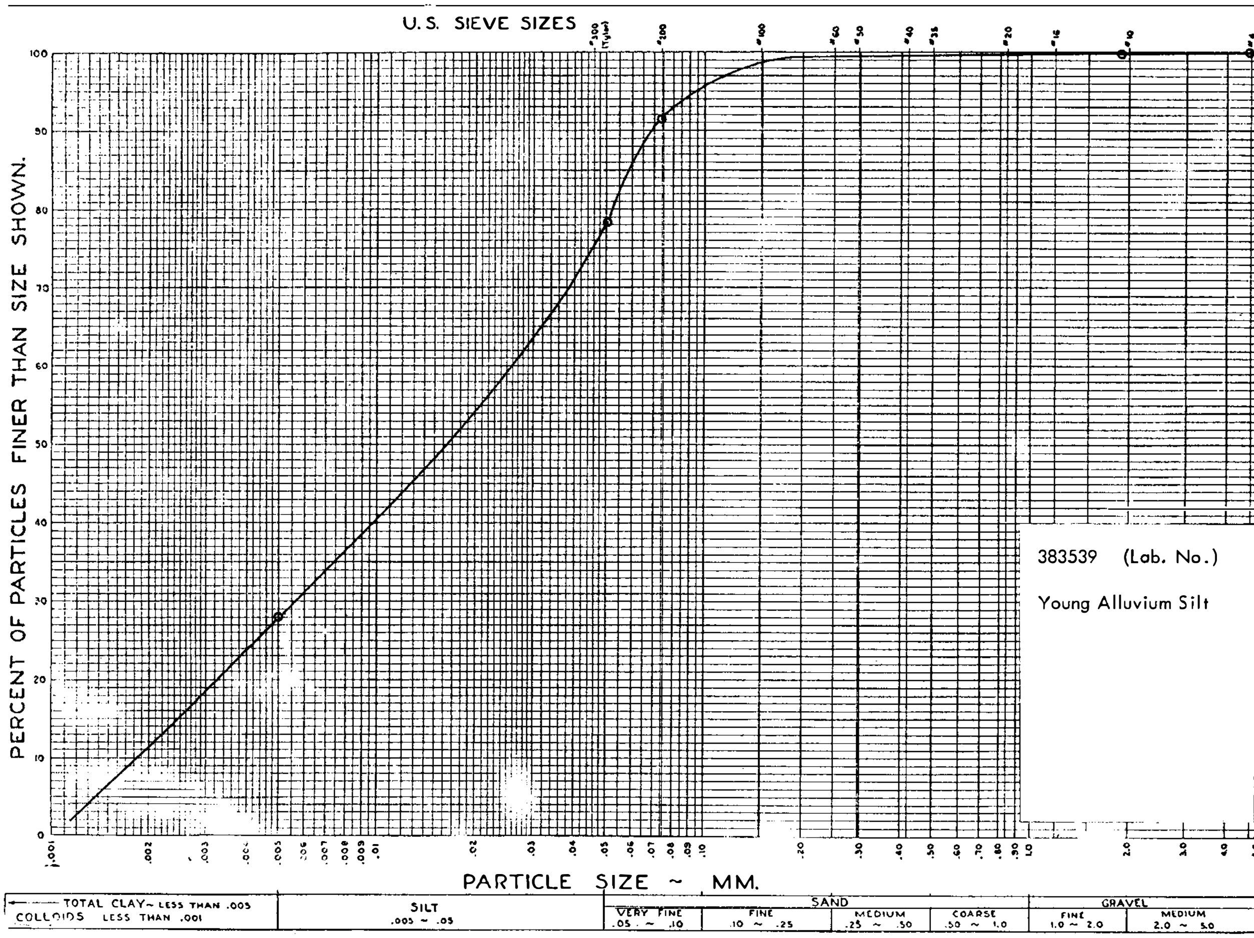
GRAIN SIZE ACCUMULATION CURVE



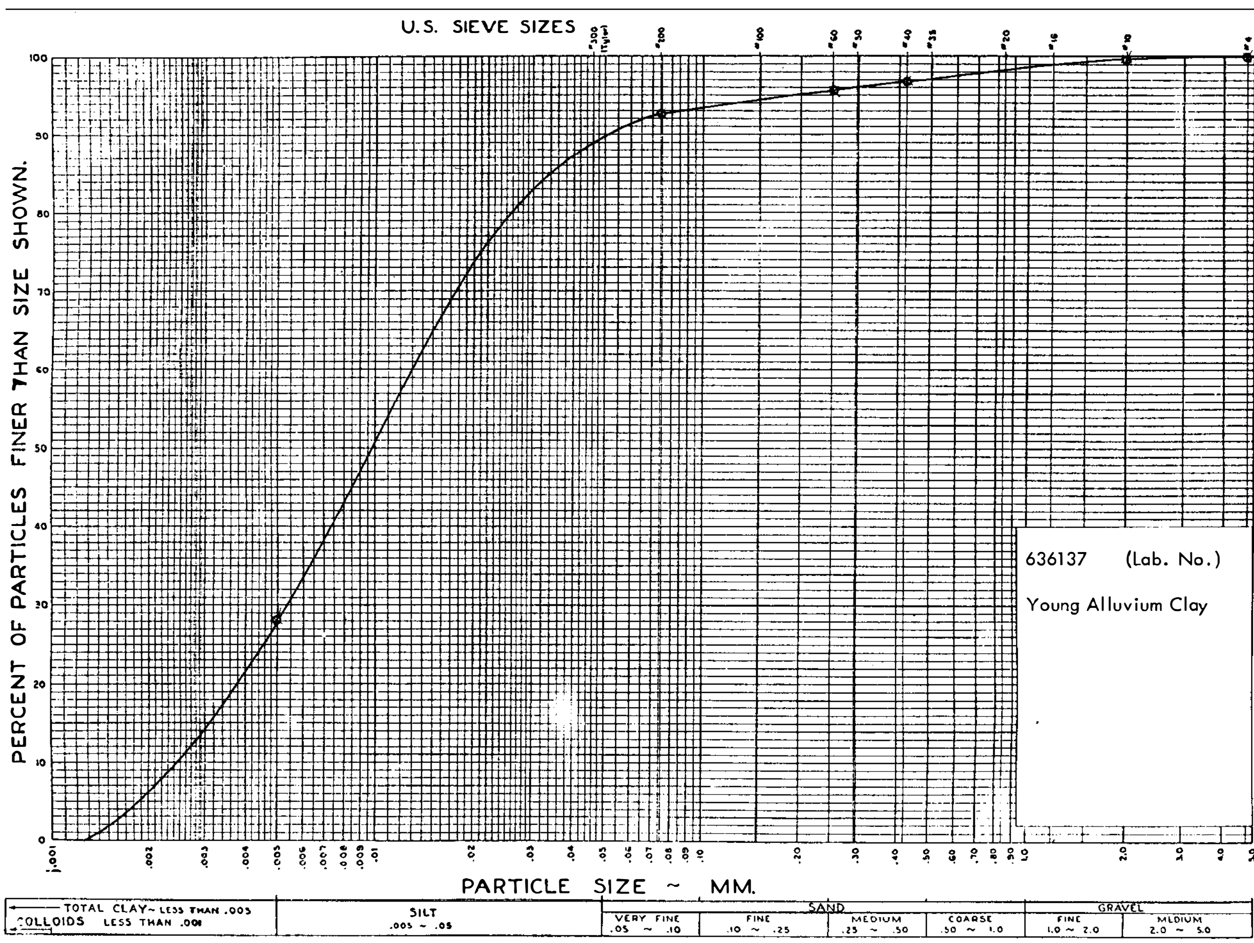

GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
TOTAL CLAY ~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 – .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0
333692 (Lab. No.)
Willamette Silt


GRAIN SIZE ACCUMULATION CURVE
U.S. SIEVE SIZES
PERCENT OF PARTICLES FINER THAN SIZE SHOWN.
PARTICLE SIZE ~ MM.
TOTAL CLAY ~ LESS THAN .005
COLLOIDS LESS THAN .001
SILT .005 – .05
SAND
VERY FINE .05 ~ .10
FINE .10 ~ .25
MEDIUM .25 ~ .50
COARSE .50 ~ 1.0
GRAVEL
FINE 1.0 ~ 2.0
MEDIUM 2.0 ~ 5.0
336894 (Lab. No.)
Willamette – clay phase

GRAIN SIZE ACCUMULATION CURVE



GRAIN SIZE ACCUMULATION CURVE



C. Unified Soil Classification System Chart*

The unified soil classification system is based on the system developed by Dr. Arthur Casagrande, of Harvard University, for the Corps of Engineers during World War II. The original classification has been expanded and revised in cooperation with the U.S. Bureau of Reclamation so that it now applies to embankments and foundations as well as to roads and airfields. It is used by both the Corps of Engineers and the USBR.

The accompanying table and the discussion given below are from "The Unified Soil Classification System," Military Standard 619, U.S. Army Corps of Engineers, 1960. More detailed information may be obtained from that publication.

The unified soil classification system identifies soils according to their textural and plasticity qualities, and their grouping with respect to their performances as engineering construction materials. The following properties form the basis of soil identification:

1. Percentages of gravel, sand, and fines (fraction passing the No. 200 sieve).

2. Shape of the grain-size distribution curve.

3. Plasticity and compressibility characteristics.

The soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Four soil fractions are recognized: cobbles, gravel, sand, and fines (silt or clay).

The soils are divided as (1) coarse-grained soils, (2) fine-grained soils, and (3) highly organic soils. The coarse-grained soils contain 50 percent or less material smaller than the No. 200 sieve, and fine-grained soils contain more than 50 percent material smaller than the No. 200 sieve. Highly organic soils can generally be identified visually.

The coarse-grained soils are subdivided into gravels (G) and sands (S). The gravels have the greater percentage of the coarse fraction (that portion retained on the No. 200 sieve) retained on the No. 4 sieve, and the sands have the greater portion passing the No. 4 sieve. The four secondary divisions of each group--GW, GP, GM, and GC (gravel); SW, SP, SM, and SC (sand)--depend on the amount and type of fines and the shape of the grain-size distribution curve**. Representative soil types found in each of the secondary groups are shown in the accompanying table under the heading "Typical names."

Fine-grained soils are subdivided into silts (M) and clays (C), depending on their liquid limit and plasticity index. Silts are those fine-grained soils with a liquid limit and plasticity index that plot below the "A" line in the diagram in the table, and clays are those that plot above the "A" line. The foregoing definition is not valid for organic clays since their liquid limit and plasticity index plot below the "A" line. The silt and clay groups have secondary divisions based on whether the soils have a relatively low (L) or high (H) liquid limit.

The highly organic soils, usually very compressible and with undesirable construction characteristics, are classified into one group designated by the symbol "Pt." Peat, humus, and swamp soils are typical examples.

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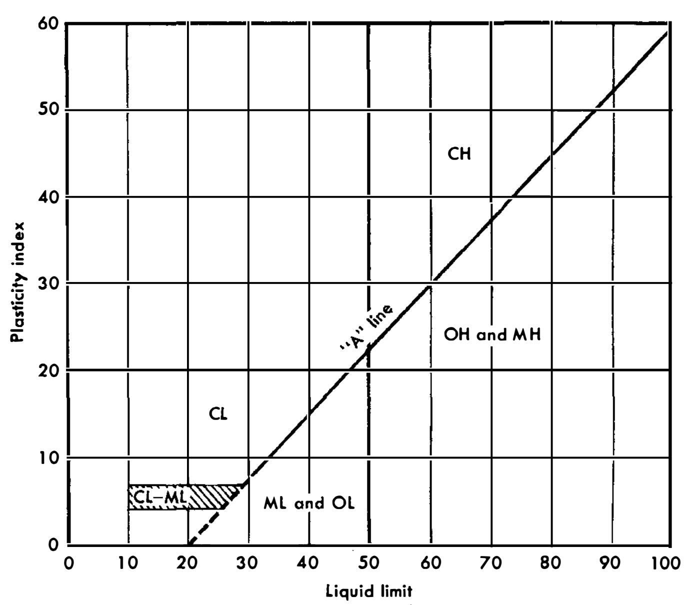
* From PCA Soil Primer, published by Portland Cement Assn., Chicago, Ill., 1962.

** The grain-size curves of well-graded materials are generally smooth and concave, with no sizes lacking and no excess of material in any size range.

Unified Soil Classification System

Major divisions			Group symbols	Typical names	Laboratory classification criteria	
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM* d / u	Silty gravels, gravel-sand-silt mixtures	Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures	Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM* d / u	Silty sands, sand-silt mixtures	Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures	Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			OL	Organic silts and organic silty clays of low plasticity		
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts		
			CH	Inorganic clays of high plasticity, fat clays		
			OH	Organic clays of medium to high plasticity, organic silts		
	Highly organic soils		Pt	Peat and other highly organic soils		

Laboratory classification criteria for coarse-grained soils: Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:
Less than 5 per cent . . . . GW, GP, SW, SP
More than 12 per cent . . . . GM, GC, SM, SC
5 to 12 per cent . . . . *Borderline* cases requiring dual symbols**



Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Reprinted from PCA Soil Primer

D. Interrelation of Soil Classification and Bearing Values Chart *

Resistance value - R

The stability, expressed as the "resistance (R) value," represents the shearing resistance to plastic deformation of a saturated soil at a given density. The test is described under AASHO T175. The stability of a soil can be determined by means of the Hveem stabilometer, which measures the transmitted horizontal pressure due to a vertical load.

The R-value may vary from 0 to 100 - - 0 representing a liquid and 100 representing a material that transmits no horizontal pressure from an applied load. The R-value is used in flexible pavement design.

Modulus of subgrade reaction - k

The modulus of subgrade reaction (k) is defined as the reaction of the subgrade per unit of area of deformation and is given in pounds per square inch (psi) of area per inch of deformation. The unit load for a deformation of 0.05 in. is generally used in determining k. However, the Corps of Engineers determines k for the deformation obtained under a load of 10 psi.

The determination of k is made in the field on the subgrade in place at optimum moisture content if possible. In any case, the moisture content and the density of the subgrade at time of test are determined and recorded. A 30-in.-diameter plate is generally used. The plate size influences bearing-test results because the forces resisting deformation consist of shear around the plate perimeter as well as consolidation under the area of the plate. With plates of 30-in. diameter and greater, the shear-resisting forces around the perimeter are of minor magnitude.

Practically all concrete pavement design is based on the modulus of subgrade reaction, k, used in the Westergaard formulas and in the PCA formulas contained in the booklet, Concrete Pavement Design.

Bearing values

Soil-bearing values, expressed in pounds per square inch, are determined in the field for (1) soils under buildings, bridges, and dams; and (2) subgrade soils and pavements in place. Various direct loading procedures are used.

The field test is usually conducted on the soil, in place, at the elevation of the proposed footing or foundation. The size of the loaded area is determined by the problem at hand, as is the type of area loaded; in some cases a footing itself may be loaded. In tests of this nature the primary data obtained consist of the unit load and a time deformation curve under load. Repetitive loading may or may not be required by the design problem. ASTM procedures and textbooks on soil mechanics may be consulted for additional details.

For large structures, field tests on soils are directed to the determination of the sizes of footings or foundations, with or without piling, needed to support the design loadings, or structures in service, without obtaining uneven or excessive settlement during or after construction. Pore pressures built up by consolidation in the presence of moisture may also require analysis.

Bearing-value field tests of subgrade soils for planned or existing pavements have certain standard procedures, ASTM D1195 and D1196. Research, plus data on unit loads and time-deformation relationship, indicates that bearing-value results for general highway pavement loadings change little for plates of 30-in. diameter and greater. For heavier loadings, plate sizes of 48- to 60-in.

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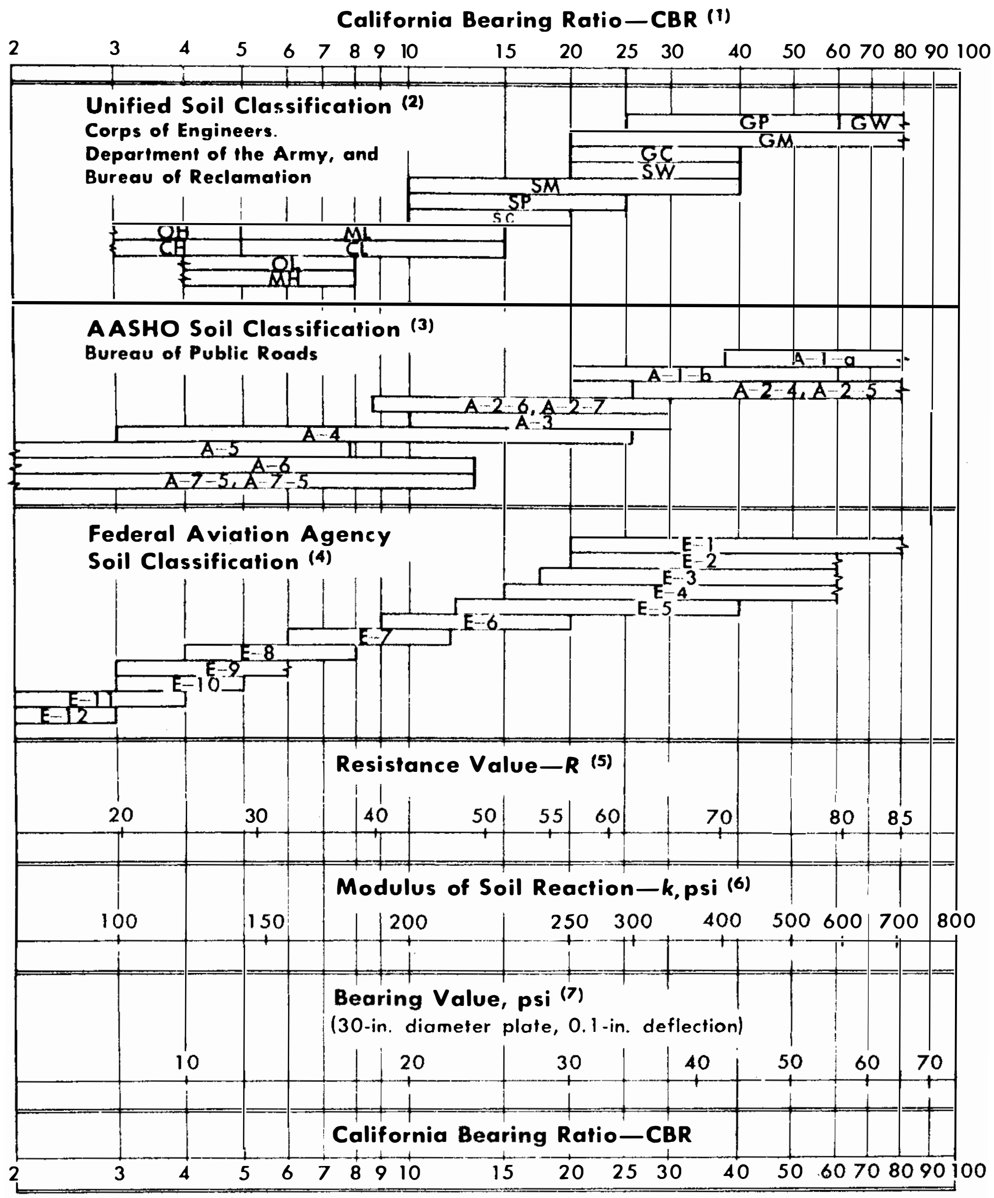
* Excerpts from P.C.A. Soil Primer

Approximate interrelationships of soil classifications and bearing values.



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting,* 1942, Vol. 22, pages 100-136.

(2) "Characteristics of Soil Groups Pertaining to Roads and Airfields," Appendix B, *The Unified Soil Classification System,* U.S. Army Corps of Engineers, Technical Memorandum 3-357, 1953.

(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting,* 1945, Vol. 25, pages 376-392.

(4) *Airport Paving,* U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements.*

(5) F. N. Hveem, "A New Approach for Pavement Design," *Engineering News-Record,* Vol. 141, No. 2, July 8, 1948, pages 134-139. *R* is factor used in California Stabilometer Method of Design.

(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting,* 1942, Vol. 22, page 152. *k* is factor used in Westergaard's analysis for design of concrete pavement.

(7) See reference (6), page 184.

diameter should be used. When necessary, large plate values can be determined by using the smaller plate loading data in connection with perimeter-area relationship.

The moisture content of the soil at time of test is basically important. For instance, a clay soil having a moisture content below the shrinkage limit may be almost as hard as a kiln-dried brick and have very high supporting power; yet when it has a moisture content near the liquid limit it is almost a liquid and has very low supporting power. As a result, determinations are made of probable maximum moisture content of the soil in service and the field test is conducted when the soil is in this condition. When such procedures are impractical, tests are conducted with a known moisture content and the data interpreted in terms of probable field moisture conditions. This interpretation becomes more useful when it is possible to conduct tests on the soil at different moisture contents to reflect directly the influence of moisture on supporting power. The tests often include repetitive loading and variations in unit loads to develop families of load-deformation curves for more exact evaluation of data for various loading conditions. Extensive tests of this nature have been conducted by the Bureau of Public Roads, the Corps of Engineers, many state highway departments, and others.

California bearing ratio

A modified punching shear test was developed by the California Division of Highways in which a piston of 3-in. end area is forced into compacted samples of 6-in. diameter. There is no opening in the bottom of the specimen mold to permit extrusion of material. Rate of piston movement is controlled and pressure readings are taken for various penetration depths. The standard of comparison for computing a material's bearing value is the following relation between penetration and load or pressure on a "standard" well-graded crushed stone.

Penetration, in.	Standard load, psi
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

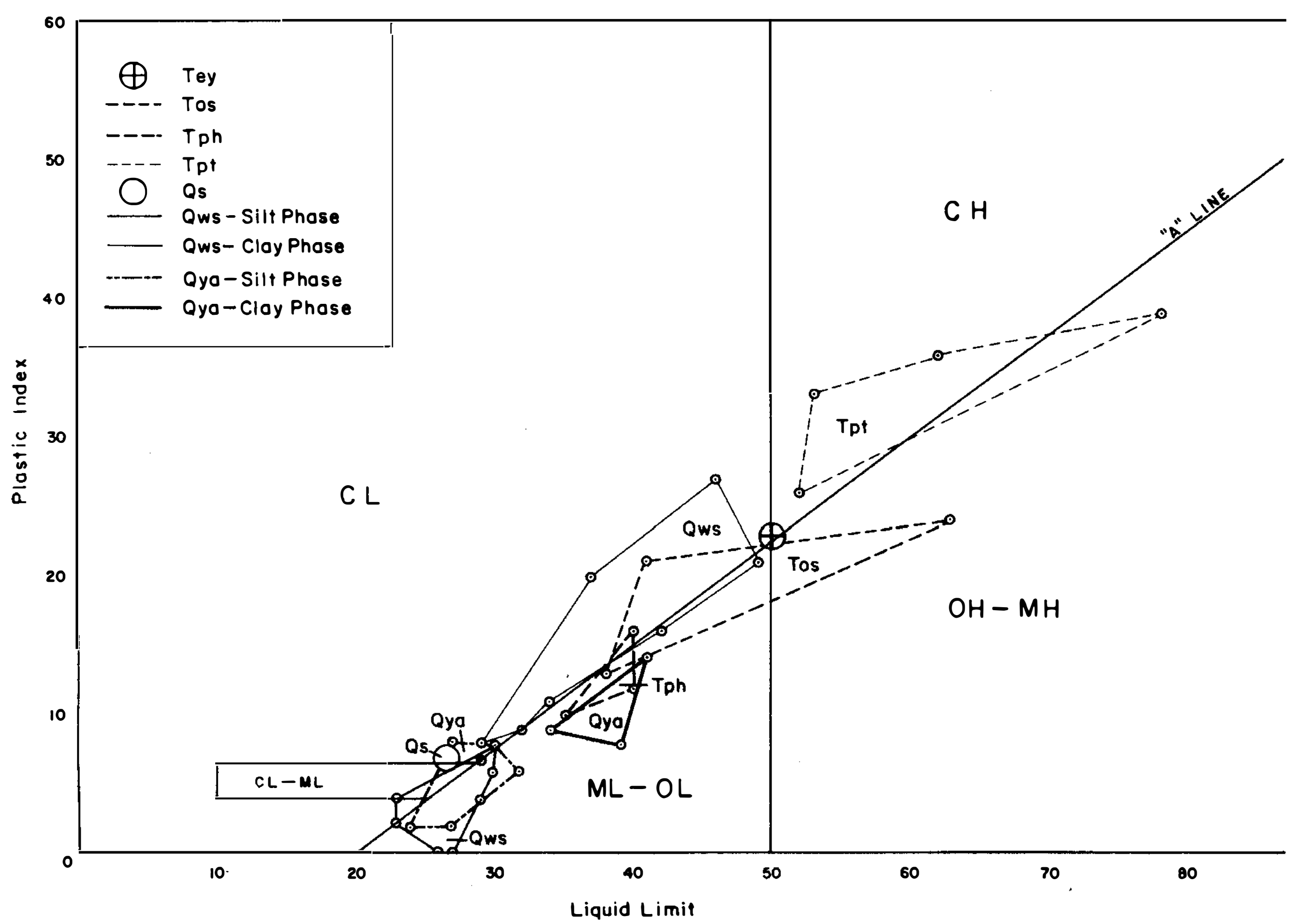
The bearing value of a sample is determined for a specific penetration by dividing the load for that penetration by the standard load for the same penetration. For example, if a specimen requires a load of 450 psi to obtain 0.1-in. penetration, its bearing value will be (450/1,000) x 100 = 45 per cent. This bearing value has become known as the California Bearing Ratio, generally abbreviated to CBR, with the "per cent" omitted.

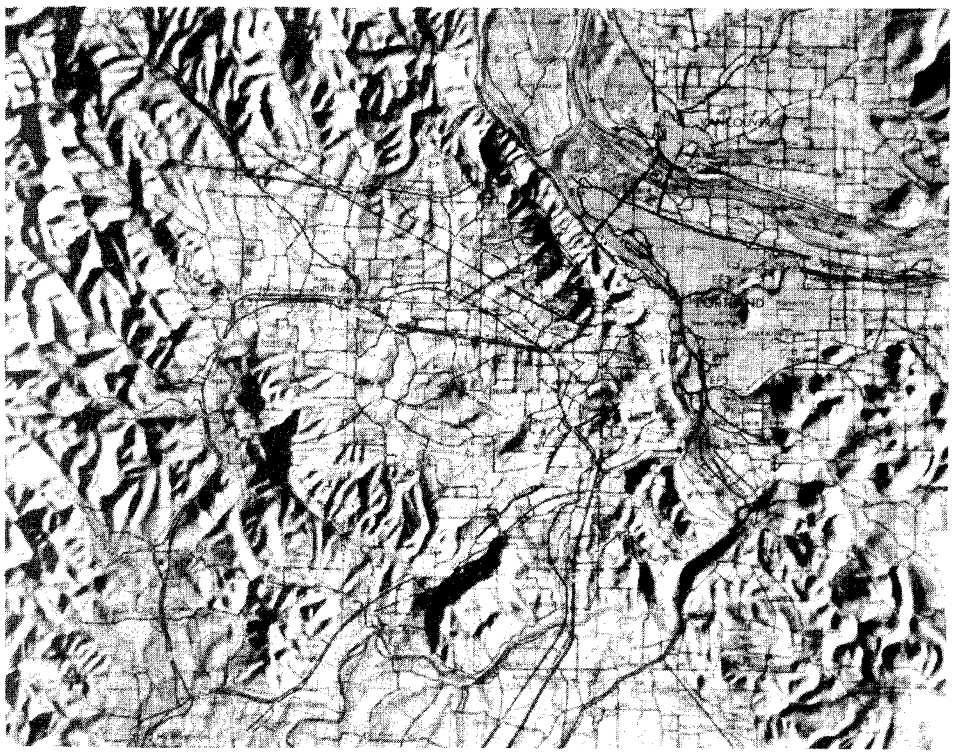
The Corps of Engineers and some highway departments use the CBR principle in conducting tests to evaluate the bearing value of materials. Methods of preparing specimens and conducting the test are given in ASTM D1883. Several agencies have their own modifications. There are numerous papers in the Proceedings of the Highway Research Board and in other engineering publications that give details on the various testing techniques and on data interpretation.

E. Plasticity Chart

The inclined "A" line represents an important empirical boundary between typical organic clays plotting above the "A" line and plastic soils containing organic colloids which plot below the line. Inorganic silts and silty clays (ML and MH groups) having liquid limits above 30, plot below the "A" line but they may range slightly above the "A" line if below 30 liquid limit.

The compressibility when compared at equal pre-consolidation loads is approximately proportional to the liquid limit, and materials of similar liquid limits will have approximately the same degree of compressibility. Soils having the same approximate liquid limits will have greater cohesion and less permeability with increasing plasticity index.

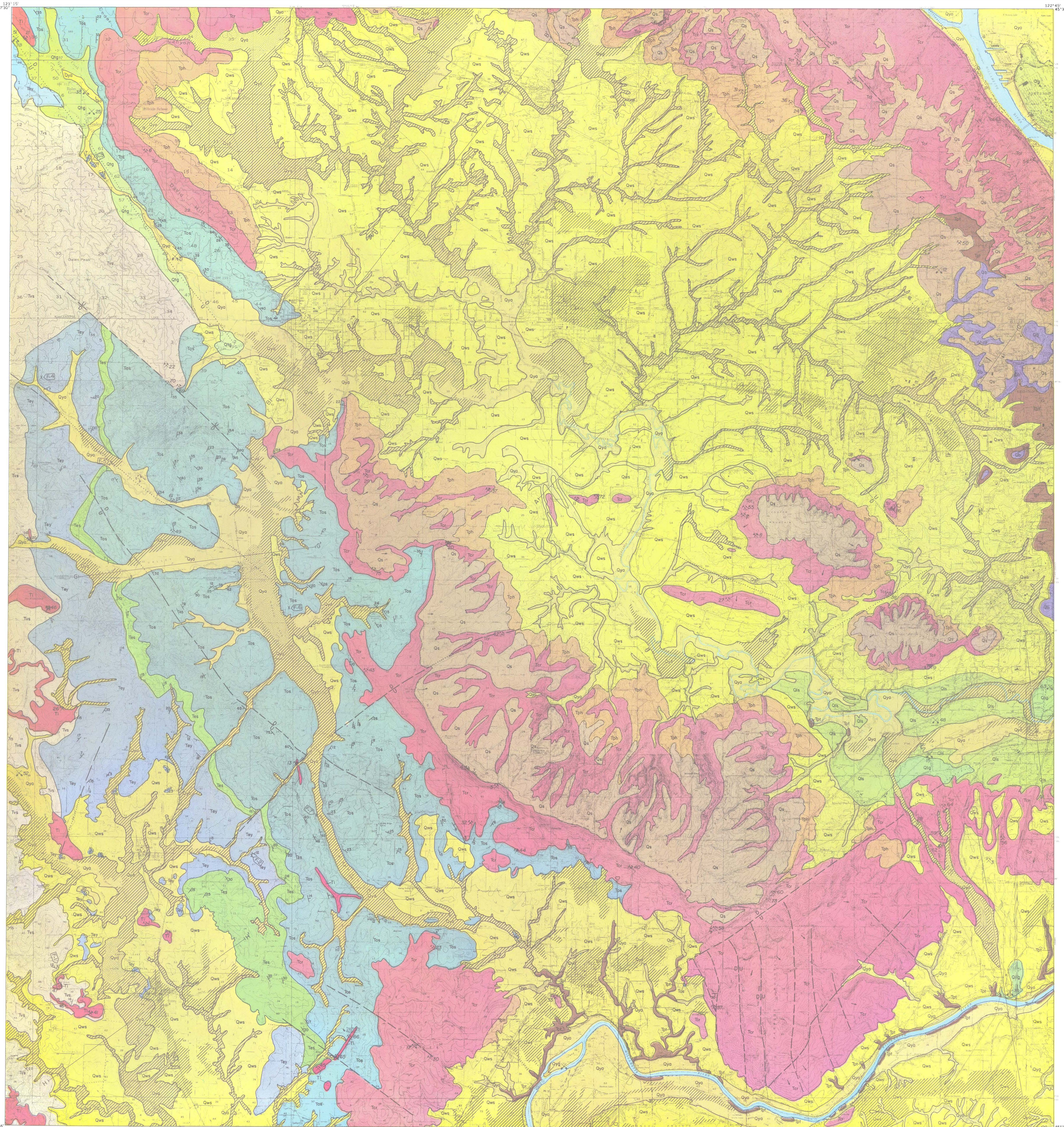




Cover: The Tualatin Valley and surrounding area. The photograph shows part of the Vancouver plastic relief map NL 10-8, series V-502 P. Vertical exaggeration is 2:1.

GEOLOGY AND SURFICIAL DEPOSITS OF THE TUALATIN VALLEY REGION, OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES



EXPLANATION

QUATERNARY

Recent

clay — Qya — peat

Young alluvium

Includes silt, sand, clay, and peat of present flood-plains. The average thickness is 20 to 30 feet. Contains poorly drained swampy areas having a permanently high water table. Clay and peat soils have separate pattern on map.

Upper Pleistocene to Recent

Qtg

Terrace gravel

Unconsolidated pebble gravel overlying sedimentary bedrock in older terraces of Gales Creek west of Forest Grove. Gravels range from 10 to 15 feet. in thickness.

Upper Pleistocene

Qlg

Lacustrine gravel

Torrential flood-deposited sand, gravel, and boulders with deltaic cross bedding. Gravel deposits are located near Durham, Cipole, and Wilsonville. The deposits range in thickness from a few feet to over 50 feet.

Qls

Lacustrine sand

Torrential flood-deposited sand with deltaic cross bedding, generally coarse grained with lenses of grit and pebbles. Occasional small cobbles or boulders can be seen in excavations. Occurs in Onion Flat area bordering the Tualatin River as far west as Six Corners and east to Tualatin. Deposits may be the fine-grained extension of lacustrine gravels.

Qws

Willamette Silt

Bedded silt and fine sand with occasional layers of clay, lenses of pebbly, fine-to-medium sand, with locally scattered granite and quartzite cobbles. Approximately 50 feet thick in center of valleys and thins toward valley margins at elevation ± 250 feet. Clay phase shown by separate map pattern.

Qs

Upland silt

Massive yellow-brown to buff, micaceous sandy silt and clayey silt. Contains occasional well-rounded basalt pebbles. Mantles ridges, spurs, and flatter areas in the Tualatin Mountains, Cooper and Bull Mountains, and the Chehalem Mountains. In the Tualatin Mountains it ranges up to 50 feet thick, and in other areas it is mostly 3 to 6 feet thick.

TERTIARY AND QUATERNARY

Upper Pliocene to lower Pleistocene

Qb

Boring Lava

Massive, blocky, gray porphyritic olivine basalt extruded from Mt. Sylvania and other local vents in the Tualatin Mountains. The basalt has an expanded texture (numerous small void spaces) and occurs principally as thin flows or intracanyon flows.

UNCONFORMITY

TERTIARY

Lower Pliocene

Tpt

Troutdale Formation

Poorly indurated gray and brown silt and clay, mottled yellow and reddish-brown silty fine sand, with occasional pebble conglomerate beds. The formation underlies most of the valley areas and extends locally up to elevations of 600 feet. Clay horizons are impermeable and highly plastic.

Tph

Helvetia Formation

Poorly indurated reddish-brown sand, sandy silt, and silty clay with local thin beds containing granitic, quartzite, and basalt pebbles. Gibbsite nodules are also common. Upper part of some exposures leached of red oxides. The formation extends to elevations of about 900 feet.

UNCONFORMITY

Middle to upper Miocene (?)

Tcr

Columbia River Basalt

Weathered and unweathered basaltic lava flows with interflow zones of breccia, ash, and baked soil. Unweathered flows are blue-black, dense, and finely crystalline basalt with massive columnar to close cubic joints. Weathered flows are reddish-brown to gray-brown, crumbly to medium dense basalt.

UNCONFORMITY

Lower middle and late upper Oligocene

Tos / Ti

Oligocene marine sediments undifferentiated

Indurated tuffaceous and basaltic sandstone, siltstone, shale, and occasional conglomerate beds, Tos. Weathers to silt and clay soils of moderate to high plasticity and locally to plastic bentonitic clay. Fine-grained, dark gray to black, close jointed, basalt intrusives of small areal extent, Ti.

Upper Eocene

Tes

Spencer Formation

Thick bedded to massive, well-sorted, friable, fine- to medium-grained felspathic sandstone with occasional thin-bedded carbonaceous siltstone and claystone interbeds in the northwest portion of its out-crop belt; becomes ± 50% siltstone in southern outcrop area. Sandstone weathers to thin permeable to slowly permeable sandy soils, and siltstone weathers to sandy clay soils of moderate plasticity.

UNCONFORMITY

Tey / Ti

Yamhill Formation

Well indurated thin-bedded shale and siltstone with occasional interbeds of green basaltic sandstone and poorly sorted tuffaceous sandstone, Tey. Shale and siltstone weathered to clay of high plasticity. Extensive landslides in outcrop area. Basalt and gabbro dikes and sills, Ti.

Upper middle Eocene

Tvs / Ti

Volcanics and sediments undifferentiated

Structurally complex basalt flows, pillow lava, tuffs, agglomerates, and breccias with well indurated marine siltstone and sandstone interbeds, Tvs. Sequence is introduced by coarse-grained gabbro and porphyritic basalt dikes and sills, Ti. Weathering is extensive and much of sequence is soft and friable.

GEOLOGIC SYMBOLS

Contact
Dashed where approximately located

Fault
Dashed where approximately located, dotted where concealed

47
Strike and dip of beds

Quarry — *Abandoned quarry* — *Sand, gravel, or clay pit.*

F-3 X
Fossil locality

Apparent dip

The preparation of this report was financially aided through a federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended.

Base maps from U. S. Geological Survey

SCALE 1:48 000

Geology by H.G. Schlicker and R.J. Deacon, 1967
Cartography by C.J. Newhouse

PLATE 2

GEOLOGIC CROSS SECTIONS OF THE TUALATIN VALLEY, OREGON

Geology by H.G. Schlicker and R.J. Deacon, 1967
Cartography by C.J. Newhouse

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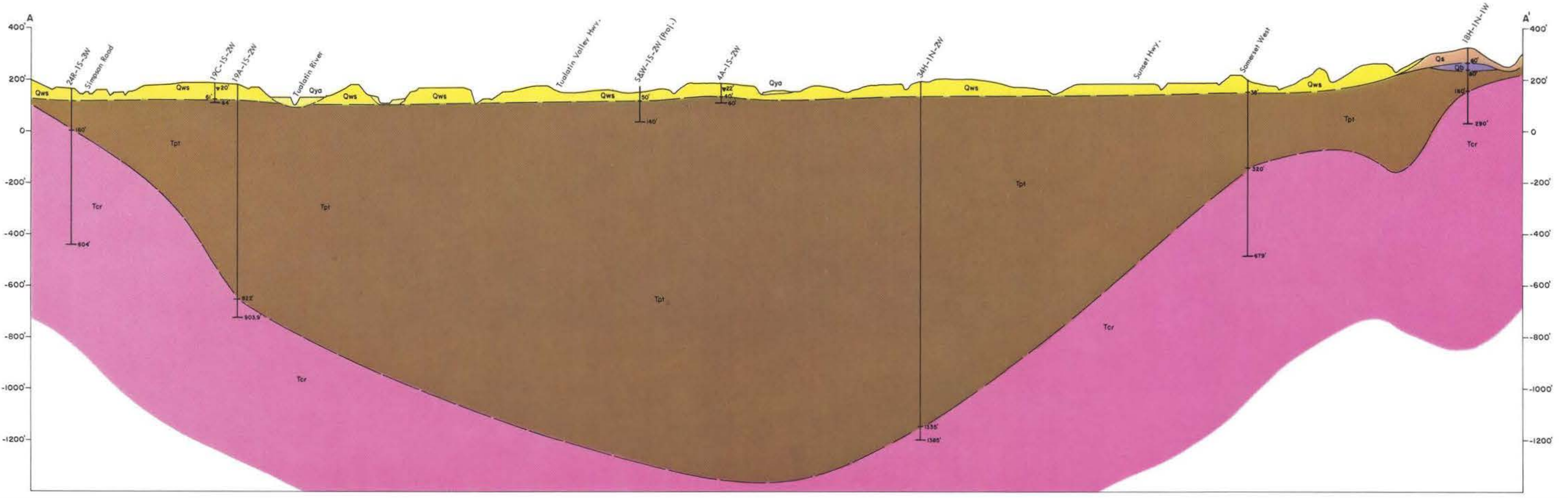
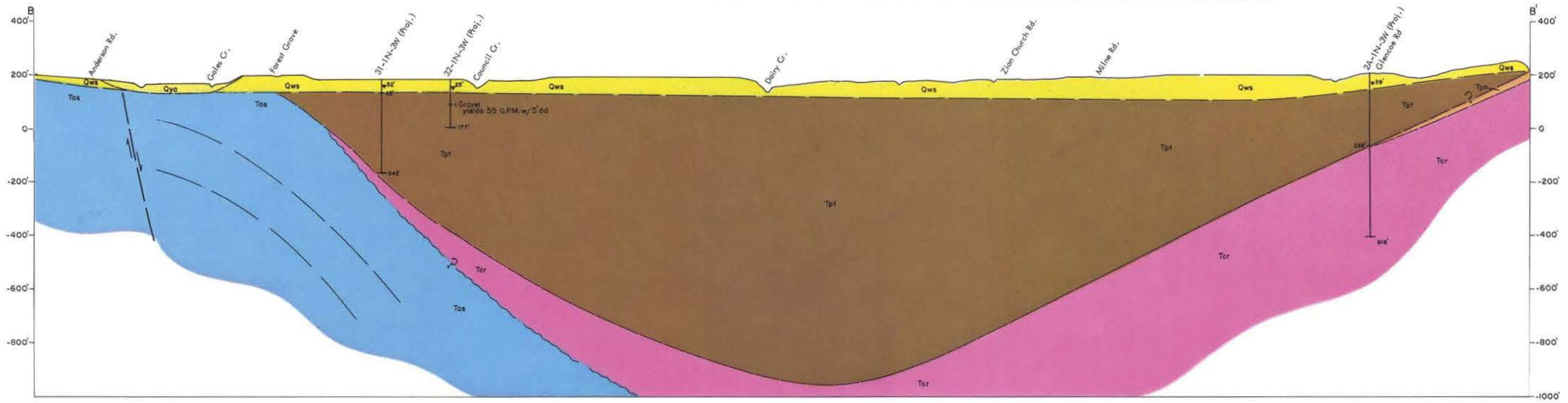
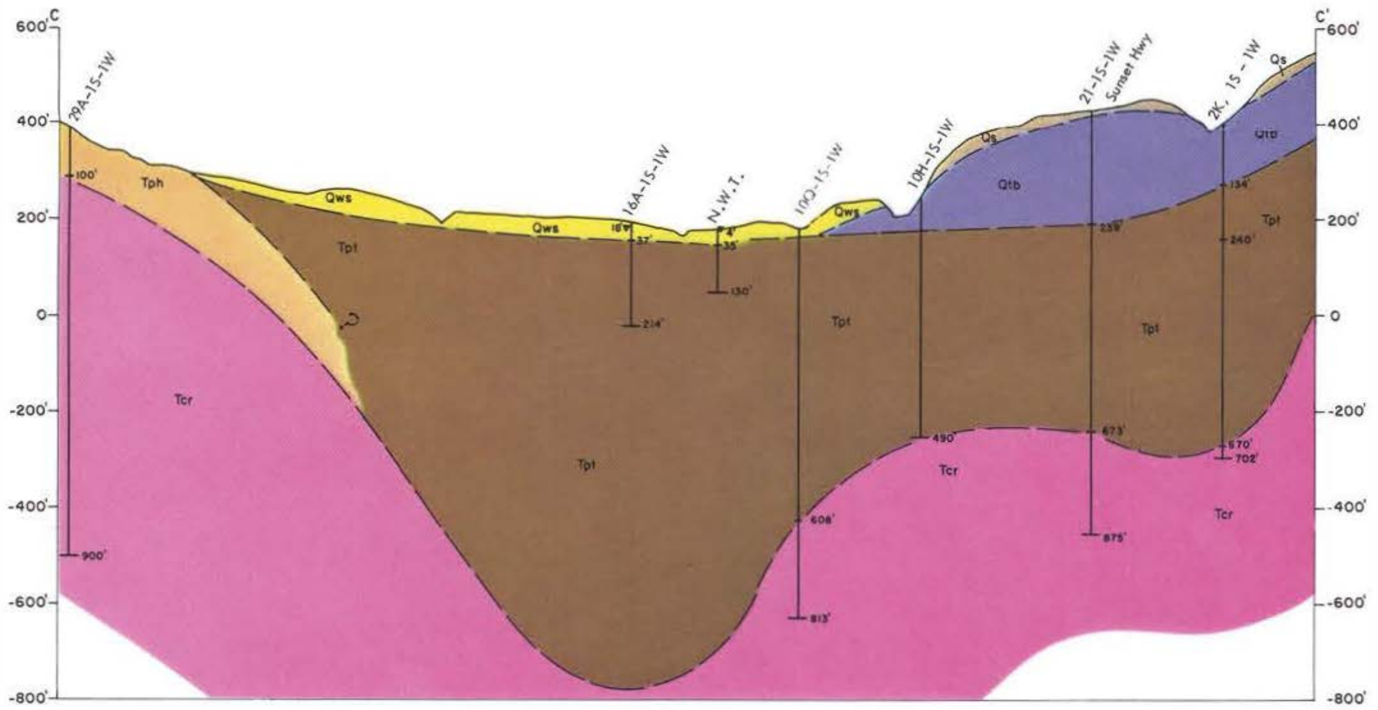
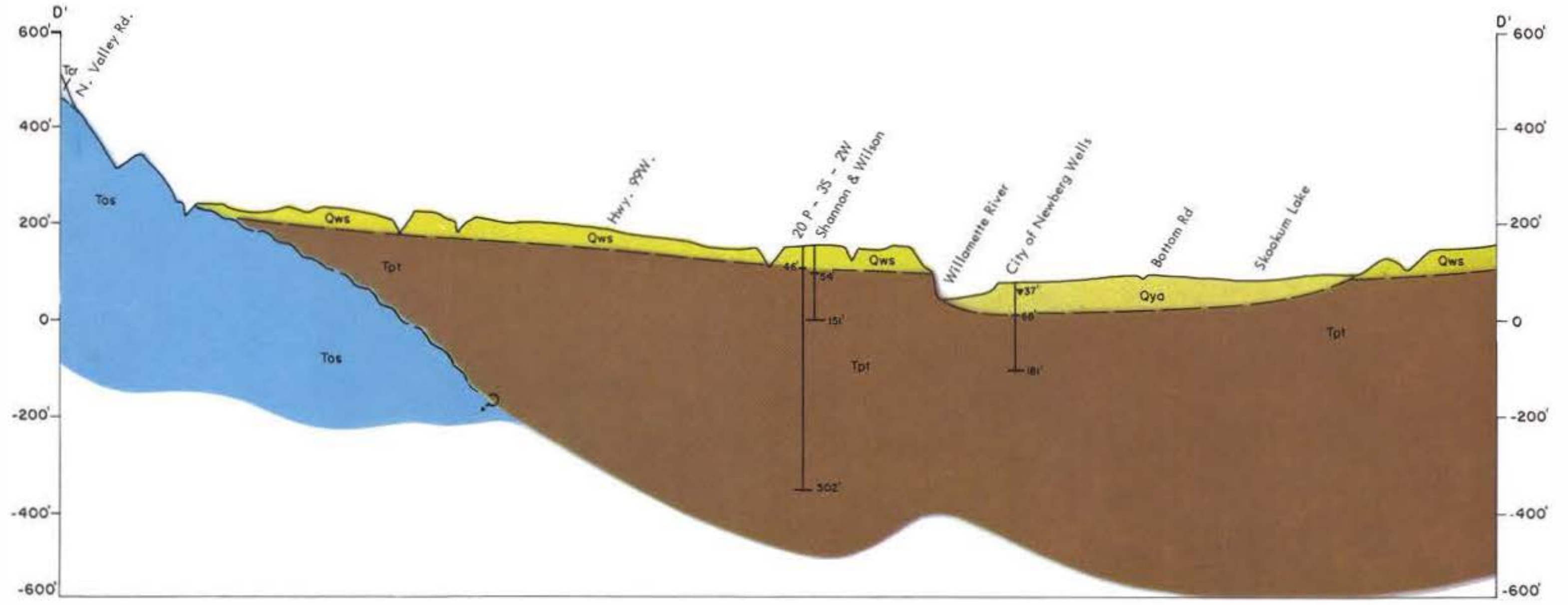
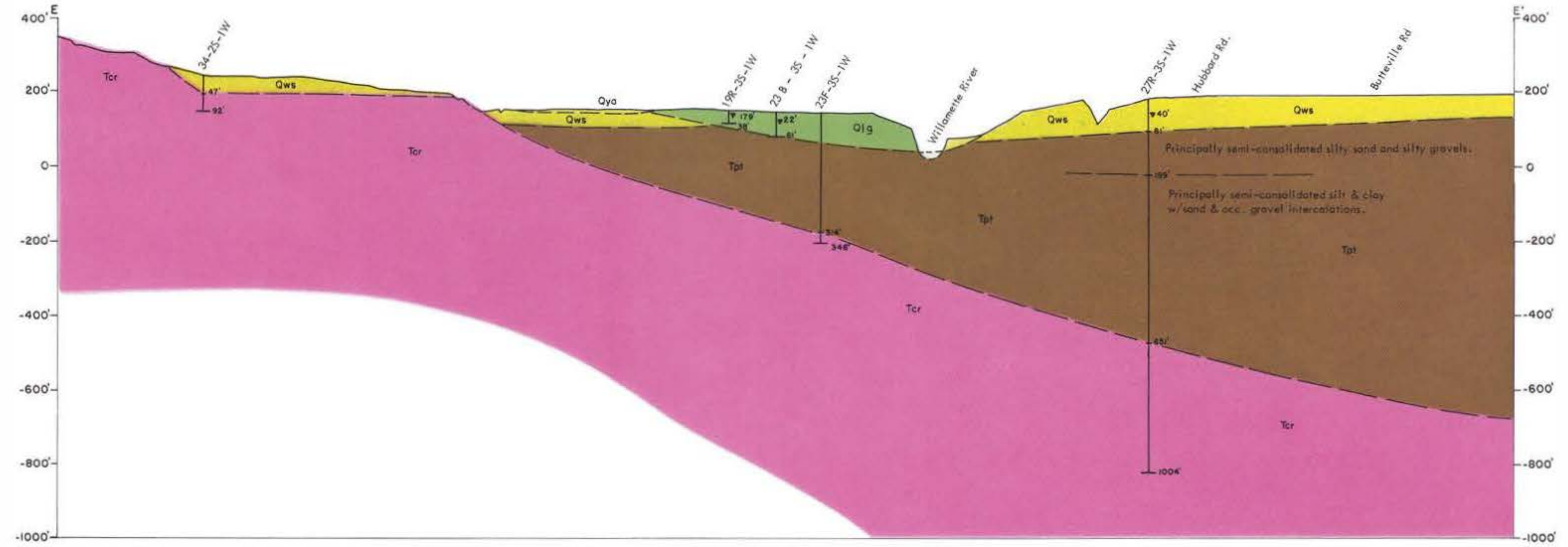
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

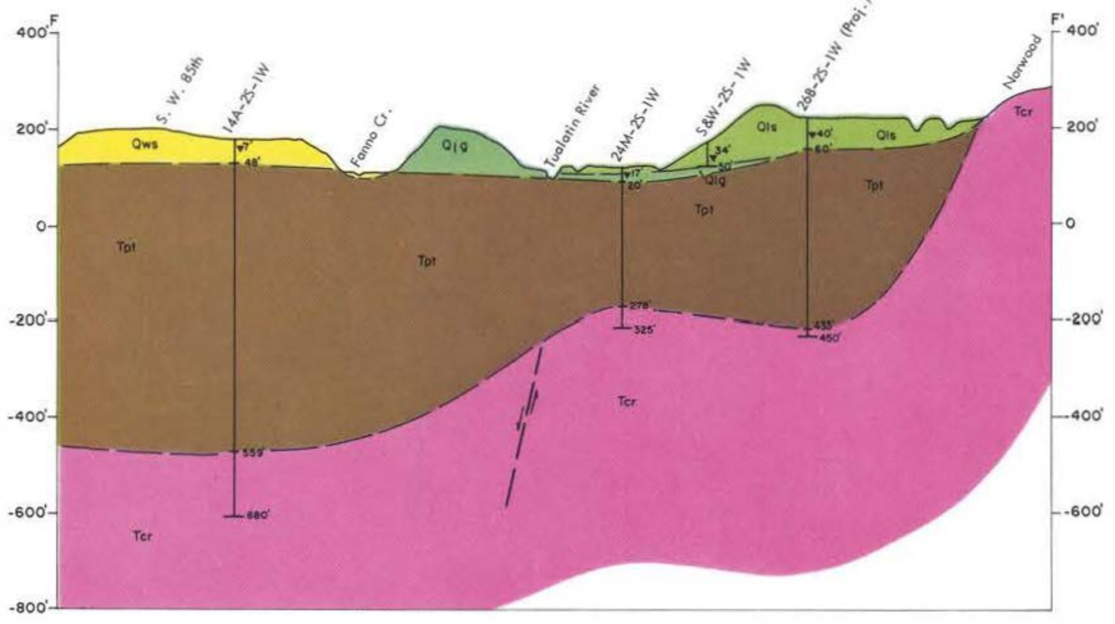


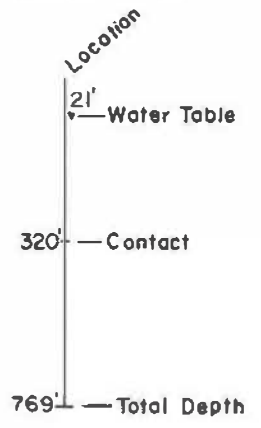


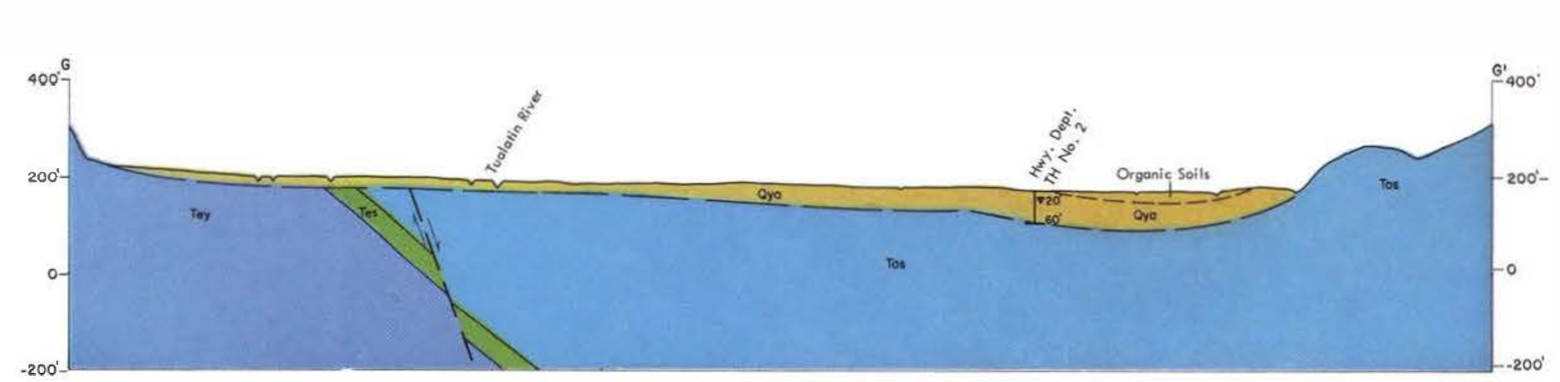












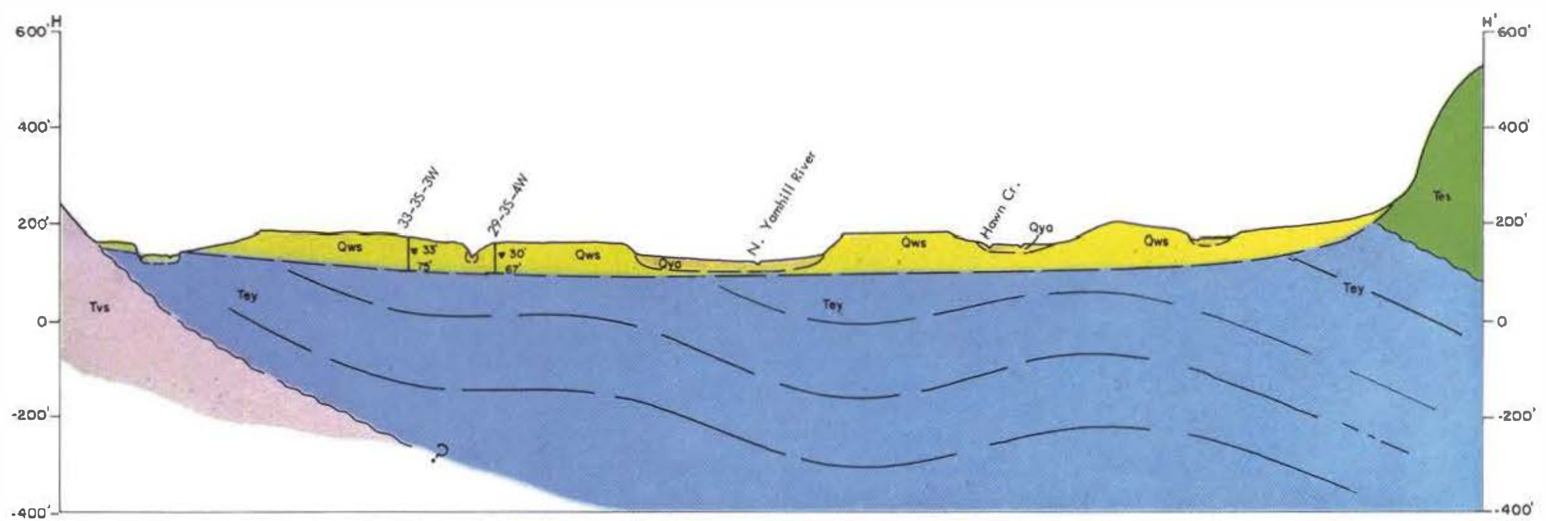
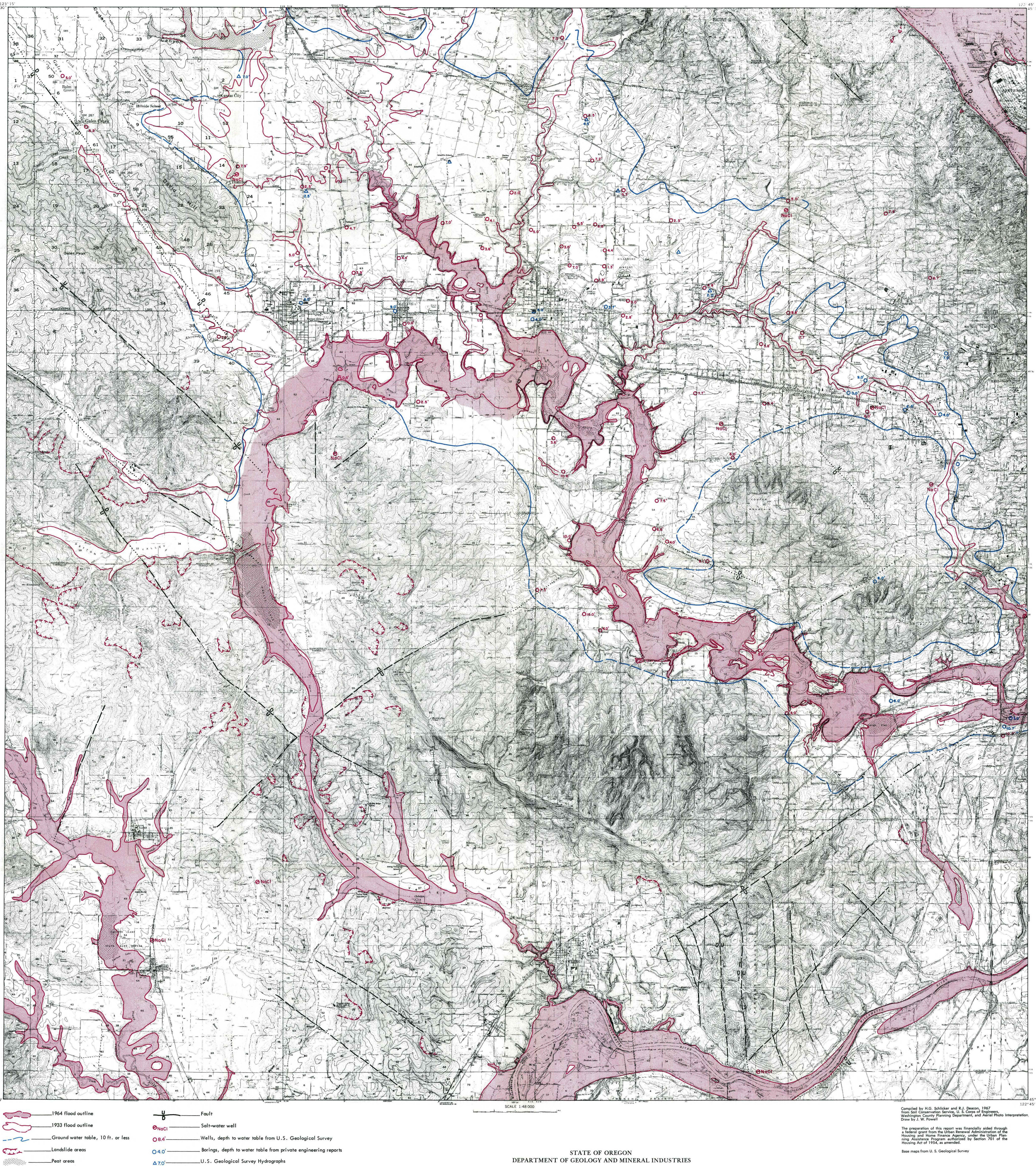


PLATE 3

GEOLOGIC HAZARDS MAP OF THE TUALATIN VALLEY REGION, OREGON



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Compiled by H.G. Schlicker and R.J. Deacon, 1967 from Soil Conservation Service, U. S. Corps of Engineers, Washington County Planning Department, and Aerial Photo Interpretation. Draw by J. W. Powell

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Base maps from U. S. Geological Survey

PLATE 4

MAP SHOWING THE DEPTH TO THE TOP OF THE COLUMBIA RIVER BASALT BENEATH THE TUALATIN VALLEY, OREGON

100 — Thickness of sediments overlying Columbia River Basalts

Tcr — Surface outcrops of Columbia River Basalt

● 220' — Boring to top of Columbia River Basalt (water wells)

SCALE 1:48 000

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

Compiled by H.G. Schlicker and R. J. Deacon, 1967
from D.H. Hart and R.C. Newcomb, 1965 and
Office of the State Engineer, 1967
Drawn by C.J. Newhouse

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