BULLETIN 99

GEOLOGY AND GEOLOGIC HAZARDS OF NORTHWESTERN CLACKAMAS COUNTY, OREGON

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STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

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GEOLOGY AND GEOLOGIC HAZARDS OF NORTHWESTERN CLACKAMAS COUNTY, OREGON

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GEOLOGY AND GEOLOGIC HAZARDS OF NORTHWESTERN CLACKAMAS COUNTY, OREGON

INTRODUCTION

PURPOSE AND SCOPE

Proper land management and land use planning require that engineers, planners, and developers have a good knowledge of the characteristics of the land. This report provides information concerning geologic factors important to land use and development in Clackamas County and includes maps showing geology and natural hazards. The report is designed to alert planners, engineers, County officials, and the public to these hazards so that, by proper land use planning and engineering, losses can be reduced to a minimum.

HOW TO USE

General

This report provides planners in Clackamas County with a synthesis of present thinking on geologic hazards and engineering geologic conditions within the study area. Those using this material should realize, however, that it is reconnaissance in nature and subject to refinement.

A regional study such as this does not take the place of site studies and on-site examination required for specific evaluations. It merely indicates regional conditions which should be considered by the developer and planner.

Prior to development, any property that may present geologic hazards indicated by this study should be inspected by a geologist. Where the geologist determines that no geologic hazards exist, development can proceed without an additional detailed study; if conditions are so extreme that the problems cannot be corrected within economic limits, additional study is not warranted, and the project should be abandoned. A detailed study, however, should be required if development is contemplated where surmountable hazards exist.

The report is organized to facilitate easy reference and use as a tool in decision making. The maps and tables interrelate the various hazards and geologic units. The text addresses specific hazards or topics and is structured around the formats of the map legends. The result is a logical progression of facts with potential for a wide variety of uses on various levels of inquiry ranging from general to specific (Figure 1).

Site evaluations

In general, data from this report should be used to assess the use potential and use limitations of a site and should be compared with specific site requirements of the proposed development and its surrounding area to determine if the development and site are compatible. Although the report is designed to guide and facilitate site evaluations, consultation of other sources of information is highly recommended.

Proposed developments in hazard areas should be accompanied by site reports prepared by licensed geologists who are responsible for the completeness and accuracy of the reports. An understanding of the limitations relative to map scale is necessary in evaluating on-site reports. The geologic map prepared by the geologist should be of adequate scale to exhibit the pertinent geologic features which are being considered.

Land use capability analyses

Data provided in this bulletin and on the maps can be used to develop land use capability maps, either directly or indirectly by using various sequences of overlays. Techniques such as these are appropriate preliminary exercises in the preparation of comprehensive plans or in their revision or refinement. To be valid, however, such maps should meet the following criteria:

1. The maps should be prepared for individual types of developments or for closely related types of development.
2. Capability categories described in the map legend should be realistic and meaningful in terms of field observations and informed professional judgment.
3. Scale must be properly appreciated, and decisions based on regional maps should be modified when more detailed site-specific maps are available.

Extrapolation of data

On the County and city levels, specialists commonly have detailed information and personal knowledge within their respective specialties but do not have a mechanism with which to project their observations into other areas. For example, an individual may have detailed site-specific information on septic-tank failures, hazardous soils, or landslides in one area but may not have adequate means of anticipating similar problems elsewhere. Both the text and maps in this report relate geologic units to specific hazards so that the specialist will be able to apply his expertise in areas where he lacks detailed information.

Policy formulation

This report can be used in conjunction with a realistic set of goals to formulate land use policies on local and regional levels. Such policies should represent a coordinated effort on the part of governmental agencies on various levels to consider all significant hazards and to make provisions for addressing local conditions as revealed by more detailed study or on-site investigation. A site investigation should evaluate the long-term effects on the surrounding area as well as on the specific site. Although policies should be designed in the best interests of society to protect the safety and well-being of the public, they should not be based on overreactions arising from inadequate or inappropriately applied information regarding geologic hazards.

Map scale and detail

Obtaining data of an appropriate level of detail for a particular task is often the most significant informational concern of the planner. Inventories are conducted for a variety of purposes and are available on several levels of detail. Confusion may result when the scale of the map is too small to display specific details needed for local site implementation. Maps made for regional application are seldom adequate for more precise site-specific decision making, the construction of large-scale zoning maps, or engineering design.

Where data are incomplete, arbitarary adjustment of the scale of the map will not generate the additional map detail that is needed. Increased detail requires that additional data be obtained by consultation, additional studies, and on-site investigation. The text of this report is primarily intended to supplement the maps and to provide understanding of the problems that need to be addressed for both regional planning and site-specific studies.

Responsibility of government regarding geologic hazards

County governments, as administered by their planning and building departments, are responsible for issuing building permits and for assuring that recommended design and construction standards are followed. Where appropriate data are available, planning departments provide information on the characteristics of the land.

The California courts have determined that the issuance of construction permits by a governmental agency for land development implies that dangerous or seriously damaging conditions are not likely to occur as a result of such construction or the continued presence of the development. Consequently, a permit-granting agency may be held responsible for damages incurred by the development if they are the result of lack of knowledge or lack of concern about geologic hazards.

In a court case between Sheffet and Los Angeles County (Los Angeles Superior Court Case No. 32487), the court ruled that the County was liable and must pay damages caused by water and mud flowing from a 12-lot subdivision above the plaintiff's property. In its decision, the District Court of Appeals declared:

> "... where a public entity approved plans for a subdivision including a drainage system, and there is damage to an adjacent property as a result of those improvements, the public entity, not the subdivider, is liable. The fact that the work is performed by the contractor, subdivider, or private owner does not necessarily exonerate the public agency if [they] follow the plans and specifications furnished or approved by the public agency.
>
> "When the work thus planned, specified, or authorized results in injury to adjacent property, the liability is upon the public agency under its obligation to compensate for the damage resulting from the exercise of its governmental power."

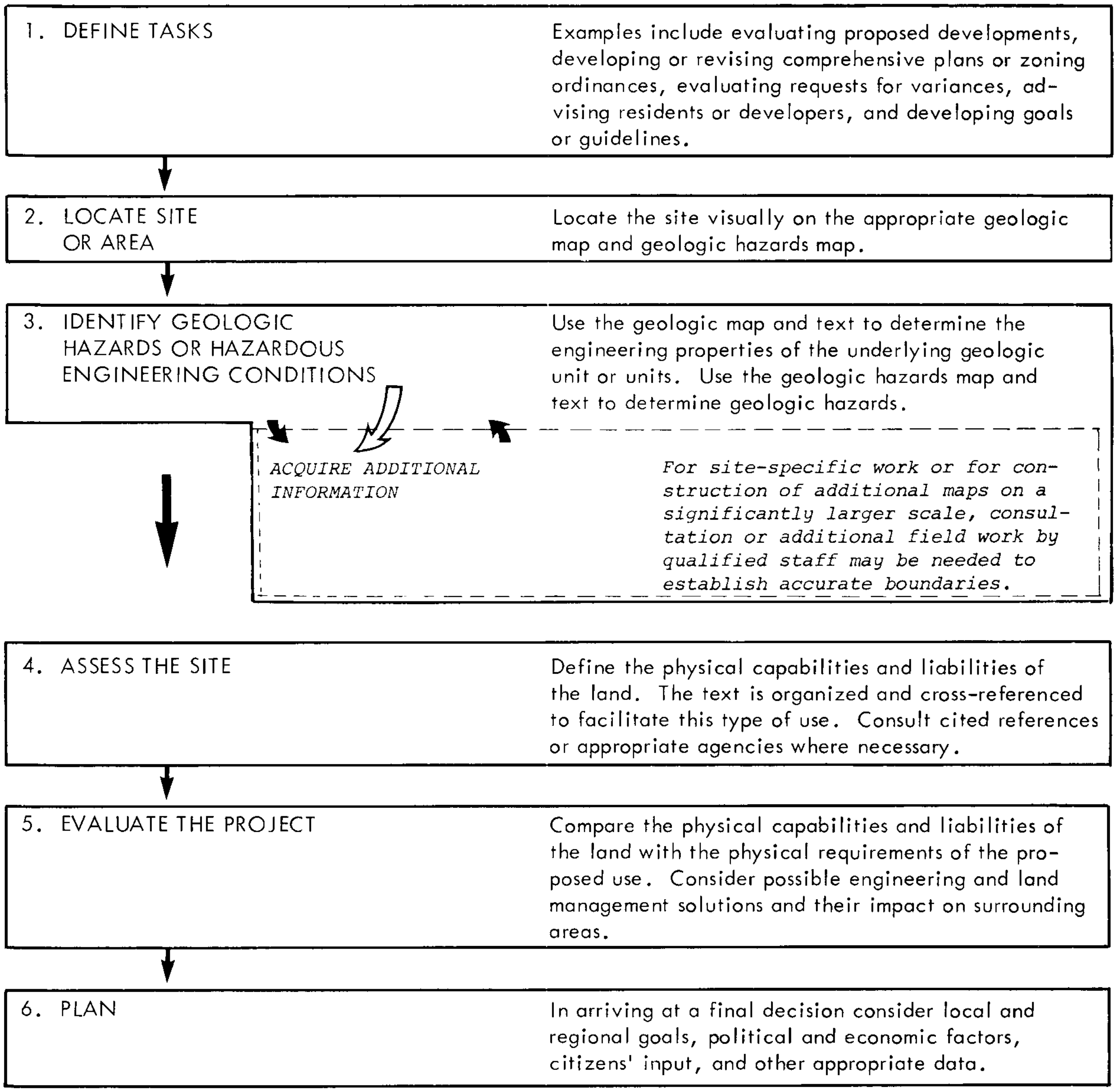

Figure 1. Suggested use of this bulletin in land use decision making.

The Sheffet decision was upheld by Superior Court Judge William Fox of Pasadena, California. In addition, the County's petition for a rehearing was refused by the State Supreme Court. Refusal by the Supreme Court to rehear the case established a judicial precedent.

Since the Sheffet decision places the responsibility on the permit-granting agency, that agency is now faced with the necessity of obtaining adequate information on hazardous conditions for the protection of local government and the unwary public, who may tend to minimize or ignore these hazards until a casualty occurs.

Construction by county public works departments can also result in liability. The Los Angeles Superior Court (Case No. 684595) ruled that road building by Los Angeles County had triggered further damaging landslides in the Palos Verdes Hills and that the County must pay damages of approximately $6 million. Since that time, additional lawsuits have cost the County at least another $12 million.

In processing applications for subdivisions and other land use developments, physical characteristics of the site should be reviewed. With a geologic or hazards map and supporting information on soils and geology, the permit-granting agency can advise developers and builders of conditions which must be evaluated.

Suggested planning actions

In Clackamas County, various combinations of geology, topography, and climate have produced a number of geologic and natural hazards, including steep slope, landslide, hazard soils, flooding, erosion, earthquake, and volcanic hazards (Table 2).

The magnitude of problems associated with these hazards can vary from insignificant to overwhelming. In all situations, the problems must be thoroughly understood, and appropriate measures must be used to mitigate the hazards. If the cost of correcting the problem adequately is too great, the project should be abandoned.

On the basis of the information included in this report, the County should

1. Prepare or modify land use plans appropriately.
2. Specify grading requirements, lot size, and water and sewage requirements for each area according to the geologic hazards present.
3. Prepare ordinances and guidelines for geologically hazardous areas relative to the geologic and engineering geologic reports required.
4. Establish a procedure for review of reports and inspection of proposed construction sites.
5. Implement a system for site inspection during and following construction to verify that recommendations in the reports are being followed.

This report is based on reconnaissance mapping and does not include sufficient data for specific site studies. The following discussion addresses the most prevalent hazards in the study area. Other hazards not specifically mentioned in this report should be identified and addressed by the consultant and the developer in specific site studies.

Review of reports required by the County

The approval and issuance of a construction permit by the County depends upon a favorable review, by County personnel or a consultant to the County, of reports required from the developer. Engineering reports should be reviewed by a licensed engineer and geology reports by a licensed geologist.

The County should provide guidelines specifying the major items to be covered in the report. The detail and extent of the study will vary according to local conditions and the type of development.

Several states, including Oregon, license geologists. The State of California has prepared guidelines for standards of the practice of geology which licensed geologists are urged to follow in making investigations and in preparing reports. The Oregon licensing bill provides that geologists adhere to a code of ethics which includes the requirement that they provide accurate and complete geologic reports to clients. Although the State of Oregon does not regulate geologic reports, Clackamas County should prepare and adopt guidelines to assure that reports meet its minimum standards.

Clackamas County has already instituted ordinances that require developers to obtain site reports from geotechnical engineers and geologists. The County should assign geologists and soii scientists to review development plans and make on-site inspections. The purpose of these reviews is to assure the County, client, and developer that the quality and completeness of reports are up to current technical and scientific standards. Thus any party concerned can be satisfied that a reasonable attempt has been made to obtain and apply the information needed to properly construct and maintain the development.

PREVIOUS STUDIES

The area covered by this study is included in a geologic map of the Portland area (scale of 1:96,000, with text), published by the Department in 1942 (Treasher, 1942b). The same general area was mapped in greater detail by Trimble (1963), who emphasized some of the engineering characteristics of the geological units. Trimble's map has been modified in this study.

These and numerous other maps and geological reports covering parts of the study area are arranged below by subject matter and listed in the bibliography:

Geologic maps
- Treasher, 1942a, b
- Wells and Peck, 1961
- Trimble, 1963
- Peck and others, 1964
- Schlicker and Deacon, 1967

Soil maps
- Kocher and others, 1926
- Piper, 1942
- Soil Conservation Service, 1970
- Other Soil Conservation Service unpublished maps

Ground water
- Griffin, 1956
- Hart and Newcomb, 1965

Loessal silt
- Theisen, 1958
- Lentz, 1977

Geophysical studies and faulting
- Berg and Baker, 1963
- Dehlinger and others, 1963
- Schlicker and others, 1964
- Couch and others, 1968
- Thiruvathukal and others, 1970
- Balsillie and Benson, 1971
- Schmela, 1971
- Couch and Deacon, 1972

Flooding (prehistoric)
- Allison, 1932; 1978a, b
- Stauffer, 1956

Flooding (recent)
- U.S. Army Corps of Engineers, 1970a, b, c
- Palmer and Bauer, 1974

Rock material resources
- Gray and others, 1978

Stream erosion
- Erickson, 1950
- Baldwin, 1957
- Palmer and Bauer, 1974

Volcanoes
- Crandell and Mullineaux, 1971
- Allen, 1975
- Crandell, 1975

SOURCES OF DATA

This report is based largely on original field work by the authors. It also includes data from published and unpublished sources listed in the preceding section and in the bibliography. In addition, soil reports by the U.S. Soil Conservation Service ORS (Oregon Revised Soils) sheets, which describe engineering characteristics, were correlated with geologic units.

Engineering reports released by clients of the engineering consulting firms of Dames and Moore, Shannon and Wilson, and L. R. Squier, Inc., were used to define engineering characteristics of geologic and soil units more precisely.

Aerial photos, sidelooking aerial radar (SLAR) imagery, and topographic maps were used to identify major lineaments, land stability problems, and stream erosion.

Flood-plain information by the U.S. Army Corps of Engineers has been reproduced in part in this report. For additional information, consult the U.S. Army Corps of Engineers publications listed in the bibliography and flood maps prepared for Clackamas County.

GEOGRAPHY

The study area includes all of Clackamas County north of latitude 45°15′ and west of longitude 122°15′. It borders Multnomah County on the north and Washington and Yamhill Counties on the west. The southern boundary west of the Pudding River adjoins Marion County (Figure 2).

The total area covers about 360 sq mi of gently sloping uplands and flood plains with deeply incised stream valleys and steep to irregular valley slopes and terrace escarpments. Elevations range from less than 100 ft along the Willamette River to more than 1,200 ft along the eastern edge of the area.

The Willamette River, the major stream, is located in the western part of the study area. Its tributaries are the Tualatin River to the west and the Clackamas River to the east. Several large tributaries to the Clackamas River are Rock, Abernethy, Clear, Deep, Eagle, and Tickle Creeks.

The area has a mild, temperate climate with average temperatures ranging from 65.2° F in July to 43.0° F in January. A maximum temperature of 107° F has been recorded during the summer, while freezing temperatures in winter are normally of short duration

Table 1. *Population of Clackamas County and major cities in the study area**

	1978	1970	1960	1950	1940
County total	220,000	166,088	113,038	86,716	57,130
Canby	7,100	3,813	2,168	1,671	988
Estacada	1,750	1,164	957	950	526
Gladstone	9,350	6,254	3,854	2,434	1,629
Happy Valley	1,450	——	——	——	——
Lake Oswego	21,700	14,615	8,906	3,316	1,726
Milwaukie	18,530	16,444	9,099	5,253	1,871
Oregon City	14,700	9,176	7,996	7,682	6,124
Sandy	2,580	1,544	1,147	1,003	473
West Linn	11,600	7,091	3,933	2,945	2,165
Wilsonville	2,380	1,001	——	——	——

*Source: Oregon Blue Book, 1979.

and rarely fall below 10° F. Snow seldom lasts more than a few days.

Annual rainfall ranges from low of 40 in. near Wilsonville to 70 in. near Sandy.

POPULATION

In 1840, the total population of settlers in the Willamette Valley was about 40 adults and 50 children. By 1940, the population of Clackamas County was 57,000. Since 1940, it has grown to 220,000—an average annual growth rate of about 3.6 percent (Table 1). The growth rate appears to be stabilizing; at the present rate, however, the County population will surpass 300,000 by the year 1987, about a 50 percent increase over the present.

Clackamas County's main industries are services, trade, manufacturing, construction, agriculture, wood, and wood products, in that order. Increasing numbers of the population work outside the County, primarily in Portland.

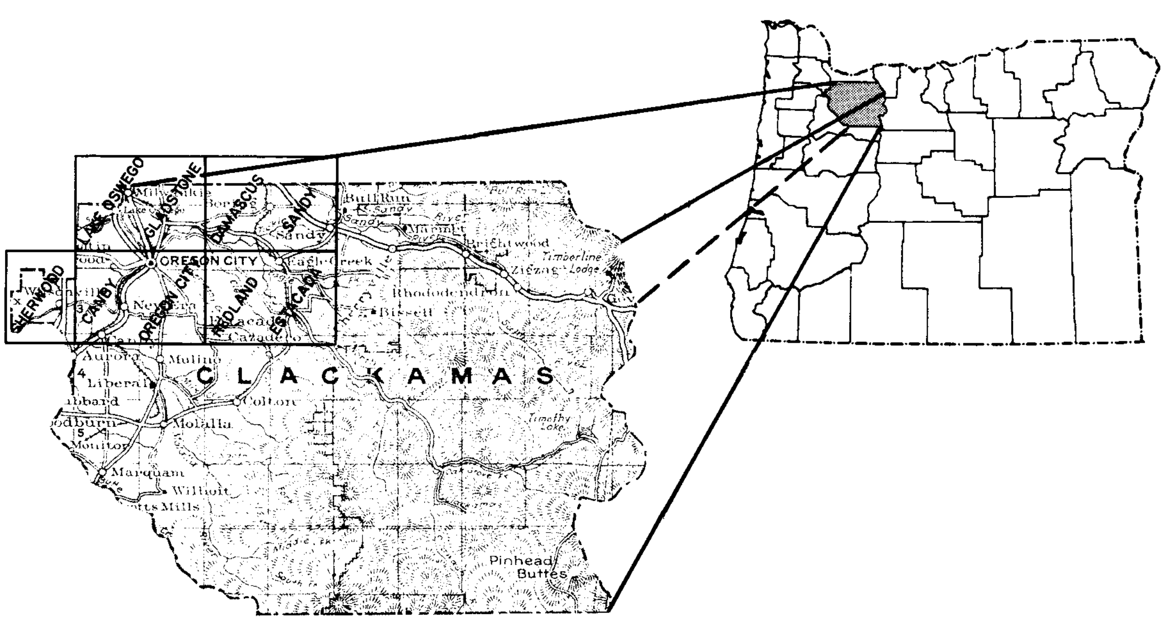

Figure 2. Index map of study area showing 7½-minute quadrangle map coverage.

ACKNOWLEDGMENTS

The authors appreciate the cooperation given by numerous individuals; consulting geotechnical firms; and local, County, State, and Federal agencies who provided the basic data for this report. We owe special thanks to Allen J. Gerig, Soil Scientist, U.S. Soil Conservation Service, Clackamas County office, for providing new data on the soils of Clackamas County and access to his agency's unpublished maps for the mapping of hazard soils; Jerry A. Marshall, Deputy Development Services Administrator, Richard L. Polson, Chief Soil Scientist, and Gary Cook, Planner, all of Clackamas County Department of Public Works, for information on field problem areas in the County, including hazards and soils, and for general review of the soils and landslide maps and the text; Paul W. Hughes, Consulting Engineering Geologist, Lake Oswego, Oregon; and William C. Doak, Consulting Soil Scientist, Oregon City, Oregon, for review and comments on the soil and landslide maps.

Richard W. Couch, Oregon State University, contributed seismic data. John D. Beaulieu and Joseph F. Riccio, Oregon Department of Geology and Mineral Industries, critically reviewed the report and made helpful suggestions. Charles L. Rosenfield, Oregon State University, provided radar imagery of Clackamas County, and William R. Akre, U.S. Army Corps of Engineers, flood information and use of photographs. Darolyn Burch, Portland State University, helped with paleomagnetic work and geology of the Boring Lava. Marvin H. Beeson and Michael Moran, Portland State University, Portland, and Beverly Vogt, Oregon Department of Geology and Mineral Industries, provided information on the Columbia River Basalt Group. Beeson and Moran also were sources of information on the Boring Lava.

Subsurface information for specific sites of Clackamas County project areas was provided by the Oregon State Highway Department; Dames and Moore, Portland; CH2M Hill, Portland; and L.R. Squier, Inc., Lake Oswego.

Among the many others who provided information and deserve our gratitude are William S. Bartholomew, Office of the State Engineer, Salem; Kenneth C. Robbins, Dames and Moore, Portland; Kerry K. Parkinson, CH2M Hill, Portland; L.R. Squier and Mavis D. Kent, L.R. Squier, Inc.; Joseph B. Gonthier and Charles A. Collins, Water Resources Division, U.S. Geological Survey, Portland; and Leonard A. Palmer, Portland State University.

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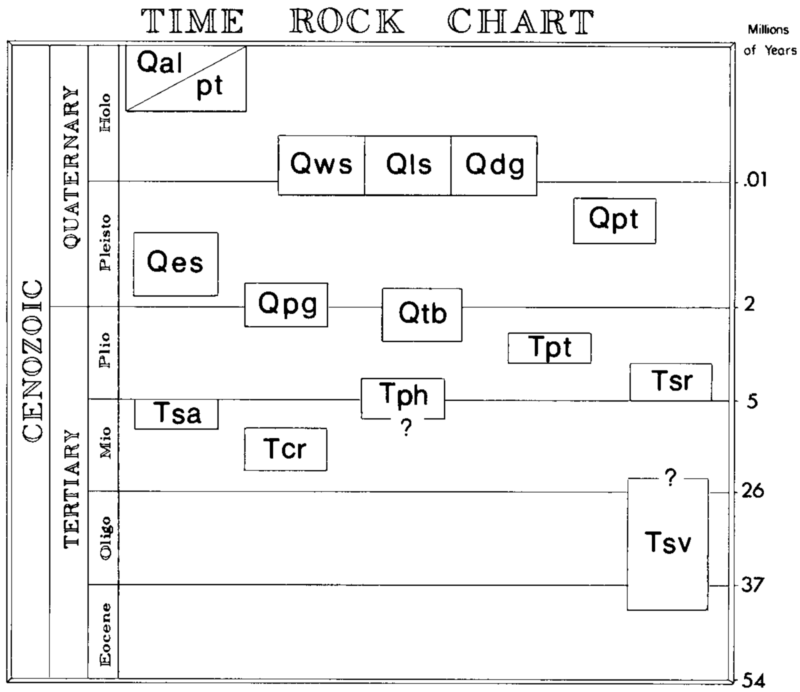


Description of units

Qal—Recent alluvium:
Unconsolidated, fine- to coarse-grained sediments in stream channels and adjacent flood plains. Includes low terrace deposits.

pt—Recent peat and organic soils:
Generally buried beneath several feet of silt in certain bottomland areas.

Qws—Pleistocene to Recent Willamette Silt; Qls—cross-bedded sand; Qdg—deltaic gravels:
These units are unconsolidated, cross-bedded to graded sedimentary beds deposited by late Pleistocene glacial floodwaters.

Qpt—Pleistocene terrace deposits:
Unconsolidated cobble and boulder gravel and mudflow deposits up to 200 ft thick.

Qes—Pleistocene eolian silt:
Loessal silt deposited on uplands above 250 ft elevation. Deposits occur up to 40+ mi south of the Columbia River.

Qpg—Pliocene-Pleistocene gravels:
Weakly indurated, poorly sorted gravel and mudflow deposits occurring along the eastern edge of the map area.

Qtb—Pliocene-Pleistocene Boring Lava:
Lava and breccia occurring in volcanic buttes and adjacent flows. Light-colored, open-textured olivine basalt weathered in places to a red soil containing large residual basalt boulders.

Tpt—Pliocene Troutdale Formation:
Sand and gravel lenses, well sorted, with up to 30 percent quartzite clasts.

Tsr—Pliocene Sandy River Mudstone:
Moderately indurated, fine-grained, nearly impermeable sediments overlying older bedrock units. Uniformly bedded, nearly flat lying to shallow dipping beds.

Tph—Pliocene Helvetia Formation:
Pebbly, fine-grained sand and silty clay, light- to reddish-brown color, overlying Columbia River Basalt Group on the flanks of the Tualatin, Parrett, and Bull Mountains.

Tsa—Miocene Sardine Formation:
Andesitic lavas, indurated pyroclastic rocks, and mudflow breccias; deeply weathered to reddish-brown laterite.

Tcr—Miocene Columbia River Basalt Group:
Lava flows composed of dark, fine-grained porphyritic basalt of low olivine content. Columnar-jointed basalt flows 30 to 60 ft thick, separated sometimes by red baked soil horizon.

Tsv—Eocene Skamania Volcanic Series:
Basalt and andesite flows and tuff breccia exposed in the Willamette River south of Oregon City. Basalt is highly zeolitized and altered.

Figure 3. Time distribution of geologic units.

GEOLOGY

GENERAL

Geologic units include basalt lavas; tuffs; flow breccias; and lacustrine, fluviatile, and eolian sediments (Figure 3). The volcanic units represent four periods of volcanism ranging from late Eocene to late Pliocene or Pleistocene in age. Sediments were deposited from Pliocene time to the present. Unconformities and local gaps in the geologic sequence separate each major geologic sequence.

GEOLOGIC HISTORY

The geologic history of this area begins with late Eocene volcanism. At least some of the lavas flowed into water, as indicated by pillow structures found in the Eocene volcanic rocks. Extensive folding and erosion of the Eocene volcanic rocks occurred prior to the mid-Miocene extrusion of flood basalt of the Columbia River Basalt Group, which emanated from numerous fissures in northern and eastern Oregon, eastern Washington, and western Idaho. In late Miocene time, uplift in the Cascade Mountains to the east resulted in deformation of the Columbia River Basalt Group. Volcanic activity was renewed along the western edge of the Cascade Mountains at the close of the Miocene, culminating in the deposition of the Sardine Formation (Rhododendron of Trimble, 1963). The Sardine Formation is composed of agglomerates, flow breccias, mudflows, and lavas.

Folding during Pliocene time produced lowlands and lakes which were later filled with sediments from adjacent uplands. These deposits, the Sandy River Mudstone and overlying Troutdale Formation, were then subjected to gentle warping and subsequent erosion.

Late Pliocene to early Pleistocene volcanism produced the viscous lavas, agglomerates, and flow breccias of the Boring Lava in the present-day areas of Clackamas and Multnomah Counties. These Boring Lava flows emanated from vents, now the sites of numerous volcanic buttes such as Highland Butte (Figure 4). In places where the lava flows were thin, weathering has nearly completely altered the lavas to red clay soils.

Following the Boring Lava event, gravel and finer sediments were deposited in the Portland area. Glacial floods of great magnitude produced channeled scablands and deltaic deposits of torrentially cross-bedded gravels (Figure 5).

Finally, within the last 100 to 200 years, minor volcanic activity has occurred on Mount Hood and Mount St. Helens.

GEOLOGIC UNITS

Skamania Volcanic Series (Tsv)

Rocks of the Skamania Volcanic Series, comprised of basalt and basaltic andesite flows and tuff breccias, are the oldest known geologic rocks exposed in the mapped area. These Eocene rocks crop out on small islands and adjacent banks of the Willamette River between Oregon City and Canby in an area covering about ¼ sq mi. In outcrop, the rocks are dark greenish gray and contain numerous cavities and fractures filled with white zeolites. Jointing ranges from blocky to massive.

A 1,500-ft-thick section of the unit is exposed in the area. Because the lower contact is not exposed, the total thickness of the unit is unknown.

The Skamania Volcanic Series unconformably underlies the Miocene Columbia River Basalt Group. In a railroad cut at Coalco, 1 mi north of the community of New Era on the Willamette River, the basalt dips about 35° to the east, while the overlying Columbia River Basalt Group dips only 9° (Schlicker, 1953). Therefore, the Skamania Volcanic Series is older than mid-Miocene, based on the angular unconformity with the overlying Columbia River Basalt Group and the similarity of the Skamania Volcanics to the Eocene Goble Volcanics exposed elsewhere in Oregon and Washington.

Engineering characteristics: The rock is primarily basalt, with minor pillow basalt and interbedded breccia zones. Abundant secondary minerals, primarily zeolites, fill or line numerous cavities and fractures. Since the rock is altered and decomposed, it has

Figure 4. Looking south toward Highland Butte, located 4 mi southwest of Estacada. Butte shown on the skyline is Boring Lava (Qtb) vent. Valley in foreground has thin alluvial soil overlying weathered Boring pyroclastic and lava flow rocks.

Figure 5. Steep foreset bedding of deltaic gravels (Qdg) in Durham gravel pit, caused by torrential current of Missoula Flood. Floodwaters poured through gap at Lake Oswego and flowed in northwesterly direction at this locality.

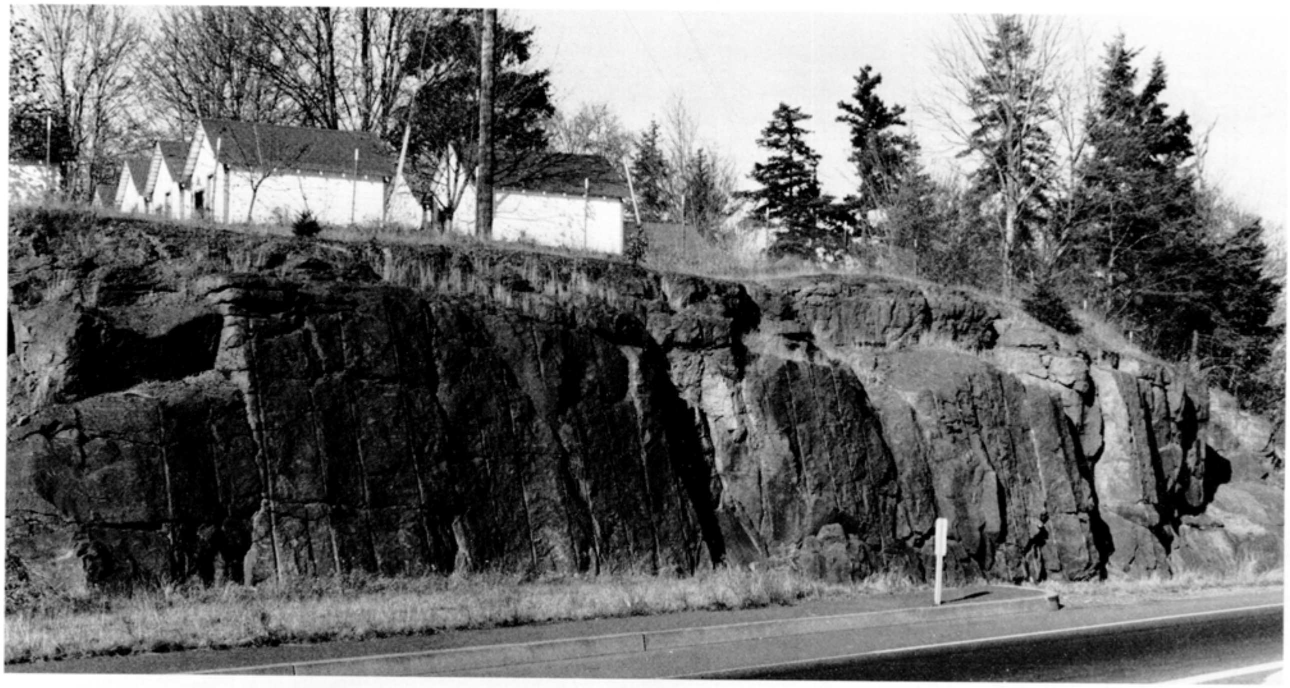


Figure 6. Roadcut in coarsely jointed Columbia River basalt (Tcr) near Gladstone. Straight vertical lines are drillholes.

little value as road metal. It could be used, however, for embankment material. Because the unit occurs in railroad and highway cuts and is of questionable quality, it is limited as a source of rock in this area.

Columbia River Basalt Group (Tcr)

The Columbia River Basalt Group is exposed along Oatfield Heights Ridge from the Clackamas River to Milwaukie (Figure 6), from West Linn to Oswego Lake, and on Pete's Mountain. It also occurs in the subsurface of much of the remainer of the County.

In outcrop, the Columbia River Basalt Group is a series of lava flows whose individual thicknesses range from 15 to 150 ft. The total thickness of the unit is about 975 ft. Individual flows have been found to extend for great distances with no apparent changes in thickness or chemical character. Numerous workers have mapped flows on the Columbia Plateau, and Beeson and others (1975) have identified and mapped several flows in the Portland area.

Flows are often separated by thin, red-baked soil zones, but in some instances by tuff beds, gravels, or thick soils that supported stands of large timber during the Miocene. In the vicinity of Oregon City, thin red soil zones are exposed in highway roadcuts. In general, thick flows of the Columbia River Basalt Group have a lower portion composed of fine-grained to glassy rock which cooled rapidly, a middle zone of columnar jointed rock, and an upper zone of vesicular or scoriaceous rock, often deeply weathered to a punky rock of gray to brown color, mostly altered to clay containing the white outlines of plagioclase crystals.

The Columbia River Basalt Group was gently folded and faulted prior to the deposition of younger sedimentary units and lavas. In areas of downwarp, the basalts are deeply buried, but in topographically high areas, they are laterized to a reddish clay containing large spheroidally weathered boulders and blocks.

The Columbia River Basalt Group overlies lower Miocene and older sediments and volcanic rocks. It overlies the Skamania Volcanic Series along the Willamette River south of Oregon City. At Oregon City and eastward it is overlain by the Sandy River Mudstone, or where that is missing, the Troutdale Formation or Boring Lava. The age of the Columbia River Basalt Group, based on stratigraphic relationships and age dating, is middle Miocene.

Engineering characteristics: Exposures of unweathered Columbia River basalt make ideal sources for road metal or basalt aggregate. Much of the rock is moderately close jointed and during blasting and excavation breaks into sizes that can be handled by a small-jawed crusher. Scoriaceous, glassy, or blocky and deeply weathered rocks present in some exposures are not as suitable for aggregate. Partially weathered rock, however, can be used for select embankment.

Saprolite often occurs in soil interbeds within the basalt, and one extensive zone of thick saprolite is

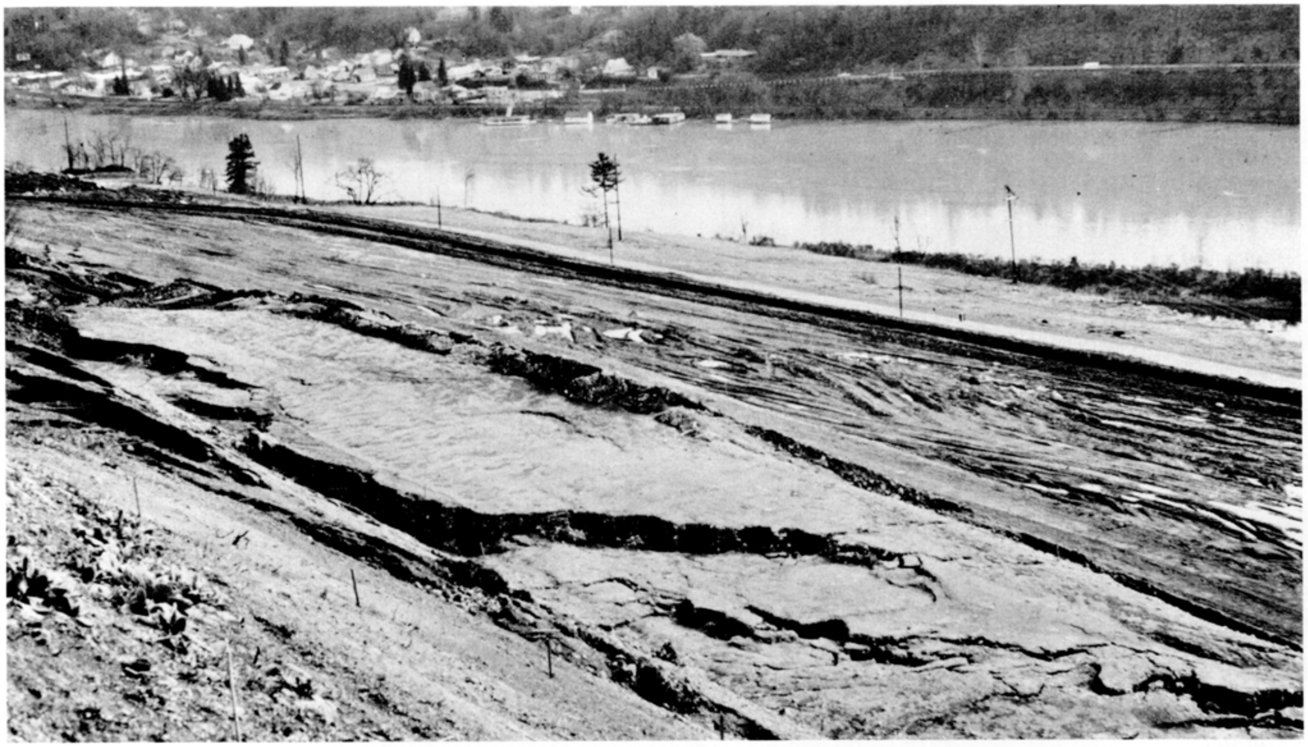


Figure 7. Landslide destroyed cut slopes and roadbed during I-205 construction 1 mi south of Willamette River bridge in West Linn. Several million cubic yards of material had to be removed to correct slide problem.

Figure 8. Closeup of same landslide. Weathered Columbia River basalt (Tcr) overlying Vantage horizon failed during construction of large cuts.

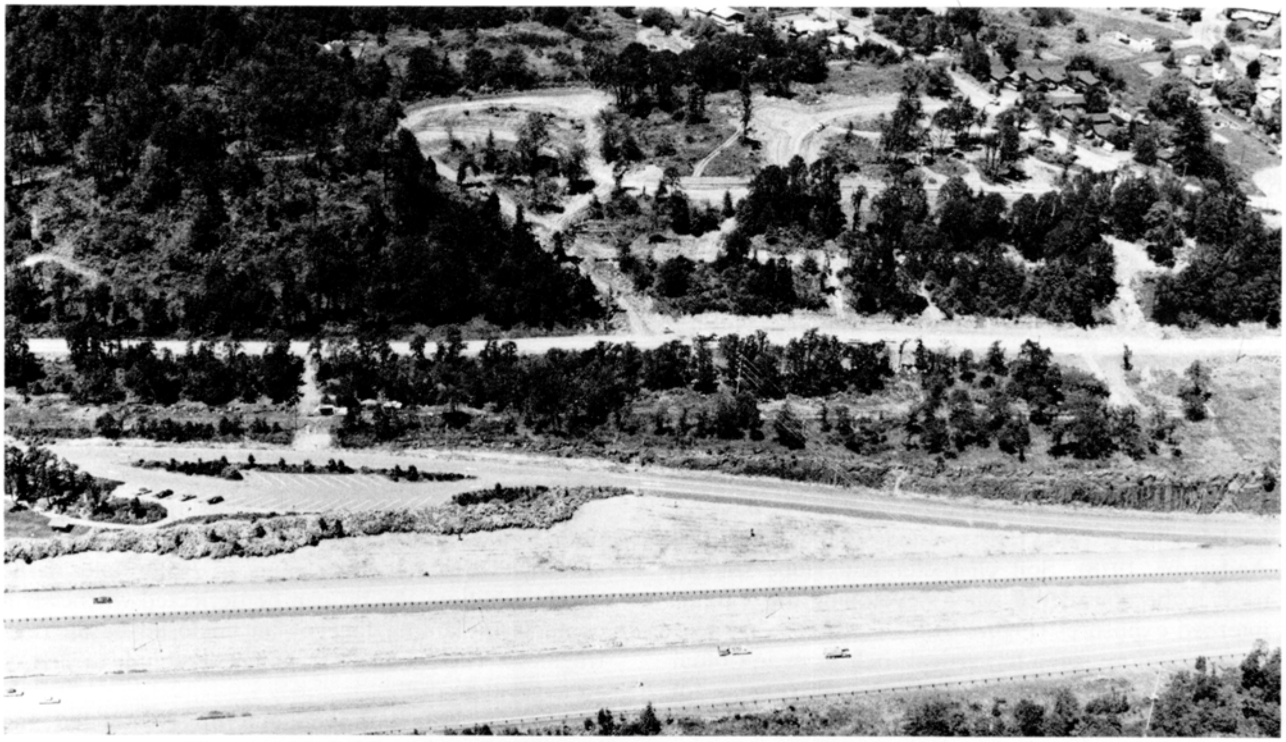
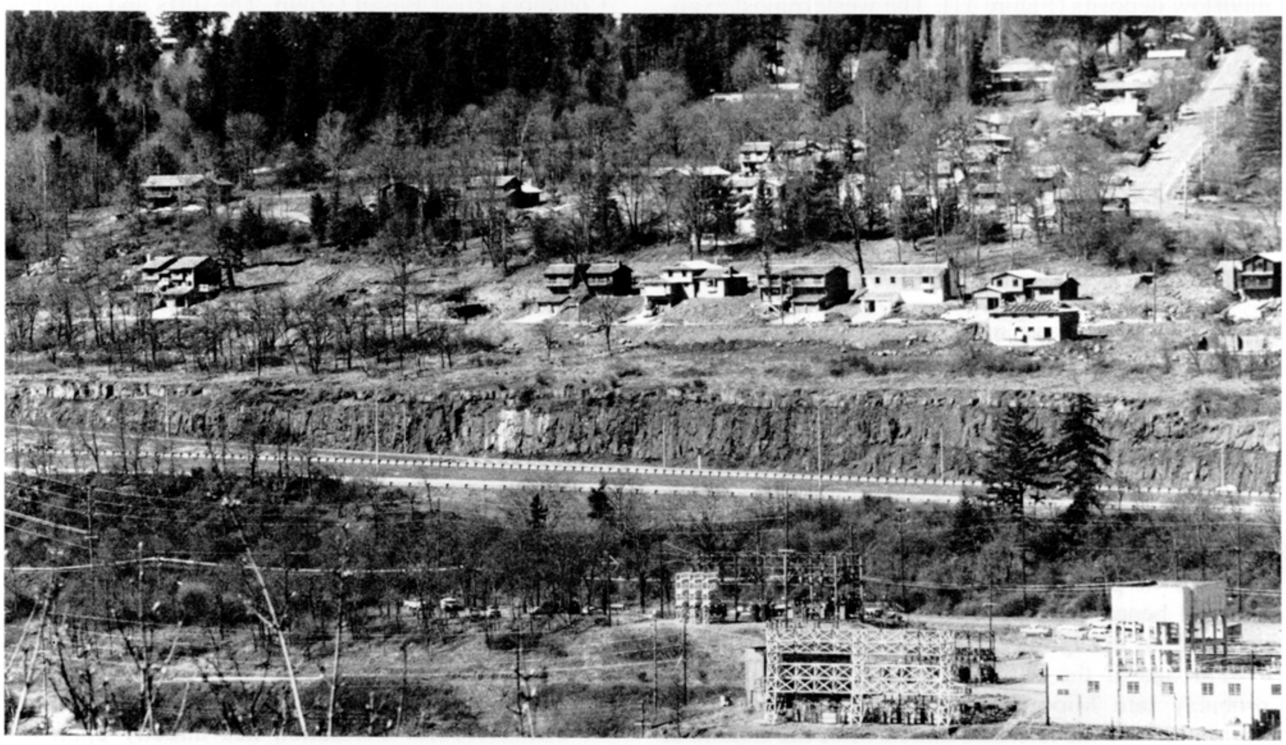


Figure 9. Houses being built on foundation of Columbia River basalt (Tcr). I-205 landslide (Figures 7 and 8) occurred to left (south) of area shown here.

Figure 10. New housing development in West Linn, southwest of I-205 bridge. Freeway cut is in Columbia River basalt (Tcr). Steep cut slopes may present rockfall hazards. Weathered basalt and residual boulders overlie basalt at building site.



informally called the Vantage horizon (Beeson and others, 1975). Where the bedding dips adversely (out of the cut face) at about 10° or more, but less steeply than the cut face, bedding plane slides can be expected to occur (Figures 7 and 8). This not only affects the cut area, but surface failure can progress upslope and cause damage in those areas. The Vantage horizon is particularly significant with regard to bedding plane slides.

The Vantage horizon is an easily recognized weathering and soil zone at the top of the Grand Ronde flows of the Columbia River Basalt Group. Deformation during Columbia River basalt time produced low, marshy areas where small lakes and forests developed. Prior to emplacement of later lavas, a thin soil developed over the carbonaceous sediments. This horizon has been recognized by workers in the Portland-Clackamas area (Beeson and others, 1975, 1976; Anderson, 1978). Soil character and slope stability need to be considered when developing the Vantage interbed exposures (Figure 9).

In addition, steep to vertical rock faces in Columbia River basalt often produce rockfall (Figure 10). For example, major roadcuts on Highway 99E have experienced rockfall problems in the past.

Sardine Formation (Tsa)

The late Miocene Sardine Formation is exposed only in the southeast part of the mapped area and is composed of hypersthene andesite, flow breccia, and mudflow deposits (Figure 11). The westernmost exposures are entirely mudflow breccia, but flow rocks occur eastward from near Estacada and predominate east of the map boundaries. The Sardine Formation thickens eastward toward the source but according to Trimble (1963) does not exceed 600 ft in the mapped area.

Originally the rocks were mapped by Hodge (1933), who named them the Rhododendron Formation. Treasher (1942a,b) and Trimble (1963) followed this nomenclature. Similar rocks mapped in the Santiam River area by Thayer (1939) were called the Sardine Series. Peck and others (1964) dropped the name Rhododendron when they included the unit in their more regional Sardine Formation.

The Sardine Formation conformably overlies the Columbia River Basalt Group (Peck and others, 1964) and is disconformably overlain by the Sandy River Mudstone (Trimble, 1963). The upper Sardine is laterized in places to a depth of about 10 ft. The material beneath the laterite zone has been appreciably altered to saprolite.

The age of the Sardine Formation in this area is probably late Miocene because of its stratigraphic position above the laterized middle Miocene Columbia River Basalt Group and its disconformable relationship with the overlying Pliocene Sandy River Mudstone. In addition, fossils found within interbeds in the Sardine Formation have been dated upper Miocene (Thayer, 1939).

Engineering characteristics: The Sardine Formation occurs in the southeast corner of the study area, where housing developments are not expected to occur in the near future. It is likely that cuts and embankments will utilize materials from the Sardine Formation, and the most likely rock units will be the mudflow breccias. Aside from bedding plane slides in areas of adverse dip, this material is quite stable.

Excavation of mudflows may be difficult because the unit contains angular blocks of rock up to 6 ft or more across. The mudflow is extremely well cemented and, unless weathered, will resist ripping. Drilling prior to blasting is difficult because the unit contains volcanic ash which easily plugs up the air holes in the bit. In addition, the bit can be deflected whenever it contacts a slanting face of an enclosed basalt rock fragment. The hard rock fragments preclude the use of an auger-type drill.

The upper 10 ft of some outcrops is laterized, and immediately below this horizon, a silica-enriched saprolite has developed. These materials should make impermeable embankments if they are compacted at optimum moisture; otherwise, absorbed moisture will weaken the structure, and slope failure could occur.

Since the unit can be up to about 600 ft thick, wells drilled for water may not penetrate to the underlying Columbia River Basalt Group. The tuffs and mudflow breccias usually are not water bearing and cannot be depended upon as a source of water.

Helvetia Formation (Tph)

The name Helvetia Formation is applied to poorly indurated Pliocene sedimentary deposits of reddish-brown, laterized, pebbly sand, silt, and clay that overlie the Columbia River Basalt Group. 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 roadcuts 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. Roadcuts in the vicinity of Helvetia expose a minimum of 25 ft of this material, and water-well logs in other places indicate reddish-brown clayey soils up to about 75 ft thick overlying the Columbia River Basalt Group.

The Helvetia Formation lies directly upon the

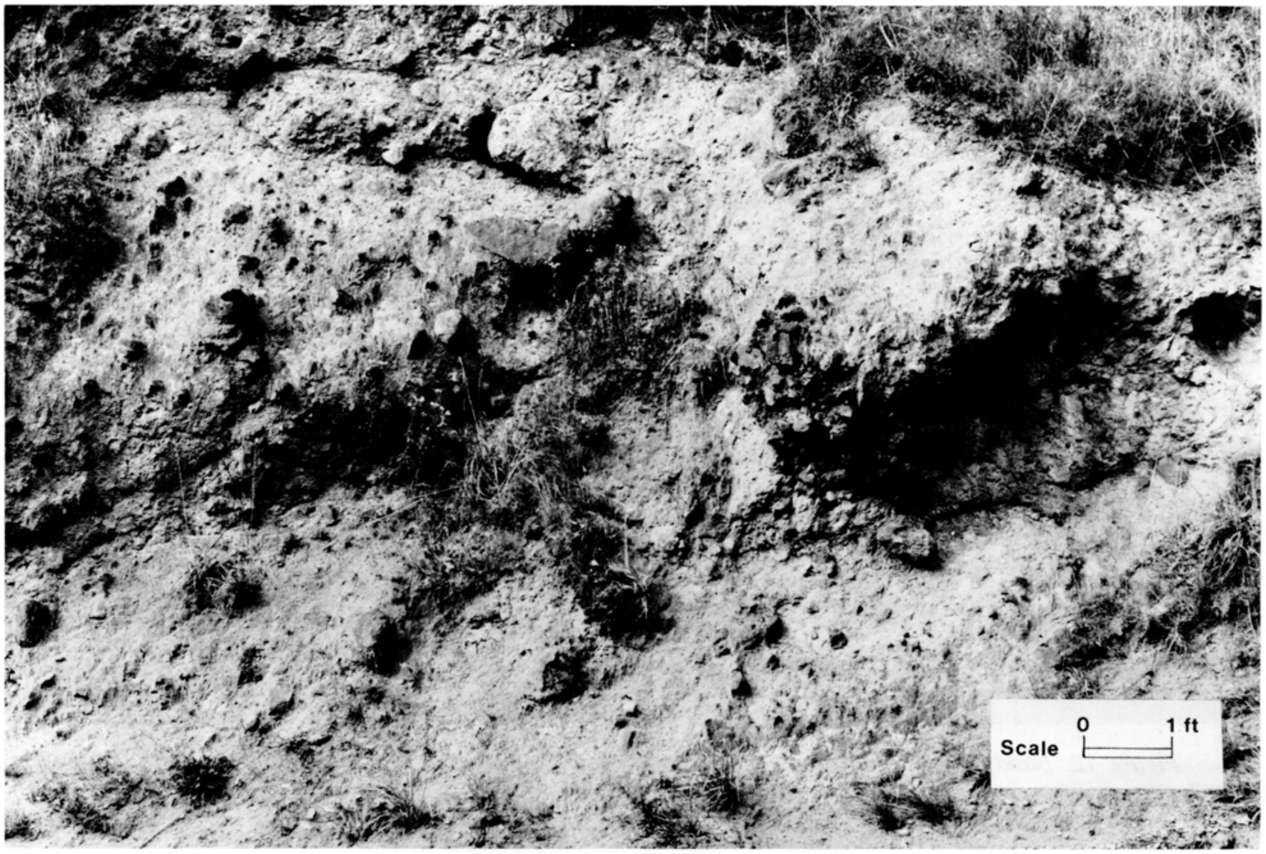


Figure 11. Mudflow deposit of Sardine Formation (Tsa), 1 mi southwest of Estacada.

weathered surface of the Columbia River Basalt Group on valley slopes at elevations ranging from 200 to about 900 ft. The Helvetia Formation is found southeast of Sherwood on the northeast flank of Parrett Mountain. This formation is overlain at the valley margins from about 250- to 300-ft elevations 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 considered to be correlative with the Sandy River Mudstone 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.

Engineering characteristics: Available test data show that soil from the Helvetia Formation is moderately plastic. Roadcuts are stable and will stand vertically to heights of 10 to 15 ft; but in cut slopes of 1:1 or 1.5:1, erosion by gullying is common. 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 on 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.

Sandy River Mudstone (Tsr)

The Pliocene Sandy River Mudstone is an extensive lacustrine deposit comprised of well-bedded fine sand and silt, with an occasional gravel lens. The mudstone occurs in the subsurface beneath the Willamette Silt throughout most of the northern Willamette Valley (Figure 12). It unconformably overlies the Sardine Formation in the southeastern part of the map area, and it also overlies the Columbia River Basalt Group in most other areas of the County.

Originally, the Sandy River Mudstone was considered by Hodge (1933) and Treasher (1942a,b) to be the lowermost unit of the Troutdale Formation; however, distinct differences in lithology and origin have led

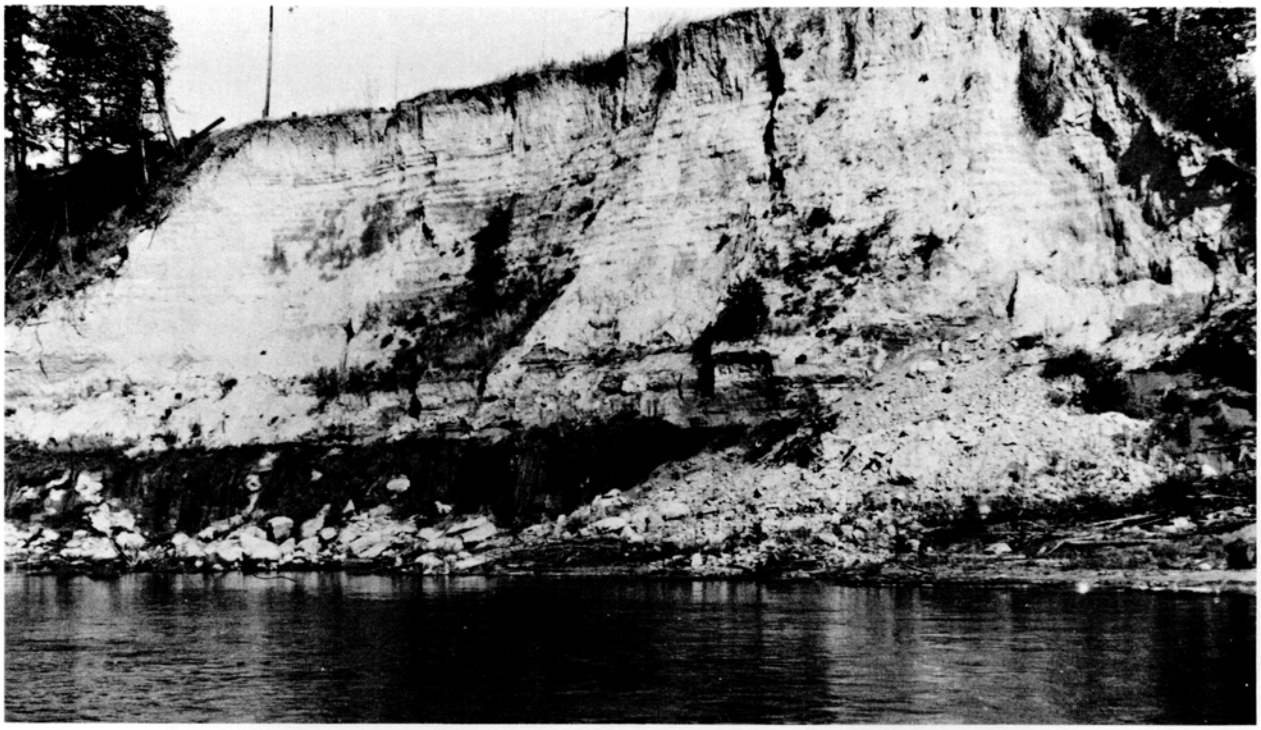


Figure 12. Sandy River Mudstone (Tsr) underlying Willamette Silt in Willamette River channel west of Wilsonville.

Figure 13. Sandy River Mudstone (Tsr) exposed in roadcut near Viola in southeast part of map area. Thin gravel lenses are present within mudstone layers.

Trimble (1963) and later workers to map the two deposits as separate units.

The Sandy River Mudstone outcrops expose at least 300 ft of material, and water wells have penetrated up to 900 ft of this formation. The total thickness is not known but probably is not much more than 900 ft.

Good exposures of the mudstone are found in steep valley sides, stream canyons, and roadcuts (Figure 13). The beds were deposited horizontally in a quiet body of water, and individual beds are a few inches to several feet thick.

Although the beds are well consolidated, cementation is limited to local iron or clay coatings. Folding has been slight to moderate, and dips are commonly less than 2° to the west and northwest (Trimble, 1963). Because the folds are broad, the Sandy River Mudstone has been downwarped locally to more than 1,000 ft below sea level; in other places it crops out at about 1,000 ft above sea level.

Because the formation rests on the late Miocene Sardine Formation and because plant fossils dated as early Pliocene overlie it (Trimble, 1963), it is considered to be early Pliocene in age. Beds containing early Pliocene leaves in the lower part of the "old" Troutdale Formation of Hodge (1933) and Treasher (1942a,b) are now regarded as part of the Sandy River Mudstone.

Engineering characteristics: Sandy River Mudstone exposures most often occur low in the canyon walls or on the steep edges of terrace escarpments; thus the formation is involved in many large slope failures.

The fine-grained mudstone tends to be an impermeable barrier to ground water. On outcrops along its contact with overlying sediments, springs and seepage zones are common. Weathering and absorbed moisture will decrease its shear strength considerably, often to the point of slope failure. Moisture-sensitive clay which expands with increasing moisture content and contracts when drying (high shrink-swell) is present in certain parts of the Sandy River Mudstone (Figure 15b). Foundations placed on moisture-sensitive clays will fluctuate vertically and severely damage structures erected on them.

The usual causes for slope failures are saturation of the slope materials and the oversteepening or overloading of the slope by stream erosion, cuts, and embankments. The cost of repair of the largest landslides is usually uneconomically high.

Expansive clay is not suitable for most embankment uses. Gravelly phases of the formation are used for gravel fill, but rarely for portland cement concrete.

Troutdale Formation (Tpt)

The Pliocene Troutdale Formation is a series of interbedded gravel, sand, and silt. The formation, which was named and described by Hodge (1933), originally included deposits lying on the west side of the Cascade Mountains and extending from the Columbia River Gorge west to the Tualatin Mountains and southward for a few tens of miles. Hodge's original description included what is now called the Sandy River Mudstone. Troutdale gravels are exposed from the Columbia River at Corbett westward and are extensive in the valleys of the Sandy and Clackamas Rivers and the adjacent terrace escarpments. The unit also occurs extensively in the subsurface of the east Portland area, south to the map boundaries near Canby, and to the west in the Tualatin Mountains. The Troutdale gravels are extensive in the mapped area, especially along tributaries of the Clackamas River.

The thickness of the Troutdale Formation varies considerably because much of it has been eroded. In general, thickness of the deposits ranges from 200 to 900 ft. Typical of the Troutdale Formation is the presence of rounded quartzite pebbles and cobbles (Figure 14). The Troutdale gravels are believed to have been deposited by an ancestral Columbia River, which flowed a considerable distance south of its present location. The gravel deposits may have been modified and redeposited in part by later streams which flowed from the Cascade Mountains westward. The lenticular-shaped beds dip to the west at an angle of approximately 2° (Figure 15a). The formation occurs as high as 870 ft above sea level and has been identified in drill holes at 230 ft below sea level.

The Troutdale Formation unconformably overlies the Sandy River Mudstone and/or the Columbia River Basalt Group. It is overlain by the Boring Lava or younger sediments (Figure 15b).

It has been dated as early Pliocene from flora found beneath its base in the Sandy River Mudstone and from two localities within the Troutdale Formation (Chaney, 1944; Trimble, 1963).

Engineering characteristics: The indurated gravels will stand vertically for several hundred feet, but a soft layer within or at the base of a slope makes them subject to failure. The gravels are occasionally mined for aggregate; however, washing is generally required to remove the clay and other impurities usually found in the gravel (Figure 16). The spoils from Troutdale Formation gravel pits are susceptible to wasting if placed on a sloping area. Furthermore, the excavations made during extraction of the gravel often undercut soft areas of Troutdale clays and silts or younger deposits, possibly resulting in slope failure.

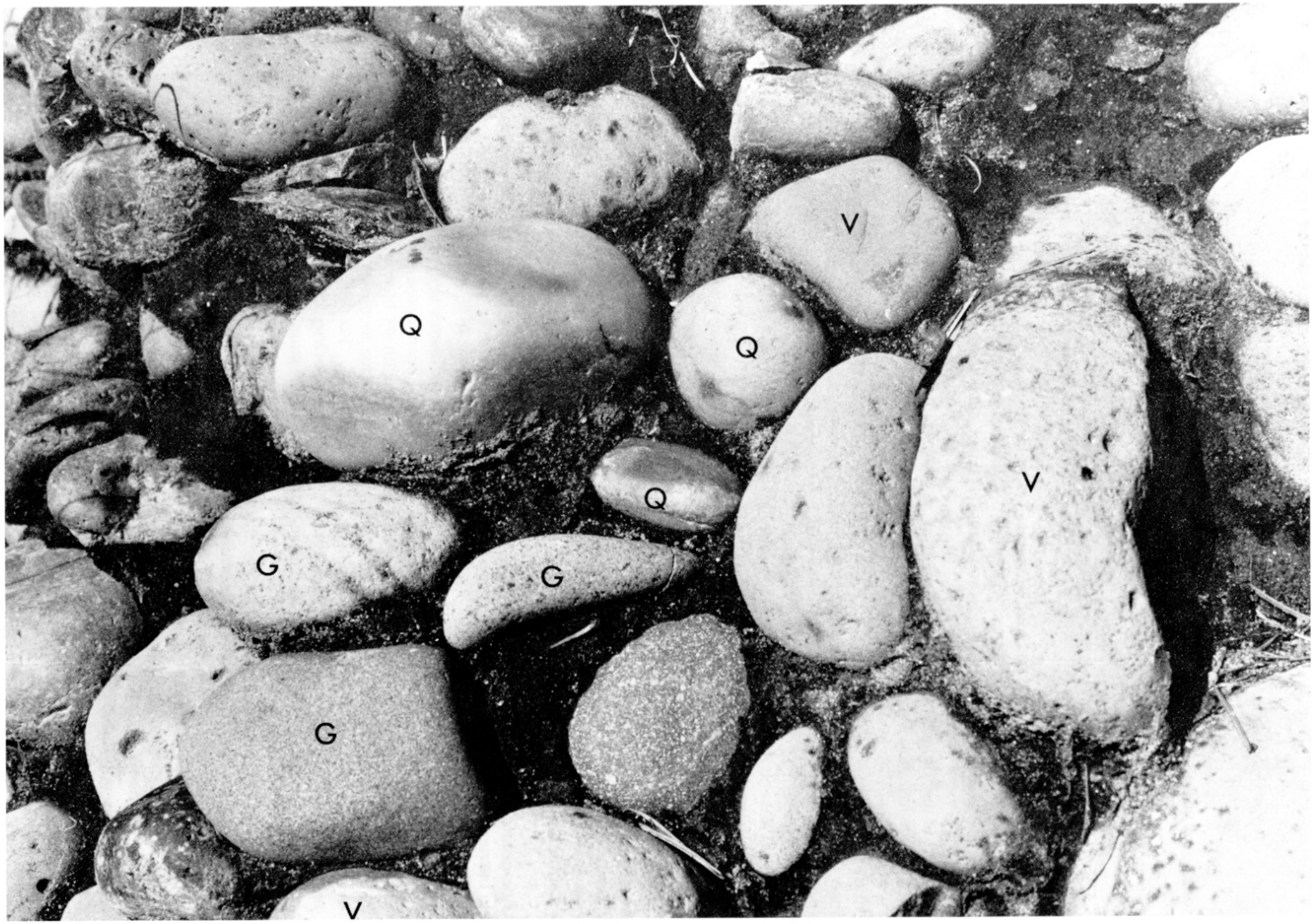


Figure 14. Troutdale Formation (Tpt) gravel containing granitic rock (G), quartzite (Q), and volcanic rock (V). Close-up is of gravel shown in Figure 15a.

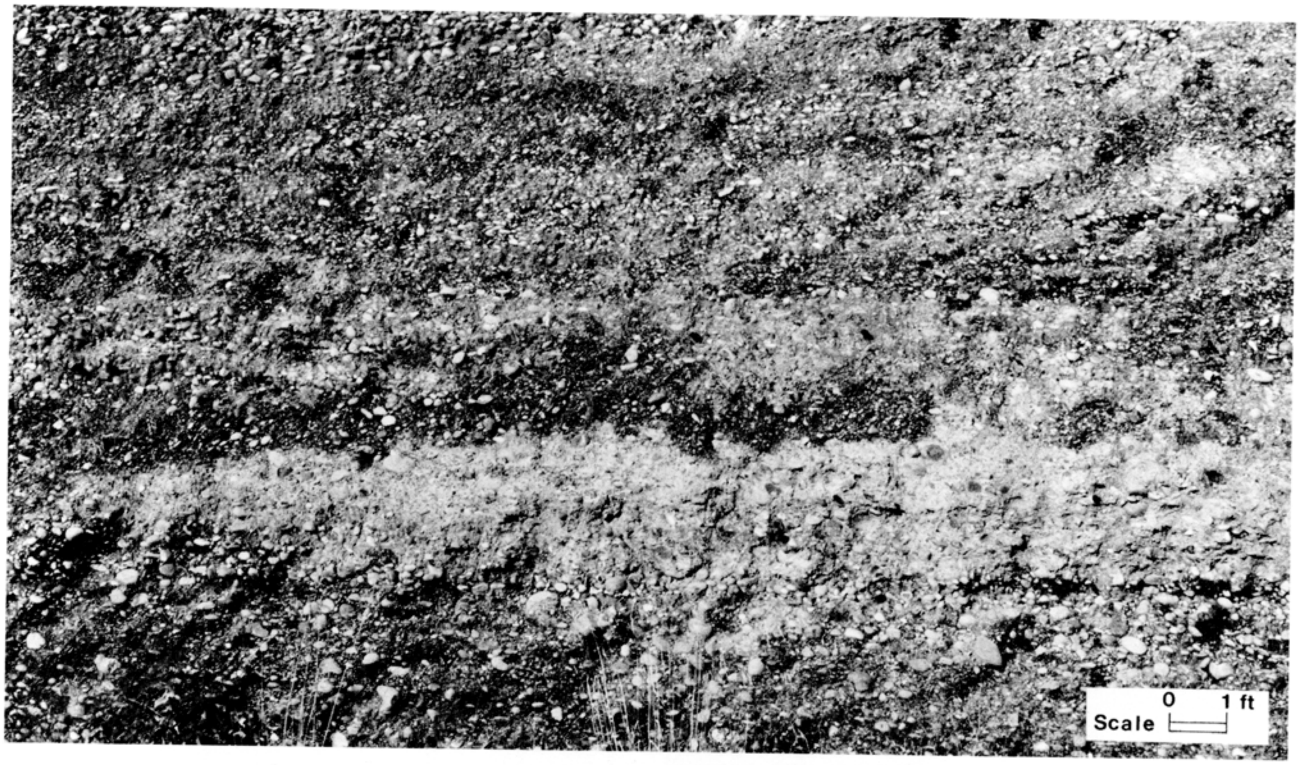


Figure 15a. Troutdale Formation (Tpt) gravel beds in roadcut about 1 mi east of Barton (NE ¼ sec. 24, T. 2 S., R. 3 E.).

Figure 15b. Contacts between Sandy River Mudstone (Tsr) (bottom unit), thin section of Troutdale Formation (Tpt) (middle unit), and overlying Boring Lava (Qtb). Photo was taken along Kellogg Creek adjacent to I-205. Note cracks in high shrink-swell soil of Sandy River Mudstone.

Figure 16. Barton gravel pit and Troutdale Formation (Tpt) gravels. Most gravels exposed in steep bank are cemented with clay, requiring extensive washing before they can be used as aggregate (NW ¼ sec. 19, T. 2 S., R. 4 E.).

Boring Lava (Qtb)

In the Portland area, volcanism which began before the end of Pliocene time continued into early Pleistocene. Eruptions occurred from numerous volcanic vents in the West Hills of Portland eastward to the Western Cascades and from Oregon City northward to the Columbia River. The products of these volcanoes ranged from tuff breccia and agglomerate to lavas (Figure 17). In some areas, the lava flows were extensive; in other areas, the lavas were thin, with little lateral extent, or completely missing. In east Portland and north Clackamas County, small amounts of lava and cinders emanated from a number of small cones or volcanoes.

The basalt is of three types (M.H. Beeson, 1979, oral communication): a highly inflated light-gray basalt; a dark, dense basalt, almost blue-black in color; and an agglomerate or flow breccia rock composed of fragments of basalt scoria in a matrix of tuff.

In thin section, the rocks are easily distinguishable from Columbia River basalt. In hand specimen, however, the dark, dense type can be confused with Columbia River basalt. The presence of olivine and the flow structure caused by the parallel orientation of the feldspars in weathered specimens help distinguish Boring Lava from the Columbia River basalt.

The Boring Lava occurs as blocky intracanyon flows, volcanic cones, or shield volcanoes which are composed of thick basalt flows, flow breccia, and agglomerate that extend for several miles from a central vent. The uneroded thickness of the formation varies from 25 to over 500 ft. The flows, where thin, are sometimes completely weathered to a red clay and scattered residual boulders (Figure 18). These weathered flows are marked "Wx" on the geologic maps.

The Boring Lava has been slightly folded. According to Beeson and others (1975), subsidence that took place as the lavas withdrew following the Boring extrusions may have produced some of the faulting that has been mapped in the Lake Oswego-Gladstone-Oregon city area.

The Boring Lavas overlie Troutdale and older rocks. They are overlain by cobble gravels, mudflows,

Figure 17. Boring agglomerate and tuff breccia (Qtb) containing scattered quartzite pebbles. Explosive volcano vent apparently penetrated Troutdale gravels, which then became incorporated in tuff breccia.

Figure 18. Roadcut in weathered Boring Lava (Qtb). Boulder in center has diameter of 30 in.; surrounding clay is residual soil formed by weathering of lava flow rock (NW ¼ sec. 19, T. 2 S., R. 4 E.).

and eolian silt of Pleistocene age.

Engineering characteristics: The varieties of material which make up the Boring Lava pose individual engineering problems.

The fresh, unweathered rock used for crushed aggregate usually breaks with a high percentage of large blocks which require secondary shooting before they can be accepted by the crusher jaws, resulting in higher than normal production costs and material waste.

Thick intracanyon flows sometimes contain unexposed lava tubes which formed when molten rock flowed out from beneath an upper solidified crust (Allen, 1975). The presence of lava tubes can cause serious problems if not detected during preliminary excavations.

Weathering of blocky lavas and agglomerate or flow breccia produces large spheroidal boulders in a matrix of sticky red clay. The boulders not exposed at the surface are not easily detected by drilling.

Normal removal of the topsoil for placement of spread footings can result in differential settlement of building foundations where one footing overlies a thick section of weathered material and another overlies a large boulder at shallow depth.

Weathering of the Boring Lava on gentle slopes produces a 1-ft-thick, impermeable clay pan overlying a bouldery clay up to 10 ft or more thick. Surface water quickly saturates the topsoil and runs in rivulets or ponds in the flat areas. Tiling is necessary to prevent erosion or ponding. Septic tanks are not feasible in impermeable soils.

Grading in areas underlain by Boring Lava may require the removal of a large number of boulders weighing up to 5 tons each. They can be buried in large embankments or used in landscaping.

Pliocene-Pleistocene gravels (Qpg)

The Pliocene-Pleistocene gravels are composed of a thick sequence of poorly indurated and deeply weathered cobbly gravel, interbedded sands, and mudflow deposits. They occur primarily in the east and northeast parts of the mapped area. Good exposures occur beneath terraces in the canyons of the Clackamas and Sandy Rivers.

Trimble (1963) mapped the gravel as two separate formations, the older Walters Hill Formation and the younger Springwater Formation. For convenience, however, the units are combined in this report because they possess similar lithologies and engineering characteristics.

The gravels include fluvial deposits and fanglomerates; the fluvial deposits probably represent reworking of the older fanglomerate. Remnants of the older fan deposit are present at Walters Hill. The flat-lying sand interbeds and the large alluvial terraces between the major streams in the area indicate a fluvial origin for much of this unit.

Mudflow deposits may be, in part, old landslide deposits; however, the tuffaceous nature of the matrix and the angular and porous volcanic fragments found in many of the mudflow units in proximity to Boring Lava vents suggests that some of the mudflows may be associated with the Boring volcanoes.

The gravels are up to 400 ft thick, thinning toward the west. The upper surface of the deposit slopes to the west, suggesting that the deposit is the remnant of a large continuous deposit (Trimble, 1963).

The gravel unit overlies the Troutdale Formation, Sandy River Mudstone, and Columbia River Basalt Group. It is capped in the higher elevations by Quaternary loess deposits.

Engineering characteristics: The Pliocene-Pleistocene gravels have been weathered to clay to depths up to 75 ft. Saprolite occurs to a depth of 20 ft. The clay is relatively impermeable and is unsuited for septic-tank drainfields and landfill sites or for use as aggregate. As embankment material, it can be used selectively for impermeable blanket or fill if placed at optimum moisture in 6-in. lifts with adequate compaction effort.

Permeability of this unit is low, and the water table stands at about 24 in. below the ground surface during winter. The flatter areas have poor drainage, and steep areas erode severely from surface runoff.

Mudflow material includes boulders and blocks of basalt up to 7 ft in diameter. The tuffaceous matrix is well cemented and may be difficult to excavate; it is relatively impermeable, and the large-size fragments make poor fill material. The gravel is weathered and is not satisfactory for aggregate or select embankment.

Eolian silt (Qes)

Eolian silt is a wind-blown deposit of fine silt, up to 55 ft thick, composed of minerals derived from the Columbia River drainage area. It occurs above 250 ft elevation from the mouth of the Columbia Gorge to west of the Portland area and southward for a few tens of miles.

The deposits may represent glacial silt (loess) blown southward from the Columbia River flood plain during periods of low water (Allison, 1978a,b). The silt overlies the Pliocene-Pleistocene gravel, Boring Lava, and older units. It is shown on the map by a pattern over the underlying geologic formation. Where less than 5 ft thick, it is not shown.

The silt is consistently uniform in appearance, texture, and composition. It contains a number of minerals, including quartz, feldspar, muscovite, biotite, pyroxene, amphibole, magnetite, tourmaline, garnet, apatite, and volcanic glass (Trimble, 1963). Clay minerals are also present.

Engineering characteristics: The eolian silt is nearly homogenous, has low plasticity, and is unstable on moderate slopes when saturated. Shallow cuts will stand vertically until they are saturated by heavy rainfall or until they thaw after a hard freeze. The deposit has low permeability and is subject to high capillary rise and therefore to frost heave.

The loess will support light foundation loads, providing minor settlement can be tolerated. On slopes, especially where the contact dips in the direction of slope, the silt is prone to landslide. Usually, initial movement causes the material to become supersaturated, and a mudflow ensues. Liquefaction can occur with slight increase in moisture content over the optimum amount, and adequately compacted embankments are therefore difficult to construct. Loosely compacted embankment is subject to severe erosion. Septic-tank drainfields are not recommended. Tile drainage installation is required for most types of development.

Pleistocene terrace deposits (Qpt)

The mid- to upper-Pleistocene terrace deposits are bouldery gravels and sands which occur on intermediate terraces along the Sandy and Clackamas Rivers. The terrace deposits are in some places overlain by about 25 ft of sandy clay. The older (higher) terraces were mapped by Trimble (1963) as the Gresham Formation and the younger (lower) terraces as the Estacada Formation. Both units contain mudflow deposits. However, only those in the higher terraces contain large boulders and blocks of basalt; the lower terrace mudflows are finer grained, with fragments of basalt less than 2 in. in diameter (Trimble, 1963).

Weathering of the higher terrace extends to depths of 25 to 30 ft, and gravels are almost completely altered to clay. The lower terraces are weathered to depths of 10 ft, with basalt fragments only partially weathered. Trimble (1963) correlates the terraces with the Leffler and Linn gravels of Allison (1953) and Allison and Felts (1956) in the southern Willamette Valley. The terrace deposits in the Sandy area were formed as the major streams intermittently cut

Figure 19. Bedding of Willamette Silt (Qws) in bank of Willamette River upstream from Wilsonville. This 40-ft-thick exposure, with beds ranging from 6 in. to 1 ft in thickness, overlies Sandy River Mudstone.

through the older formations and flood-plain deposits until they reached present-day channels that are several hundred feet lower than the Pleistocene terrace deposits.

The terraces are cut into and overlie the Troutdale Formation and the Sandy River Mudstone. They display relatively flat upper surfaces and steep unstable escarpments facing the rivers. The terrace deposits are up to 150 ft thick but may be as thin as 30 ft.

Engineering characteristics: The terrace deposits are unconsolidated; therefore, heavy foundation loads will require special treatment and design based on detailed site studies.

Silt and clay layers and weathering profiles disrupt ground-water movement, producing perched water tables. Water moving into the terrace deposits from adjacent bedrock units can produce high water tables throughout much of the summer. Water flowing onto terrace escarpments through permeable layers exposed on the slopes can cause erosion and instability. Terrace slopes throughout the County have failed by landslide.

Developments on terraces require adequate sewage and storm disposal to prevent ground-water contamination and pollution and accrual of excess water from springs on slopes. The planning of roads and developments on terrace escarpments should include consideration not only of active slide areas but also of areas which could become unstable because of adverse conditions caused by the development.

Terrace deposit gravel produces satisfactory aggregate for construction. Five pits are operating in this part of the County.

Lacustrine sediments

The lacustrine sediments include silt deposited in the Willamette Valley and sand and gravel deposits in and near Portland.

The deposits are twofold (Allison, 1978a). The early phase sediments represented by the Willamette Silt were deposited between 34,410 ± 3,450 years B.P. (Glenn, 1965). The late phase sediments described in this report as lacustrine sand and deltaic gravel are a product of the Missoula Flood, considered to have occurred about 13,500 years B.P.

Willamette Silt (Qws): The Willamette Silt underlies nearly all of the lowlands in the southwest part of the map area. It generally extends onto the surrounding uplands to an approximate elevation of 250 ft, where it occurs on gently sloping terraces. The Willamette Silt lies on the erosional surfaces of 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-in. beds, with 3- to 4-ft beds locally present (Figure 19). In many areas, the silt is massive, without distinct stratification. Lenses of pebbly, fine- to medium-grained sand with scattered cobbles of granite and quartzite occur in some of the outcrops. The silt is usually light brown to buff 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 clay at a shallow depth beneath the silt. Clays have also been concentrated in poorly drained, shallow depressions on the surface of the Willamette Silt.

Within the study area, the Willamette Silt ranges from a few feet to about 40 ft in thickness. It is 5 to 10 ft thick on the higher elevations and about 30 ft thick adjacent to the Willamette River west of Wilsonville.

The Willamette Silt is correlative with widespread lacustrine deposits of similar composition which mantle almost the entire Willamette Valley from Portland to Eugene up to an elevation of about 250 ft. The silt south of the study area has been studied by Allison (1932, 1933) and Glenn (1965). Glenn provides data to indicate that silt was deposited in the Willamette Valley during at least 40 large Columbia River floods.

Mammoth bones have been found at the base of the Willamette Silt on the surface of Troutdale sediments on the north bank of the Willamette River, sec. 29, T. 3 S., R. 1 W. (Glenn, 1965).

Lacustrine sands (Qls): Torrential flood deposits of cross-bedded sands occur within a 2-mi-wide belt along the Willamette River from Oregon City to Lake Oswego and also in the area north of Canby. The surface of the deposits is irregular, containing low parallel ridges and small closed depressions.

The sands are well exposed in several pit excavations located a short distance north and east of Onion Flat (Figure 20). Here the sands are at least 50 ft thick and are medium to coarse grained. Thin, pebbly lenses are present. They contain a few limonite pebbles, scattered cobbles of basalt, and rare cobbles of granite and quartzite. The granite and quartzite clasts are probably 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, well sorted. Sand-size lithic volcanic clasts, quartz, and feldspar predominate.

Deltaic gravels (Qdg): Cross-bedded coarse sand and gravel deposits near Durham, Onion Flat, Wilsonville, and east of Canby were deposited during late Pleistocene torrential flooding. Trimble (1963) mapped the deposits at Durham as an extension of widespread Pleistocene lacustrine deposits in the east Portland area. The authors of this report believe that the pebbly sands near Onion Flat and gravels at Wilsonville and Canby were deposited during the same event.

The gravels at Durham and Wilsonville are of similar composition and gradation; they consist of cross-bedded, unsorted, bouldery pebble and cobble gravel in a matrix of silt and medium- to coarse-grained sand (Figure 21). Boulders in the gravel are as much as 5 ft in diameter. The gravels are principally of basaltic clasts, with scattered granitic, metamorphic, and limonite clasts (Figure 22). Most of the basalt clasts were derived from the Boring Lava and Columbia River Basalt Group in the Tualatin Mountains adjacent to Lake Oswego. Quartzite and granite cobbles are from gravel deposits of southeast Portland across from Lake Oswego. Limonite cobbles have their source in a limonite deposit at Lake Oswego.

Composition of the gravels, the structure of the deposits, and the orientation of foreset bedding give credence to the occurrence of a gigantic flood during the late Pleistocene. About 13,500 year B. P., floodwaters poured through the gap which cut the present bed of Oswego Lake, washed gravel and blocks of basalt through Oswego gap in the Tualatin Mountains, and deposited them in the delta at Durham. The flood waters stripped the scabland at Tonquin and carried basalt boulders and gravel to the Wilsonville area, where they were finally deposited. Floodwater rushing southward through the Willamette River channel south of Oregon City dumped gravel near Canby.

Engineering characteristics: The lacustrine deposits have widely variable characteristics, depending upon the various depositional environments during the late Pleistocene flood. Composition, slope, and thickness, in turn, are highly variable. In general, the gravel makes good aggregate, but large boulders in some of the deposits create considerable waste and problems of disposal.

Excavations in this unit will stand vertically in shallow gravel excavations; stability is less for the sand and silt. Excavations as shallow as 5 ft can fail suddenly and must be braced. In low areas, excavations may be partially filled with water. The strength of sides of an excavation will be decreased considerably where water seeps from the sidewalls or is present in the bottom of the trench.

Foundation of the gravel is adequate for most

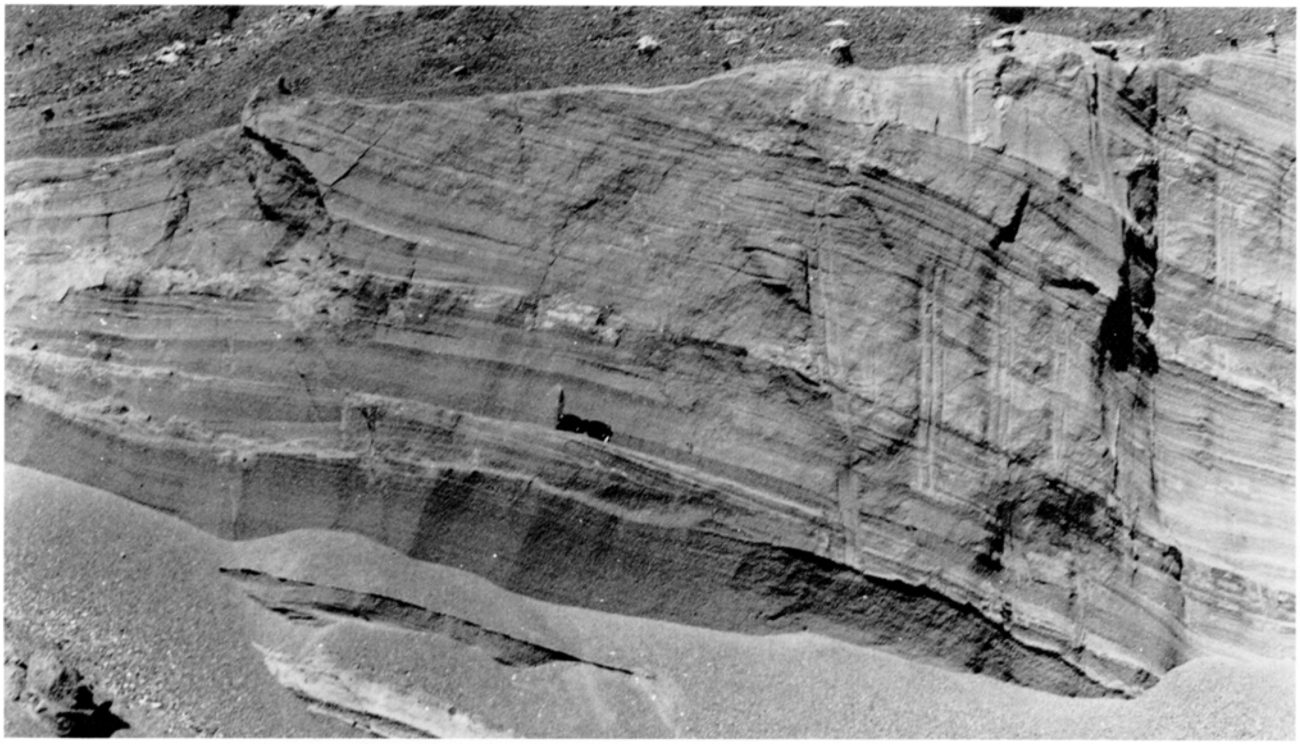


Figure 20. Lacustrine sands (Qls), cross-bedded coarse sand and fine gravel exposed in pit west of Tualatin, deposited by Pleistocene floodwaters which crossed Tualatin mountains at Oswego Lake gap. Note sunglasses in center of photo for scale.

Figure 21. Unsorted deltaic gravels (Qdg) in old pit at Durham.

Figure 22. Limonite cobble in gravel deposit (Qdg) at Durham. Limonite was carried from its point of origin near Lake Oswego by waters from Missoula Flood. Limonite deposit occurs just below water tower at 325-ft elevation in NW ¼ sec. 9, T. 2 S., R. 1 E.

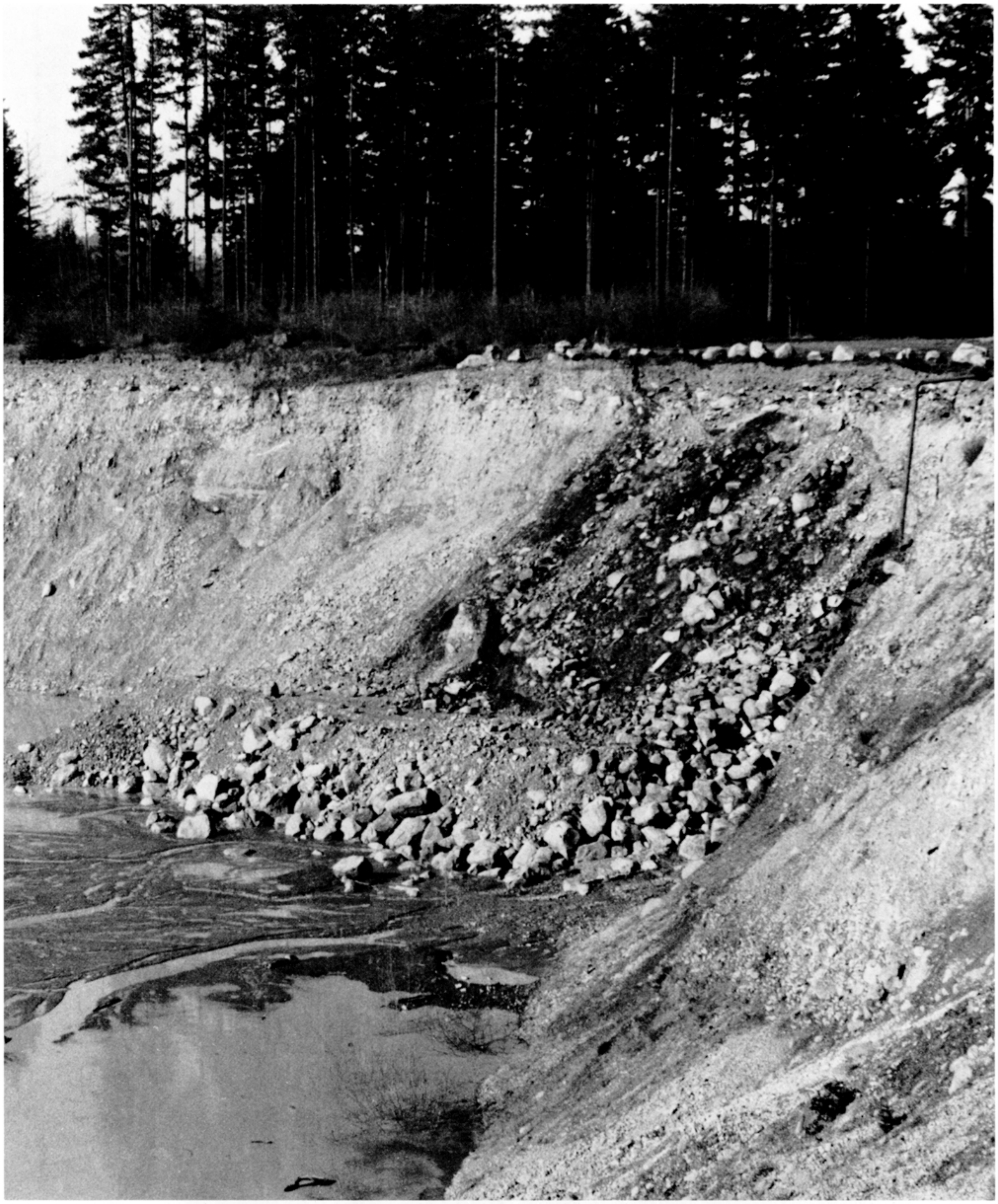


Figure 23. Deltaic gravel (Qdg) in old pit northwest of intersection of I-5 and Carman Road. Photo taken about 1961. Large unsorted boulders scattered throughout deposit were carried from Lake Oswego channel several miles to right (east) of site shown in photo. Note pollution of standing ground water from discharge pipe near upper right margin.

Figure 24. Omark industrial park development area on Minthorn Creek, 1 mi east of Milwaukie. At this location, underlying peat soils need to be considered.

structures; however, exploration must be done at each site to determine the conditions. The presence of a large boulder or block of basalt in shallow foundations can result in differential settlement. Sand and silt units will provide adequate support for light to moderate foundation loads; however, exploration and testing are necessary to provide data for design criteria.

Moderate amounts of ground water can be obtained from this unit. In areas adjacent to deep excavation, contamination can occur from infiltration of surface water and pollutants (Figure 23).

Gravel within the unit makes good quality aggregate. Areas mapped as Willamette Silt having gravel production may be thin silt overlying or interbedded with deltaic gravels (Qdg). The rock is of good quality but may need washing to eliminate clay particles.

Alluvium (Qal)

Alluvial deposits include all of the material in the channels of present-day streams, their flood plains, and abandoned channels. Alluvium consists of gravel and sand in the stream channels, gravel and sand lenses usually overlain by silt and minor clay on the flood plain, and organic material usually in abandoned channels beneath several feet of silt or clay. Areas underlain by organic or peaty soils have been designated "pt" on the geologic maps. Undiscovered organic soils no doubt exist.

The thickness of the alluvium is variable. In small stream channels where gradients are high, the sand and gravel is generally thin and rests on bed rock. The smaller flood-plain deposits of silt and gravel tend to be narrow, thinning out at the canyon sides, whereas the larger flood plains may contain recent alluvium up to 30 ft thick or more. Generally, gravel excavation in the bed of the Willamette River has extended below the alluvium into older but unweathered gravels. The gravel in alluvial deposits is generally good for most uses; for use as concrete aggregate, however, blending may be necessary.

Engineering characteristics: The areas underlain by alluvium are subject to flooding. Some areas flood annually; other may flood only under extreme prolonged rainfall and snowmelt conditions. Floodways generally should not be filled to provide building sites or bridge approaches, because restriction of the floodway area will force water to rise upstream and cause flooding in areas previously considered safe. Also, increased velocities in the remaining floodway will result in increased erosion, especially around bridge piers and footings.

The water table in bottomland areas is less than 1 ft below the ground surface during part of the year. In well-drained flood plains and low terraces, the water table ranges from 1 to 6 ft or more below the ground surface.

Foundation strength ratings are weak to very weak. The weakest foundation soils are found in the bottomland areas of small streams or abandoned channels underlain by wet silt or organic soils (Figure 24). Organic soils will compress excessively under light to moderate loads. Drilling of exploration holes for organic soils should be done in areas of lake or bottomland sediments.

Septic-tank disposal is not recommended in areas of high water table or low permeability soils.

GEOLOGIC HAZARDS

GENERAL

Geologic hazards are geologic processes or geologic conditions which constitute threats to any activities of man and include erosion, deposition, mass movement (landslide), flooding, high water table, and soil and bedrock instability. Each of the major hazards implies some sort of restraint to development. The relations of geologic hazards to geologic units and to land use in northwestern Clackamas County are indicated in Tables 2 and 3, respectively.

SLOPE HAZARDS

Steep slope

Definition: Steep slope refers to a slope that presents restraints to certain types of land use (see Tables 2, 3, and 4). The degree of slope creating a hazard varies relative to the individual type of development and the local geological conditions.

Impact: Any sloping ground may present problems of surface and subsurface water flow, creating hazards to development relative to erosion and wastewater and septic-tank disposal. Septic-tank drainage overflow can cause pollution of streams, creating a health hazard. Even with only four to five houses per acre, up to 50 percent of the ground surface can be covered by buildings, driveways, sidewalks, and streets. Runoff from these impermeable surfaces is transferred, in part, to the open ground. Landscape watering also contributes moisture to the ground. Slope instability, failure of cuts or embankment areas, and road construction problems may present further hazards that ultimately point to the greater hazard of slope failure.

The size and placement of cuts and embankments along streets and driveways can cause oversteepening and overloading of critical slopes. Embankments may also act as dams by restricting the flow of surface water and shallow subsurface water. These factors cause water buildup in the soil and may lead to disastrous landslides in areas that may have had no previous history of landslide or slope instability.

Mass movement

Definition: Mass movement or mass wasting, popularly known as landslide and, to the engineer, as slope failure, is the downslope movement of earth materials in response to gravity. In this report, we shall consider the general features of mass movement, the landforms it has produced, and some of its other manifestations, such as slump, planar landslide, mudflow, debris flow, soil creep, and rockfall.

Causes: A slide is caused when the shearing stress of soil or rock exceeds its shearing strength. Increased shearing stress in a soil mass is generated by external causes; loss of shear strength of the soil is caused by internal changes. Among the external causes of landslides are the undercutting of the toe of a slope by erosion or by excavation (oversteepening), addition of weight from embankment material or waste deposited along the upper edge of the slope, and added weight of increased moisture content. Earthquakes may be a cause; in fact, vibrations from any source may trigger a slide. The usual internal cause of landslides is water in the ground. Ground water produces both immediate and progressive decrease in shear strength of the soil. Immediate decrease of shear strength is generally caused by increase in pressure from water in the voids. This pressure is analogous to the forces exerted by a hydrostatic head.

Seepage pressure is a force exerted by ground-water flow due to the viscosity of water moving through minute passages in the soil. Continued seepage through slopes expels the air and destroys apparent cohesion between the soil particles, further weakening the soil. Seepage pressure frequently affects (1) slopes surrounding reservoirs during rapid drawdown, and (2) river banks when waters recede following a flood. Seepage pressure can also cause cut slopes to fail in trenches excavated below the water table. Progressive decrease in shear strength results from the removal of the soil binder and from chemical decomposition of the mineral grains by ground-water action.

A deep frost followed by heavy rains greatly increases the susceptibility of a slope to failure. Frost heaving or the expansion of soil by formation of ice crystals and by the freezing of water pockets results in

Table 2. *Geologic unit vs. potential hazard, northwestern Clackamas County, Oregon*

POTENTIAL PROBLEM RATING

- ● High or great
- ◒ Moderate
- ○ Low or small
- — None

GEOLOGIC UNIT		HAZARD											
		Rockfall	Landslide topography (old)	Slump	Mud flow-debris flow	Compressible soils	Shrink-swell	Thin soils	Wet soils - high water table	Flooding	Stream bank erosion	Slope erosion	Faulting
Alluvium	Qal	—	—	○	○	◒	○	—	●	●	●	◒	○
Organic soil (on hazards maps)		—	—	—	—	●	◒	—	●	●	○	—	—
Willamette Silt	Qws	—	○	◒	◒	○	◒	—	◒	◒	●	◒	○
Lacustrine and fluvial sediments	Qls	—	○	○	○	○	○	—	◒	○	◒	○	○
Deltaic gravels	Qdg	—	—	—	○	—	○	○	○	○	○	○	○
Pleistocene terrace	Qpt	○	◒	●	●	○	◒	○	◒	○	◒	◒	○
Eolian silt	Qes	—	●	●	●	○	○	○	◒	—	—	○	○
Pliocene-Pleistocene gravel	Qpg	○	○	○	○	—	○	○	○	—	○	○	○
Boring Lavas	Qtb	◒	○	○	—	—	—	◒	—	—	—	—	○
Troutdale Formation	Tpt	◒	◒	◒	◒	○	◒	○	◒	—	○	○	◒
Sandy River Mudstone	Tsr	○	●	◒	◒	○	●	○	◒	○	◒	◒	◒
Sardine Formation	Tsa	◒	◒	◒	◒	—	○	◒	—	—	—	○	◒
Columbia River Basalt Group	Tcr	◒	○	○	○	—	◒	◒	—	—	—	—	●
Skamania Volcanics	Tsv	○	○	○	—	—	—	◒	—	—	—	○	●

increase of void spaces in the soil. This increased moisture capacity of the soil is sometimes sufficient to start liquefaction and slide action on moderate to steep slopes.

Landslides often occur, or recur, several years following a development because water from a large open area has been concentrated into a much smaller area by septic-tank drainfields, roof drains, dry wells, and inadequate storm drainage systems. This concentration can have about the same effect as a 50 percent increase in the annual rainfall. Because topography has developed naturally as the result of a balance between slope attitude and soil strength and is dependent upon the prevailing rainfall, any long-range increase in rain infiltration as just described can result in a decrease in the stable slope angle and produce slope failure.

Slide development: As the shearing forces approach the shear strength of a soil mass, certain sections fail, causing rearrangement of the soil grains,

Table 3. *Geologic hazard vs. land use, northwestern Clackamas County, Oregon*

POTENTIAL PROBLEM RATING

- ● High or great *
- ◒ Moderate **
- ○ Low or small ***
- — Not applicable
- X Not recommended

GEOLOGIC HAZARD	LAND USE: High density development	Low-density development	Heavy foundation loads	Roads and streets	Drainfield disposal	Utilities underground	Landfill	Basements	Underground storage units	Public buildings, schools
Rockfall	X	X	—	●	—	—	—	—	—	X
Landslide topography	X	X	●	●	●	●	X	●	●	●
Slump	X	●	●	●	●	X	X	●	X	X
Mud and debris flow	X	●	●	◒	●	X	●	●	X	X
Compressible soils	●	●	●	◒	●	●	◒	●	X	●
Shrink-swell soils	●	●	◒	◒	●	●	○	●	●	●
Thin soils	◒	●	○	○	●	●	X	◒	●	◒
Wet soils and high water table	●	●	●	◒	●	◒	◒	●	●	◒
Flooding	X	X	●	●	●	◒	X	X	●	X
Stream bank erosion	●	◒	◒	◒	—	—	—	—	—	●
Slope erosion	●	◒	◒	◒	●	●	X	●	●	●
Faulting (inactive)	○	○	●	○	○	○	○	○	○	●

* Serious problems; requires detailed study to determine feasibility of proposed land use

** Site study required

*** Few problems anticipated; site inspection required

Table 4. *Percent slope vs. hazard, northwestern Clackamas County, Oregon*

POTENTIAL PROBLEM RATING

- ● High or great
- ◒ Moderate
- ○ Low or small
- — None

PERCENT SLOPE	Stream downcutting	Poor drainage	Ponded areas	High water table	Flooding	Impermeable soil	Surface pollution from septic tanks	Gullying	Unstable slopes	Landslides	Rockfall	Bedrock exposure; thin soil
0 - 10	○	●	●	●	◒	◒	○	—	—	○	—	○
10 - 20	◒	○	○	○	—	○	○	◒	○	◒	—	○
20 - 35	●	—	—	—	—	—	○	●	●	◒	—	◒
35 - 50	◒	—	—	—	—	—	◒	●	●	●	—	◒
50 +	○	—	—	—	—	—	◒	●	●	●	◒	●

which in turn produces a sudden increase in pore pressure and formation of hairline cracks. Excess water in the disturbed soil is forced into other sections of the soil, and failure of the soil mass continues as if by chain reaction. When the shear strength along a possible slide plane is reduced sufficiently, the entire mass becomes mobile, and a slide occurs. Movement of the slide rapidly increases as the soil loses its strength. As the slide progresses, the driving force is reduced through reduction in slope and mixing of the slide material with more stable foreign soil. When the resisting force again equals the shearing force of the soil, the movement passes from sliding into slow creep. The surface of an old slide is particularly susceptible to the effects of excessive rainfall, since numerous deep fissures provide easy entrance for water, and drainage is greatly disrupted (Schlicker, 1956).

Landslide topography: Landslide topography refers to large areas in which bedrock failure has produced an irregular, hummocky topography (Figures 25 and 26) and includes ancient landslides that have been stable for many years. Erosion may have greatly modified the ground surface, and original landslide features may no longer be evident. Such areas may be characterized by anomalous slopes; fan-shaped deposits at the toes of ancient slides; or evidence that material has dammed a valley, displaced a stream channel, or flowed out into a flat area. Close examination of the bedding and structure of the rocks reveals large blocks of displaced material (float) carried downslope in the slide mass. Exposures in roadcuts and stream valleys often reveal a haphazard orientation of fragments of bedded rock. Old, inactive landslides will show no evidence of movement such as tilted or bent trees, back-tilted blocks, or sag ponds. Ancient landslides have had no historical movement but exhibit a subdued, rolling topography and drained sag ponds. Large trees, if present, are straight, and the angle of the surface slope is less than that of the adjacent areas. Slides classified as ancient may have ceased to move hundreds or thousands of years ago.

Sometimes portions of such a slide become reactivated as a result of stream erosion at the toe of the slide or improper development of the landslide. Other problems to development include disrupted subsurface drainage, unpredictable source of ground water, and restricted use of septic tanks. Before such areas

Figure 25. Landslide topography ½ mi south of Carver in Pleistocene terrace deposits (Qpt). Sliding occurs along most terrace escarpments.

Figure 26. Hummocky landslide topography in Sardine Formation (Tsa), north of Cazadero. Cutting of Clackamas River channel has caused massive landslides in the geologic past.

are developed, extensive exploration should be made to determine that movement is no longer taking place and that the proposed development will not contribute to instability of slopes. Under these conditions, developments should include water and sewage systems and storm drains to prevent surface water from the development from entering the subsurface and creating instability or contamination.

Active slide areas within old landslides will generally contain lakes, ponds, swamps, springs, tilted or tipped trees, cracks, and other signs of recent movement. Sometimes these active areas will expand to areas which have been inactive during historic time. These large landslide areas generally occur on very long slopes, high terraces, or escarpments.

Slump: Slumps or rotational slides develop major slip planes which are spoon shaped. Usually the slip plane at the top or heel of the slide is vertical. The radius of the curve increases toward the toe of the slide, which causes the sliding mass to develop a series of parallel subsidiary slide blocks. Each block is rotated backwards as the sliding mass moves downslope. Where the arc of the sliding surface intersects the surface, the sliding material pushes out on the ground surface in a jumbled heap, eventually resisting further movement. On the sliding surface, trees and fence posts tilt uphill (Figure 27). When a slump occurs high on the slope, the toe will develop into a mudflow. This type of slide occurs in homogeneous material or where competent bedded material is underlain by a weak material. The failure occurs on a steep slope when the underlying material fails. Slump-type slides can range in size from small popouts (Figure 28) of a few cubic yards to tens of acres.

Planar landslide: Planar or block-glide landslides develop where lateral support is removed and sliding takes place on a material layer or plane of weakness such as a bedding plane or a joint plane which slopes less than the cut face or ground surface. Bedded rocks often contain weak layers. One such layer only a few inches thick in a thick layer of otherwise sound rock can cause failure of the entire unit.

Mudflow and debris flow: Mudflows and debris flows are common types of slope failure on construction projects and natural slopes (Figure 29). When moisture-sensitive soils become oversaturated, they begin to move as a mass due to added weight and loss of strength. The subsequent decrease of pore space caused by the shifting of the silt and sand grains as movement begins produces excessive pore water pressure which buoys the soil mass, promoting movement down even gentle slopes. Once these slides begin moving, they can travel hundreds of feet after they reach horizontal surfaces, often riding up the slopes on the opposite sides of valleys. Slides occur on steep slopes overlain by granular rock fragments and soil and tend to develop rapidly during heavy rainfall. Debris slides are initiated or easily reactivated by natural or man-made alterations in slope, increased water content, or excessive surface runoff.

Mudflows move downslope in any available channel. As they reach the toe of the slope, they fan out, making a characteristic lobate deposit. These deposits vary in size. The larger ones are detectable on a topographic map.

Soil creep: Soil creep is slope failure in which no slip surface has developed. It most frequently occurs in thick soils, weathered surface materials, and colluvium. Because the surface moves a greater distance than the subsoil, trees and fence posts tip or are displaced downhill. The rate of movement may be imperceptible, but structures built on this ground will suffer damage within a short period of time. Creep causes cracks which allow more water to infiltrate the ground, producing, in turn, other, more rapid types of mass movement.

Areas of soil creep have not been mapped separately in this study. Most terrace escarpments have some creep, especially those adjacent to slopes having mass movement.

Rockfall: Rockfalls occur on very steep surfaces when material becomes dislodged, sometimes by ice-wedging, and tumbles, slides, or falls downward to the bottom of the slope in response to gravity. Rockfalls are generally limited to areas where rivers or streams undercut the toes of steep slopes to produce overhangs which fail with little or no warning. Small rockfalls occur along steep, high roadcuts in combination with planar and slump-type slides.

Recommendations

It is imperative that all landslides, potential landslides, and unstable slopes be identified in an area where development or construction is to take place. Geologic and engineering reports should routinely be required for these areas, and safe heights and slope attitudes for cuts and embankments must be specified. Drainage must be controlled. Foundation design must be compatible with slopes to promote stability.

The overall plan should consider the future slope stability after the increased pressures of the development have had their full effect, especially the long-range effects of storm drains, waste-water disposal, and irrigation of landscaping.

Active landslides: Large, obviously active landslides will, in almost every instance, cost more to stabilize than the property is worth afterward. Such areas should be left undeveloped. If the original cause of the landslide is still in effect, such as erosion of the toe of the slide by a stream, future sliding will probably occur.

Figure 27. Slump in Sandy River Mudstone (Tsr) adjacent to settling pond at Barton quarry, secs. 24 and 25, T. 2 S., R. 3 E. Note grabenlike block and tipped trees.

Figure 28. Slump in roadcut in Sandy River Mudstone (Tsr) near Viola.

Figure 29. Debris-type landslide on north slope of Mount Talbert, NW ¼ sec. 3, T. 2 S., R. 2 E. Note tipped trees and large amount of mudflow debris in small valley at left center of photo. Rolling topography was developed by previous slide.

Old landslides: Old landslides which still exhibit features such as bent trees and water-filled sag ponds should be evaluated conservatively. Many such areas may be moving imperceptibly and intermittently as much as a few inches per year. Sometimes, motion can be detected only by instrumentation. This type of movement will cause continual damage to structures, and maintenance costs may, in time, force abandonment. If either old or ancient landslides are determined to be stable, the land can be developed, providing its stability can be preserved.

Housing developments must be properly designed and drained so that the moisture content of the slope will not increase. The number of excavations and embankments and the density of housing should be kept to an absolute minimum. If development is not properly designed, ancient and old landslides can be reactivated, but this will usually take place about 5 to 25 years or more after the houses have been built. In a densely developed area, almost half of the ground is covered by streets, driveways, sidewalks, and houses, and most of the moisture that strikes the ground will be concentrated in the remaining open areas.

All water that soaks into the ground adds considerably to the subsurface soil water content. Much of the overall soil moisture is not reduced during the dry season because evaporation and transpiration losses are eliminated in ground covered by the development. If moisture content of the ground increases to a critical degree, slope failure is likely to occur, particularly where the slopes have been steepened. Septic tanks, dry wells, and leach fields should not be permitted in areas of old landslides. Development of these areas will require the installation of sewage and drainage systems.

Hillside areas which develop gradually on a lot-by-lot basis are especially prone to slope failure and erosion. With piecemeal development, comprehensive geologic or engineering reports are seldom, if ever, prepared, and installation of sanitary and storm sewer systems is not economically feasible. Water, therefore, can build up in the soil from septic-tank drainfields, dry wells, improperly controlled surface water, and landscape irrigation. Urban densities can be achieved on a hillside if the entire area is preplanned and if appropriate safeguards to prevent slope failure are applied. Urban densities are two to six units per acre, unless the entire area is preplanned.

Sloping areas: Sloping areas should be developed only after thorough geologic studies and appropriate engineering designs, including sanitary and storm sewers, have been made. High-density or cluster developments, properly designed, offer the best degree of safety and economics relative to slopes.

Since even gentle slopes may be subject to sliding, they should be examined for signs of failure. Old landslide scars are obvious signs of dangerous slopes. Although these slides may have affected only a small part of the area, the entire slope should be considered susceptible to failure. According to Terzaghi (1950), all slides except those due to earthquake and spontaneous liquefaction will show signs of progressive failure prior to sliding. Indications of progressive slope failure are bent trees, linear features such as fence lines out of alignment, vertical objects such as fence posts tipped downhill, and tension cracks along the upper edge of the unstable area.

Although some slopes have not failed, any steepening such as by addition of material at the top or removal of material at the toe, may alter the conditions enough to cause sliding. Failure, however, will probably not occur until there is a sufficient decrease of soil strength and/or addition of weight during a period of excessive moisture.

The treatment of slides and critical slopes should achieve a satisfactory degree of safety within economical limits. Moderate expenditure will in some cases reduce the slope hazard. However, if a slope failure would endanger critical installations or human life, the treatment should achieve absolute safety, which may exceed economical limits.

General mitigation: Potentially unstable slopes which may affect dwellings must be made unquestionably safe; therefore sliding on only a small scale can be economically corrected. In general, stabilization can be effected by unloading the top of the slide and placing material on the toe and by installing surface and subsurface drainage. All sources of surface and ground water leading into the slide area should be located and diverted. Control of long slopes is difficult and often economically impossible, especially if the slide occurs partway up the slope.

Piling driven through a thin, unstable layer of soil into an underlying soil may add stability but should not be used without a study of the forces involved. Piling of proper strength must be driven sufficiently deep into firm, stable material to resist its being pushed over or broken off by the force exerted by the unstable soil mass. Piling or a retaining wall should not be expected to overcome the entire force of a large soil mass but should be used in conjunction with other procedures such as drainage or resloping.

Close spacing of homes on small hillside lots affected by a slide may prevent the most satisfactory correction, such as diversion of surface water away from the slide, resloping, and construction of retaining walls. Proper treatment in this case can be accomplished only by cooperation on the part of all persons involved.

Landscapers of homes located on steep hillsides should consider slope stability. Care should be taken when retaining walls are built on slopes below the level of the house and filled with soil to provide level or nearly level yards. Only qualified engineers should design retaining walls. Most trouble comes from underdesigned retaining walls, poor foundations in which to anchor the walls, little or no drainage facilities for relieving water pressure building up behind the walls, and, probably the greatest cause of failure, inadequate compaction of backfill or use of inadequate fill material such as moisture-sensitive silt or clayey silt. The moisture content and size gradation is extremely important in arriving at satisfactory compaction. The body of the fill should be made of a well-graded soil which, when compacted, will have a minimum of void space, thereby providing as little volume for moisture as possible. It should be placed with a computed optimum moisture content and compacted to at least 90 percent maximum by hand or pneumatic tampers. To insure sufficient compaction, the fill should be placed and compacted in layers not exceeding a depth of 6 in. Drainage tile should be installed in a gravel base behind the retaining wall, and through-wall drainage should be provided.

Corrective measures for landslides which occur after an area is developed may be difficult or even impossible. Sometimes a slide will affect only one or two lots, but the correction procedure may involve measures which include neighboring properties. Seldom do the adjoining property owners see the need to become involved in the expense or the inconvenience. Therefore, the most expedient, economical, and long-range correction may not be applied.

HAZARD SOILS

Definition

A hazard soil is any soil or soil condition which can cause problems to land use or adversely affect engineering and construction. Hazard soils include organic soils, which have high compressibility; high shrink-swell soils, which react to moisture changes; thin soils that overlie hard bed rock and therefore have poor drainage characteristics; and wet soils that have a high water table or slow drainage.

Soil hazards as mapped in this report indicate major problem soil areas. Small patches of these soils may also be present within areas mapped as nonhazard soils, and nonhazard soils may be found within areas shown primarily as hazard soils. The maps should be used as a guide for planners and developers so that obvious hazards are not overlooked. The maps are not a substitute for on-site geologic or soil investigations.

Types of hazard soils

Organic soils: Peat and organic soils form thick deposits in areas where a slow steady rise of the water level induces a continued steady growth of sphagnum moss and other similar water plants. Because sedimentation commonly occurs in such areas, silt and other material may cover deposits of peat. In regions of high water table, therefore, peat may occur in the subsurface, although there is no surface indication of its

Figure 30. Omark industrial park development area on Minthorn Creek, 1 mi east of Milwaukie. Problems caused by organic soils and high water table have been considered during construction at this location.

Figure 31. Expansive clay in roadcut exposure of Sandy River Mudstone (Tsr), 1½ mi north of Viola in valley of Clear Creek.

presence (Figure 30). It is usually water saturated and can consolidate under moderate loads to less than 50 percent of its original volume. In addition to causing excessive uneven foundation settlement, the soil can fail by shearing under heavy embankment loads. Heavy embankments can produce an elevated ridge parallel to the toe of the embankment as the fill sinks.

Fine-grained alluvial soils deposited on flood plains may contain layers of soft organic material. Roads built on these areas will settle unevenly and produce an undulating grade. Subsurface investigations and soil testing are needed to determine the extent of such material and to provide the engineer with information necessary to minimize the uneven settlement.

High shrink-swell soils: High shrink-swell soils are bentonitic clay soils which readily absorb water and swell when wet to several times their volume when dry. The soil consists of montmorillonite and colloidal clay minerals produced by devitrification and alteration of volcanic glass, tuff, or ash.

Certain soils in Clackamas County contain moderate amounts of swelling clay. High shrink-swell soils occur in poorly drained bottomland, concave areas on terraces, and certain beds within the Sandy River Mudstone and Troutdale Formation (Figures 15a and 31). They are mapped on unpublished U.S. Soil Conservation Service maps as Hazelair, Dayton, Concord, Verboort, Cove clay, and Labish soils. The clays containing the largest amounts of bentonite have the greatest coefficient of expansion. When excavations expose this material, it will either gain or lose moisture, depending upon ambient conditions.

High shrink-swell soils will cause severe cracking of streets, driveways, floor slabs, footings, walkways, and walls. The swell-exerted pressures can lift and fracture foundations and tilt structures. It is recommended that identification of these soils be made by qualified soil engineers. Tests have shown that high shrink-swell soils should be avoided for use in foundations or embankments whenever possible. If thin or limited in extent, they can be removed. In areas where expansive soils are extensive, elaborate design may be necessary to keep soil at a constant moisture content to prevent excessive volume changes and the resulting damage to structures.

Thin soils: Thin soils are soils less than 2 ft thick that overlie bed rock.

They occur on steep slopes where most or all of the soil and weathering products are continually being removed by gravity or in flatter areas where the soil and loose rock are scoured and carried away by flood waters. Areas with thin soils or exposures of hard bed rock can pose problems in certain types of development. Septic tanks cannot be used because of inadequate drain fields. Excavation can be a problem, especially for installation of underground utilities. Blasting required for underground utilities for housing developments should be done before any buildings are constructed. Bed rock is usually slowly permeable, and water stands at its surface during the rainy season. Because of difficulty of excavation, basements are not recommended. In addition, thin soils on steep slopes may be slide prone.

Wet soils — high water table: Wet soils are soils having a high water table. In these areas, water will stand in open holes 18 in. or less below the surface (Figure 30). During wet periods, water may stand on the surface.

Trenches dug while the water table is low will likely fail when the water table rises and seepage occurs in the cut faces. If water floods a trench and is then pumped out, the cut faces are likely to fail from rapid drawdown due to pore water pressure, unless the sides are properly braced.

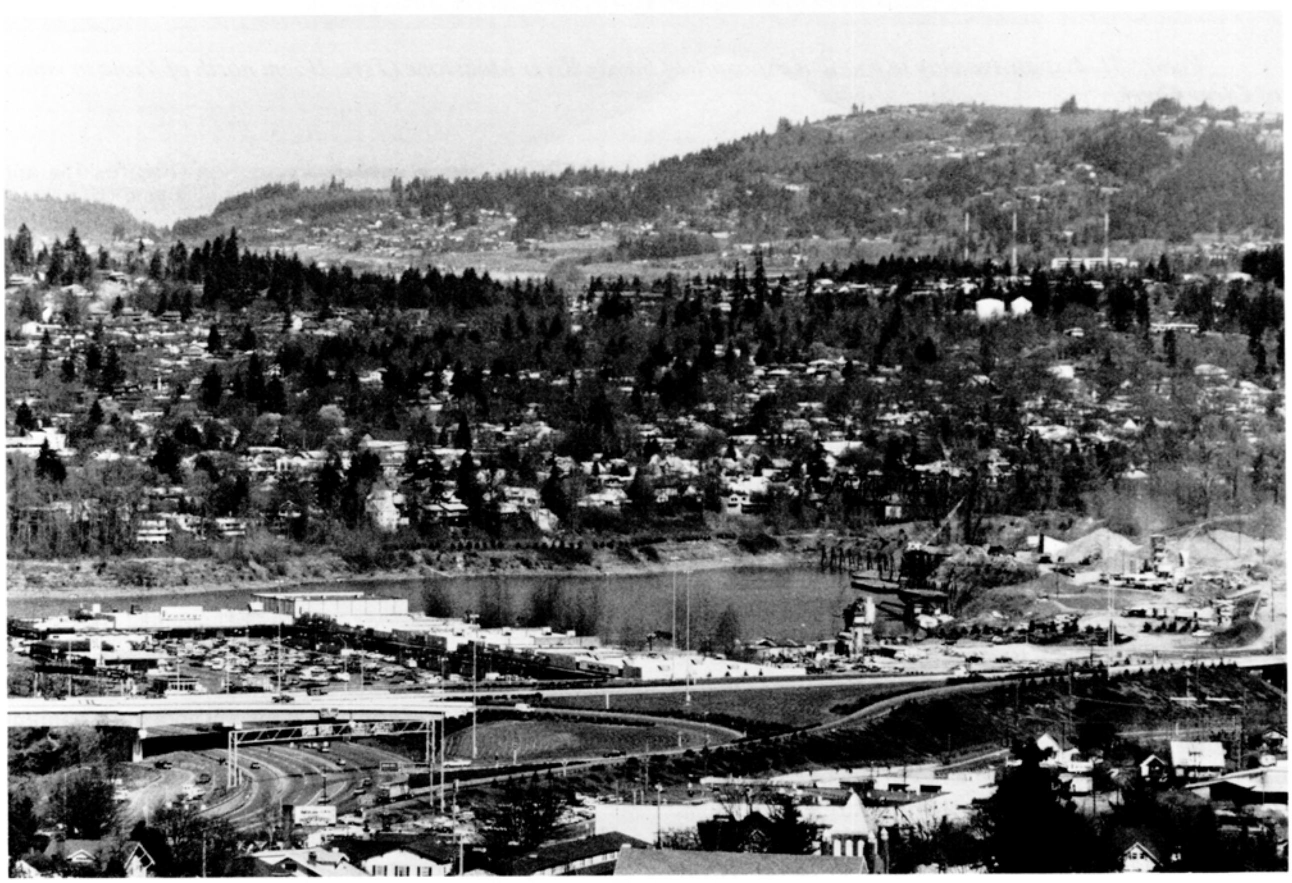
A high water table can develop pressures sufficient to cause basement floors and walls to crack or fail and empty storage tanks to be buoyed to the surface. Soils which shrink and well will react strongly to fluctuation in water table.

Areas mapped as wet soils in this study may also include small patches of other types of soils including such hazardous soils as thin, high shrink-swell, or organic soils. The areal extent of these soils has been extrapolated from geology and soils maps, topography, and engineering borings.

FLOOD HAZARDS

Flooding within Clackamas County occurs near the cities of Oregon City, West Linn, Gladstone, and Jennings Lodge, all situated in the Willamette River basin. Tributaries to the Willamette River in this vicinity are the Tualatin River, entering from the west, and the Clackamas River and Abernethy Creek, which

Figure 32. Shopping center and gravel pit at I-5 and 99E interchange. View toward north. Note that although shopping center has been here for more than 15 years, gravel extraction has been able to continue.



flow into the Willamette River from the east. Developments along these streams have been flooded many times in the past. Even with flood-control storage reservoirs operating upstream, these developments are still susceptible to larger floods such as that of December 1964.

Flooding occurs in Clackamas County from October through April, with larger floods occurring in December and January. The larger floods result from area-wide heavy rains of 2 to 5 days' duration, augmented by snowmelt and a high percentage runoff.

Two categories of floods, the Standard Project Flood and the Intermediate Regional Flood, have been defined for development standards. The Standard Project Flood is defined as the largest flood that can be expected from the most severe combination of meteorological conditions that could reasonably occur, excluding extremely rare combinations. Standard Project Floods should be considered in the design of any development in the flood plain. The Intermediate Regional Flood is defined as a flood having an average recurrence frequency of once in 100 years. Such a flood has a 1-percent chance of occurring in any one year. The Intermediate Regional Flood represents a major flood, although it is much less severe than the Standard Project Flood. Floods of the magnitude of an Intermediate Regional Flood were observed on the Willamette River at Wilsonville in December 1861 and December 1964. On the Pudding River, an Intermediate Regional Flood would be somewhat larger than the December 1964 flood, whereas an Intermediate Regional Flood on the Molalla River would be somewhat smaller than the December 1964 flood (U.S. Army Corps of Engineers, 1970b).

Willamette River

The greatest flood known to have occurred in the Willamette River basin was in December 1861. The only available information is from high water marks. Without upstream flood regulation, the December 1964 flood would have been approximately as great as the 1861 flood. Under the conditions of a larger flood, the river will rise 0.2 to 0.3 ft per hour, and water velocities will range up to 15 ft per second in the main channel of the river.

Figure 33. Willamette River falls at Oregon City, nearly obscured by December 1964 floodwater.

Figure 34. 1964 flood—Oregon City shopping center, looking west toward Willamette River. (Photo courtesy U.S. Army Corps of Engineers)

Figure 35. 1964 flood—Oregon City shopping center, looking east. (Photo courtesy U.S. Army Corps of Engineers)

Figure 36. 1964 flood—north part of Oregon City, looking southeast. (Photo courtesy U.S. Army Corps of Engineers)

Figure 37. 1964 flood—Willamette River at Wilsonville. Water came to eaves of houses. After flood, houses were raised about 8 ft for floodproofing.

Figure 38. Flood plain at confluence of Pudding and Molalla Rivers near Canby during 1964 flood.

Figure 39. Orchard sustained heavy damage from erosion and siltation of 1964 flood on Molalla River west of Canby. Orchards are visible in floodwaters near center of Figure 38.

Most of the area along the Willamette River is devoted to manufacturing, warehousing, and urban development. Major urban developments exist in the Oregon City (Figure 32), West Linn, Gladstone, and Jennings Lodge areas.

Principal transportation facilities in the area include the main Southern Pacific railroad line, State Highway 43, and U. S. Highway 99E. Portions of the railroad and Highway 99E lie within the flood plain.

Many structures in the flood plain have been damaged or destroyed by past floods. A papermill, sewage treatment plant, shopping center, lumberyard, sawmill, County shops, filling station, athletic field, and some residential areas sustained heavy damages during the December 1964 flood (Figures 33 to 37).

Table 5. *Ten greatest observed floods in order of magnitude, Willamette River at Willamette locks upper gage, Oregon City, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)	Elevation (ft)[2]	Peak discharge (c.f.s.)[3]
1	February 1890	22.8[4]	73.0	510,000
2	December 25, 1964	19.9	70.1	385,100
3	January 9, 1923	19.2	69.4	357,800
4	January 3, 1943	18.3	68.5	324,800
5	December 24, 1955	17.2	67.4	287,600
6	January 22, 1953	17.1	67.3	284,300
7	January 30, 1965	16.9	67.1	278,000
8	January 10, 1948	16.8	67.0	275,000
9	January 1, 1946	16.5	66.7	266,000
10	February 13, 1961	16.4	66.6	263,000

[1] Source: U.S. Army Corps of Engineers, 1970c.

[2] Elevations are referred to mean sea level, 1947 adjustment.

[3] The discharges were determined using known stages and the estimated discharge rating table dated September 1965.

[4] Stage shown is estimated from the September 1965 rating table on the basis of discharge.

Molalla River

The Molalla River drainage area covers 878 sq mi, entirely within Clackamas County. Upstream the river flows through a steep, narrow canyon in a mountainous area. The downstream part flows through rolling and terrace topography within the Willamette Valley. The portion of the Molalla River covered in this report is from its mouth to the Canby area, a distance of about 4 mi.

Elevations in the basin vary from a maximum of 4,880 ft in the Cascade Range to 50 ft at the mouth of the Molalla River. In the study area, the stream gradient averages 3 ft per mi. One major tributary, the Pudding River, flows into the Molalla River at river mile 1.3.

The flood plain of the Molalla River ranges in width from ½ to over 1 mi. Where the Molalla River and Pudding River flood plains merge, they form a common flood plain nearly 2 mi wide (Figure 38).

Nearly all of the flood plain is used for agricultural production (Figure 39). The major developed area is the city of Canby, which lies partly within the Molalla River flood plain. Barlow, however, is located entirely within the flood plain.

The Southern Pacific Company operates two railroad lines in the study area. The main line of the railroad and U.S. Highway 99E cross the Molalla River at Canby. About ½ mi southwest of Barlow, both U.S. Highway 99E and the Southern Pacific main line would be inundated by an Intermediate Regional Flood.

Except for the bridges, no manmade obstructions to flood flow exist on the Molalla River in the study area. The first 2 mi of the Molalla River are subject to backwater from the Willamette River.

The U.S. Geological Survey maintains two streamflow gages on the Molalla River; one is within the study area, and the other is upstream at river mile 40.4. Records for the downstream gage at Canby are available for the years 1928 to 1959 and 1963 to 1969. Crest stages and discharges for observed floods exceeding bankfull stage of 10.2 ft at the Canby gaging station have occurred 39 times between March 1931 and February 1968.

Table 6. *Ten greatest observed floods in order of magnitude, Molalla River near Canby, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)[2]	Elevation (ft)	Peak discharge (c.f.s.)
1	December 22, 1964	16.8	120.8	43,600
2	November 1960	13.8	117.8	28,000
3	January 7, 1948	13.2	117.2	25,100
4	March 31, 1931	12.6	116.6	22,300
5	January 18, 1953	12.3	116.3	21,000
6	January 28, 1965	12.2	116.2	20,700
7	February 18, 1949	12.2	116.2	20,600
8	December 22, 1955	12.0	116.0	20,200
9	November 23, 1942	12.0	116.0	19,900
10	November 23, 1953	11.7	115.7	18,800

[1] Source: U.S. Army Corps of Engineers, 1970b.

[2] Stages are based on the discharge rating table dated February 1968.

Pudding River

The Pudding River originates in the Waldo Hills, east of Salem, and flows in a northerly direction for about 60 mi to its confluence with the Molalla River. The Pudding River drains an almost circular basin encompassing 530 sq mi. The part of the Pudding River discussed in this report extends northward from the Marion County line for a distance of about 3 mi. Because of the extensive meander pattern, the river distance is almost 5 mi.

Elevations in the Pudding River basin range from 55 ft at its mouth to 70 ft at Aurora. All eight major tributaries to the Pudding River are upstream from the study area.

The width of the area that would be inundated by an Intermediate Regional Flood is over 1 mi at the mouth of the Pudding River. The depth of flooding in the downstream reach is influenced by the Willamette River backwater.

The flood plain is devoted almost entirely to agriculture. The hazard maps show the flood areas of the Pudding River occurring within the study area.

No manmade obstructions to flood flow exist on the Pudding River in the study reach. The bridges are above the flood plain and do not restrict flood flows. The first 1½ mi of the Pudding River is subject to backwater from the Willamette River.

The U.S. Weather Bureau maintains a stream gage at river mile 8.1 on the Pudding River. Stage observations are made only during high-water periods. Records available from 1928 to 1969 indicate 62 floods exceeding bankfull stage of 19.8 ft at the Aurora gage. Table 7 lists the greatest floods in order of magnitude.

Table 7. *Ten greatest observed floods in order of magnitude, Pudding River at Aurora, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)[2]	Elevation (ft)	Peak discharge (c.f.s.)
1	December 23, 1964	29.6	101.8	26,200
2	December 30, 1937	29.4	101.6	25,400
3	February 19, 1949	28.7	101.0	22,200
4	January 20, 1953	27.0	99.3	15,600
5	January 7, 1948	26.7	98.9	14,600
6	February 11, 1961	26.5	98.7	14,000
7	December 23, 1933	26.5	98.7	13,900
8	April 1, 1931	26.2	98.4	13,000
9	December 22, 1955	25.9	98.1	12,300
10	November 27, 1942	25.8	98.0	12,100

[1]Source: U.S. Army Corps of Engineers, 1970b.

[2]Stages are based on the discharge rating table dated October 1964.

Tualatin River

From its headwaters in the Coast Range, the Tualatin River meanders easterly for more than 75 mi to its confluence with the Willamette River near West Linn. More than 59 mi of the winding course is through a wide flood plain. The Tualatin River basin is one of the larger tributary areas of the Willamette River, with a watershed covering 712 sq mi. Excessive runoff from the headwater areas is restricted because of channel constrictions and flat stream gradients. During a major flood, water in the Tualatin River can rise up to 1.3 ft per hour. Tualatin River velocities range up to 13 ft per second. Velocities greater than 3 ft per second, combined with depths of 3 ft or more, are considered hazardous.

Most of the flood plain is devoted to agricultural or related purposes. The city of West Linn is located near the mouth of the Tualatin River but lies mostly above the flood plain.

Inflow into Oswego Lake is via a diversion canal from the Tualatin River. It has been determined that Intermediate Regional and Standard Project Flood conditions in the Tualatin River would cause the water level in Oswego Lake to rise a maximum of only a foot. Any Willamette River flood would crest at least 50 ft lower than the spillway crest and thus would not affect the lake elevation.

> "Since 1928, there have been several major floods. The floods resulted from prolonged periods of precipitation augmented by snowmelt. Flooding throughout the central portion of the basin persisted for days and covered large acreages. When extreme high water occurs in the lower reach, the headworks on Oswego Canal are overtopped, and control over the lake inflow is lost" (U.S. Army Corps of Engineers, 1970c).

Table 8. *Ten greatest observed floods in order of magnitude, Tualatin River near West Linn, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)[2]	Elevation (ft)[2]	Peak discharge (c.f.s.)[3]
1	December 23, 1933	19.43	105.48	29,300
2	December 20, 1937	18.48	104.53	26,300
3	December 23, 1955	16.81	102.86	21,400
4	January 28, 1964	15.40	101.45	17,700
5	December 26, 1964	15.40	101.45	17,700
6	January 24, 1936	15.40	101.45	17,700
7	February 20, 1949	14.33	100.38	15,100
8	December 22, 1941	12.90	98.95	11,900
9	January 3, 1943	12.90	98.95	11,900
10	January 23, 1953	12.90	98.95	11,900

[1]Source: U.S. Army Corps of Engineers, 1970c.

[2]Stages and elevations were computed on basis of discharge shown using rating table and gage datum in use April 1968.

[3]Discharges shown include flow of Oswego Canal, which diverts water from Tualatin River at a point 5 mi upstream from the gaging station.

Clackamas River

The lower reach of the Clackamas River is subject to backwater from the Willamette River during floods. No major tributary flows into the Clackamas River in this reach. The section of flood plain of the Clackamas River which would be inundated by an Intermediate Regional Flood varies in width from 750 ft at Bakers Bridge to about 1 mi just above the Willamette River backwater.

The flood plain near Oregon City and Gladstone is highly developed (Figure 40). Most of the remaining

Figure 40. Aerial view looking south from Milwaukie toward Gladstone and Clackamas River during 1964 flood. Note Highway 99E (right) and railroad (left of shopping center) under water.

study area is made up of small farms and residential property. Transportation facilities in the area include the Southern Pacific railroad line, U.S. Highway 99E, State Highway 213, and several County roads.

Average channel velocities are 8 ft per second, with maximums during floods approximately 50 percent greater. Overbank velocities of about 5 ft per second are expected. The December 1964 flood, the largest flood observed in the Clackamas River basin, is estimated to have been approximately a 100-year flood.

Table 9. *Ten greatest observed floods in order of magnitude, Clackamas River near Clackamas, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)	Elevation (ft)	Peak discharge (c.f.s.)[2]
1	December 22, 1964	27.0	77.7	120,000
2	March 31, 1931	20.7	71.4	82,000
3	January 6, 1923	20.3	71.0	80,000
4	November 24, 1960	19.2	69.9	73,000
5	January 7, 1948	18.8	69.5	71,000
6	December 28, 1945	17.7	68.4	64,000
7	December 15, 1946	17.0	67.7	60,000
8	December 19, 1917	16.7	67.4	58,500
9	November 20, 1921	16.5	67.2	57,500
10	November 22, 1909	16.3	67.0	56,000

[1] Source: U.S. Army Corps of Engineers, 1970c.
[2] Discharges prior to October 1962 were estimated by correlation with Clackamas River gage at Estacada, Oregon.

Abernethy Creek

Abernethy Creek drains an area of about 30 sq mi and enters the Willamette River from the east at river mile 25.4. It flows for 16 mi through the hills east and north of Oregon City before reaching the flood plain near its mouth. Holcomb Creek flows into Abernethy Creek at river mile 2.4 and is the only sizable tributary.

Most of the flood plain of Abernethy Creek is devoted to industrial, commercial, and residential development. Transportation facilities include the Southern Pacific railroad line, U.S. Highway 99E, and State Highway 213. There are also a number of secondary roads in the area.

Besides the bridge obstructions, there are some natural obstructions. The channel meanders and is choked with vegetation. Backwater from the Willamette River affects the water elevation in the lower reach of Abernethy Creek.

The stream responds quickly to periods of heavy rainfall. Periods of high water are of short duration and can occur with little advance warning between late October and the end of April.

Three of the larger recent floods on the Willamette River occurred in December 1964, January 1943, and January 1923. They produced stages at the mouth of Abernethy Creek of 49.5, 42.1, and 47.5 ft, respectively.

Flooding near the mouth of Abernethy Creek consists mainly of Willamette River backwater. Flood stages would be the same as in the Willamette River.

Johnson Creek

Johnson Creek enters Clackamas County west of 82nd Avenue and flows westward near the north County line and then south through the northern city limits of Milwaukie until it enters the Willamette River at Waverly Heights. The Johnson Creek drainage area has an east-west orientation and is approximately 24 mi long and 3 mi wide. Only 44 sq mi of the total drainage area of 54 sq mi directly contribute runoff; a topographic low in the Powellhurst area retains all direct runoff from the remainder of the basin.

Most of the basin in the study reach is devoted to industrial and residential development. Any major flood, especially an Intermediate Regional Flood or a Standard Project Flood, would cause substantial damage. During the 1964 flood, the creek reached crest stage in 36 hours. The average rate of rise was 0.3 ft per hour; the maximum rate was 1.3 ft per hour. Johnson Creek remained above bankfull stage for 53 hours.

Average channel velocities are 8 ft per second, with maximums during floods approximately 50 percent greater. Overbank velocities of about 5 ft per second can be expected.

Table 10. *Ten greatest known floods in order of magnitude, Johnson Creek at Sycamore, Oregon*[1]

Order of magnitude	Date of crest	Stage (ft)[2]	Elevation (ft)	Peak discharge (c.f.s.)
1	December 22, 1964	14.71	243.18	2,620
2	November 24, 1960	13.70	242.17	2,180
3	February 10, 1949	13.53	242.00	2,110
4	January 7, 1948	13.00	241.47	1,900
5	November 20, 1962	12.78	241.25	1,830
6	January 4, 1956	12.75	241.22	1,820
7	November 23, 1942	12.59	241.06	1,770
8	January 4, 1966	12.13	240.60	1,620
9	January 22, 1954	12.03	240.50	1,590
10	March 7, 1957	11.93	240.40	1,560

[1] Source: U.S. Army Corps of Engineers, 1970a.
[2] All stages are adjusted to the rating table in use in September 1968.

Kellogg Creek

Kellogg Creek is located south of Milwaukie and flows along the Milwaukie-Oak Grove city limits into Kellogg Lake, which has its outlet on the Willamette River. Kellogg Creek has a drainage area of 16.6 sq mi.

The downstream developments include houses and apartments. This area has been inundated in the past from Willamette River backwater and from flooding of Kellogg Creek and would be subject to severe flooding should an Intermediate Regional or Standard Project Flood occur in either the Willamette River or Kellogg Creek. In the past few years, the upstream reach has been transformed from an agricultural to a residential area with many new homes. Overbank flows in the critical reach near the mouth can be expected annually. However, with present development, it takes only a 5-year flood to produce significant flood damages.

High water occurs frequently during the rainy season, November through April. Floods are of short duration, and peak stages last only a few hours.

In the reaches under study, the channel is 2 to 3 ft deep, and overbank flows occur frequently. However, appreciable flood damages occur only if the depth of overbank flow exceeds 2 ft.

Mt. Scott Creek

Mt. Scott Creek has a drainage area of 11.8 sq mi and is located about a mile east of Milwaukie. It joins Kellogg Creek from the east at river mile 2.0.

There is continued light industrial development in the Mt. Scott Creek flood plain. Severe flooding of Intermediate Regional Flood or Standard Project Flood dimensions would affect most of the developments. One business establishment in the area has been inundated by past floods.

High water flows occur frequently during the rainy season as the result of heavy rainfall. Floods are of short duration, normally not more than 2 days, and peak stages last only a few hours. In the study area, the channel is 2 to 3 ft deep, and overbank flooding can be expected annually. However, it requires at least a 5-year flood to produce significant damage.

In Mt. Scott Creek, the average velocity varies from 2 ft per second at low water to 9 ft per second during floods. The overbank velocities are less than 3 ft per second.

Recommendations for flood-plain use and development standards

To assure that flood-plain regulations are effective, minimum standards or guidelines should be established for flood-plain use and development. Although larger floods can occur, it is recommended that flood-plain regulations be based upon a 100-year flood, which is defined as a flood having a 1 percent chance of occurrence in any single year. Flood plains should be analyzed as two separate areas: (1) the floodway, and (2) the floodway fringe, which is the flood-prone area outside of the floodway but within the selected flood limits. The type and extent of regulations needed will vary between the two areas.

The floodway: Because certain intensive development in the floodway will aggravate the flood situation, the floodway should, wherever possible, be maintained as open space for such uses as agriculture or recreation.

The floodway fringe: Inasmuch as development in the floodway fringe will not aggravate the flood problem appreciably, regulations need not prohibit structural development but should control floor elevations or require floodproofing to an elevation above that of a 100-year flood. Storage or processing of noxious or floatable materials should be carefully controlled in this area. Any water-supply or sewage-system facilities developed in this area should be designed and constructed so as not to be contaminated or to be a source of contamination during flood situations.

The potential for damages will not necessarily be reduced with the construction of new dams or other flood-control measures such as levees and channel improvements. More and more people are moving onto the flood plains, and it is not possible to build flood-control works adequate to protect all of the areas which may be developed for residential, commercial, and industrial use.

The best way for communities or the County to minimize flood damage in the future is to allow only certain types of development on the flood plain, and then only in predetermined areas where the risks are reasonable and where the development will not increase flood heights appreciably. For example, the more flood-susceptible areas near streams could be reserved for the development of open-space facilities least susceptible to flood damages.

Flood forecasting: In Oregon, the U.S. Department of Commerce's National Weather Service (NWS) River Forecast Centers in Portland and Medford are responsible for stream-flood forecasting. This forecasting is accomplished by using data from a network of automatic and manual stations measuring streamflow and precipitation throughout the State. The Weather Service should be urged to provide 24-hour rather than 8-hour surveillance.

Flood warning: When meteorological, hydrological, or other conditions indicate that a flood is imminent, the River Forecast Center transmits a warning to the State Executive Department's Division of Emergency Services. The Division forwards this warning to city and County officials through its communication systems, including the National Warning System (NAWAS).

Flood insurance: The National Flood Insurance Act of 1968 was enacted by Title XIII of the Housing and Urban Development (HUD) Act of 1968 (PL 90-448) and has two major purposes: (1) to offer insurance at subsidized rates to present flood-plain occupants, and (2) to discourage future unwise development of flood plains. In order to qualify for this coverage, an appropriate unit of government must have enacted adequate flood-plain regulations.

STREAM-BANK EROSION

Description

Streams continually erode their channels by either cutting downward or migrating laterally, thus developing slope hazards on the stream banks. The amount of work a stream can do is greatly accelerated during floods. Factors influencing the behavior of a stream include gradient, rate of discharge, slope angle, bank material, width, and depth of channel.

Youthful streams with high gradients cut vertically downward. The valley sides develop slopes whose angles depend upon the strength of the materials within the slopes. As the streams cut downward, the valley widens by slope failure. Slide debris is carried away by the stream.

Mature streams no longer cut vertically but migrate laterally by erosion of their banks and develop a wide flood plain. Oxbow lakes or abandoned channels are present on the flood plain and younger terraces.

Generally, a meandering stream erodes and migrates toward the outer bank, simultaneously depositing sand and gravel along the inside of the curve (Figure 41). When floodwaters leave the stream channel and spread out over the flood plain, water velocities are reduced, and consequently sand, silt, and clay are deposited, forming natural levees in certain areas.

Recommendations

Hazards connected with youthful streams are deep, steep-sided canyons with unstable slopes. Although flat areas on some parts of the slopes might appear to make excellent building sites, they may be the result of slumping and should therefore be avoided.

Development along a youthful stream normally requires construction of a primary road and a number of private roads to provide access to individual properties. The primary road should be either at the bottom or top of the slope. If built at the bottom, the road should be above the flood level but not where steepening by cuts could cause a landslide or where a fill would obstruct the stream flow. Side roads should not be located where significant cuts are essential to achieve grade. Stream channels or draws crossed by road embankments should be adequately tiled to prevent ponding or washout during heavy rains.

Figure 41. Erosion at outside of curve and deposition on inside cause streams to move laterally and develop meanders. Good gravel can usually be found inside meander loop, as in large gravel pit at bottom of picture. Photo is of Clackamas River at river mile 14, looking north toward Barton School.

Figure 42. Riprap being used to prevent erosion of north bank of Clackamas River at Clackamet Park.

Figure 43. Erosion where banks were not riprapped at Clackamet Park.

Development along an older meandering stream should accomodate the direction and rate of lateral stream migration. The study required for such development should utilize data covering a sufficient period of time to give an accurate estimate of the rate of erosion that can be expected. It may also be necessary to consider long-term trends in channel migration and cutoff to assess all of the potential hazards adequately. The rate of erosion may be estimated from eye-witness accounts of long-time residents or from comparison of older maps or aerial photographs with recent ones. Normally, a setback from the edge of the eroding bank is the surest means of protection from stream-bank erosion. The amount of setback required depends upon the average annual rate of stream-bank erosion, the anticipated life expectancy of the structure, and minimum setback which can be physically tolerated. In certain areas, riprap may have a temporary effect in preventing erosion (Figures 42 and 43).

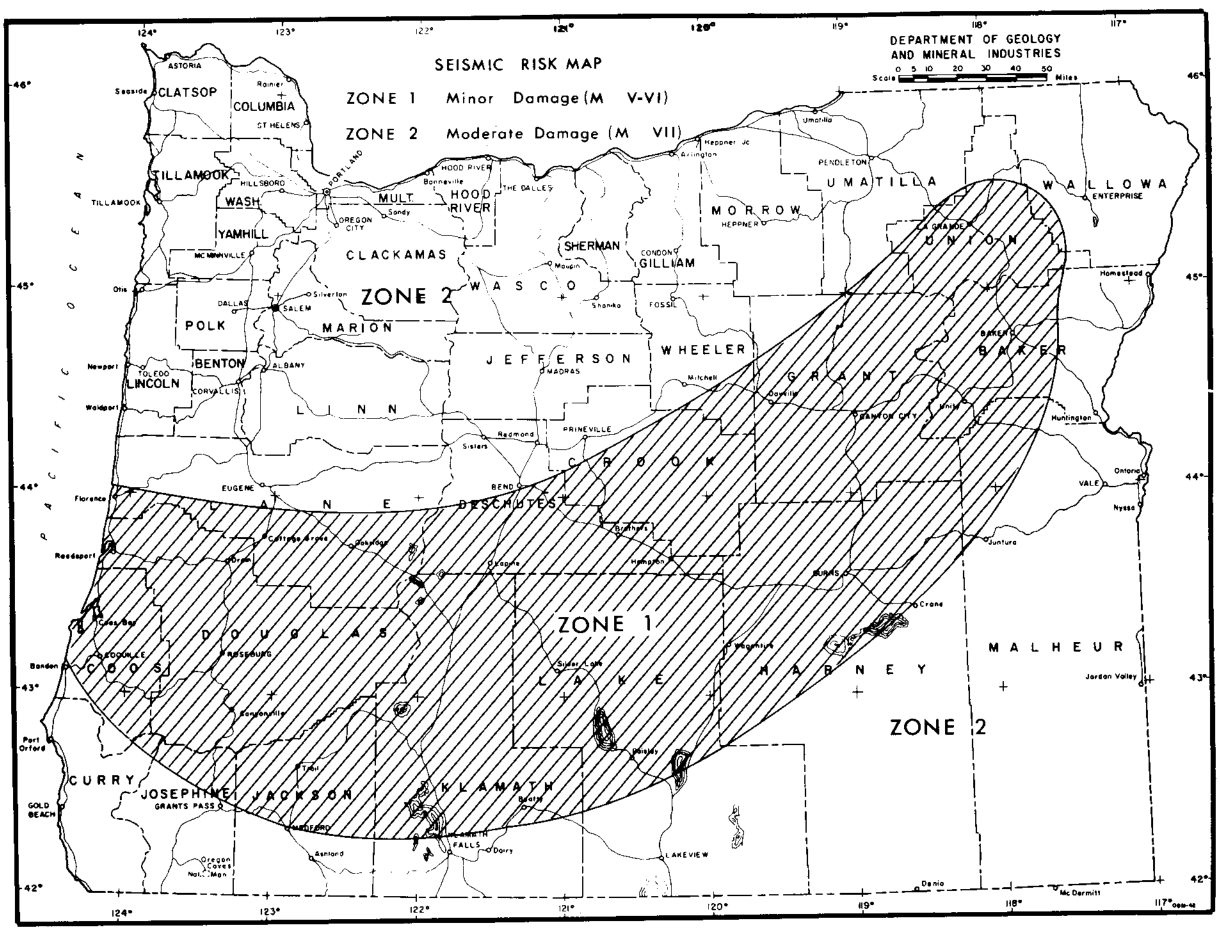
EARTHQUAKES AND SEISMIC ENERGY RELEASE

Introduction

Seismic records indicate that the Pacific Coast sector of the circum-Pacific earthquake belt extends through southern California, passes out to sea toward the north, and is present approximately 200 to 300 km west of the coast of Oregon at Astoria. Although Oregon does not experience the level of seismic activity of its neighboring states, it has been shaken by many more earthquakes than is generally realized, and many of them have occurred in the vicinity of Portland.

Records indicate there have been at least 192 earthquakes in Oregon since 1841, not including those originating out of the State or at sea but felt in the State. Only about 30 quakes are known to have occurred prior to 1900; many, undoubtedly, were not

Figure 44. Seismic risk map of Oregon.



reported because of the scattered population, poor communications, and lack of instrumentation. Thus, Oregon's recorded seismic history is rather limited and insufficient in itself for an assessment of the State's seismic activity (Figure 44).

Crustal earthquakes in most cases are caused by the sudden fracturing or faulting of rocks at depth. The specific location of energy release within the earth is called the focus, and the geographic location on the earth's surface above the focus is called the epicenter. Faults associated with earthquakes do not always extend to the surface and therefore cannot always be shown on a map. Maps delineating faults show only the visible surface traces of faults and do not always indicate whether they are active or inactive. No fault movement has been observed in association with earthquakes in Oregon.

Earthquake waves are vibrations which travel through the earth as elastic waves. The primary or *P*-wave vibrates in the direction of propagation and is longitudinal and compressional in motion. It is the fastest wave and arrives first, traveling at a velocity that equals the speed of sound through rock, which varies with the density of the material. The secondary or *S*-wave is a transverse wave which vibrates at right angles to the direction of propagation.

Focal mechanism studies summarized by Dehlinger and others (1971) identify a regional stress field which suggests a gradual extension of Oregon in an east-west direction and documents a north-south compression. This will produce the right-lateral strike-slip motion that is proposed for the Portland fault.

For this report, in addition to mapped faults, major lineaments have been recognized, based on topographic features and SLAR imagery. The abundance of lineaments and possible faulting suggests that detailed studies should be undertaken to determine future seismic probability.

Measuring earthquakes

Magnitude: The magnitude of an earthquake is its strength, determined by measuring the amplitude of its waves recorded on a seismogram, corrected for the distance from the epicenter. Magnitude is independent of the location of the recording station. The most commonly used magnitude rating is the Richter scale. Magnitudes range on a logarithmic scale from less than 1 for small shocks to over 8.75 for the largest earthquakes. The magnitude of an earthquake is related in a general way to the amount of energy released; however, the magnitude is not a quantitative measure of energy.

Intensity: Intensity refers to the observed or felt effects of an earthquake. It indicates the amount of shaking or damage at a specific location. Intensities differ from area to area, depending upon the local geology and distance from the epicenter of the quake. The intensity rating is not a damage report; consequently, secondary damages such as those caused by fire, flood, or landslide are excluded when assigning an intensity rating. The modified Mercalli scale of intensity is most commonly used today (Table 11). Intensities range on the modified Mercalli scale (1956 edition) (Richter, 1958), abbreviated MM, from intensity I, which is not felt, to intensity XII, in which damage is nearly total.

Earthquake prediction

Earthquake prediction is a subject of great interest to many scientific investigators; however, the difficulties to be overcome are numerous. Records indicate that earthquakes will probably recur where they have occurred in the past and that the intensity of the recurrence can be much greater than that of previous quakes. The probability that an earthquake will recur increases proportionally with time.

A capability for reliable earthquake prediction can be expected to be developed in the near future. Scientific instruments will detect geophysical signals that can be interpreted to forecast earthquake occurrence. For general planning purposes such as those addressed by this study, it is more important to determine where future earthquakes are likely to occur rather than specifically when they are going to occur.

Earthquake prediction for any one area must take into account the impact of earthquakes occurring in surrounding areas. A severe earthquake can produce maximum lateral accelerations on both bed rock and alluvium up to 50 mi from an epicenter. Long waves can produce severe damage on thick alluvium up to 200 mi away. Because earthquake damage on alluvium can be caused by earthquakes approximately four times more distant, alluvium is about 16 times more susceptible to earthquake damage than is bed rock. The Puget Sound area has been the focus of a number of major earthquakes that have also been felt in Clackamas County.

Effects of earthquakes on earth materials

Major seismic-related effects other than ground shaking during an earthquake are liquefaction, subsidence, landslide, and ground rupture.

Liquefaction: This is a change of granular material from a solid state into a liquefied state, resulting from increased pore-water pressure caused by rearrangement of mineral grains and subsequent decrease of pore space during ground vibration or shaking. Conditions which control liquefaction include degree of water saturation, permeability, grain size, sorting, and

Table 11. *Scale of earthquake magnitudes and intensities*

Mercalli intensity	Description of effects	Equiv. Richter magnitude
I	Not felt except by a very few under especially favorable circumstances.	
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	3.5
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.	to 4.2
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing motor cars rock noticeably.	4.3
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. A few instances of cracked plaster; unstable objects overturned. Some disturbance of trees, poles, and other tall objects noticed. Pendulum clocks may stop.	to 4.8
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	4.9–5.4
VII	Everyone runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.	5.5–6.1
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.	6.2
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.	to 6.9
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.	7.0–7.3
XI	Few if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	7.4–8.1
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.	Max. recorded 8.9

*Adapted from Holmes (1965) and U.S. Geological Survey (1974) depth to the water table. For example, in free-draining coarse sands and gravels, pore pressures may dissipate so rapidly that liquefaction cannot develop. With the water table at depths below 50 ft, near-surface materials may show no significant increase of pore pressure or its effects.

Subsidence: This is a relatively rare phenomenon which involves the rapid subsiding of the ground surface due to consolidation of previously unconsolidated materials or to internal collapse of a subsurface void. This may accompany sand boils and expulsion of water.

Landslides: Slides and rock falls are types of ground failure that often occur during an earthquake. Landslides may occur in unconsolidated sloping ground due to rapid increases in pore pressure and resultant loss of shear strength, on steep ground underlain by consolidated and/or cemented materials, or in jointed or fractured rock. During wet seasons, many slopes have a low safety factor, and shaking will cause sliding.

Ground rupture: In most observed earthquakes, ground rupture generally occurs in alluvium along zones a few hundred feet wide on the trace of the fault movement. However, sympathetic ground rupture can occur along unknown secondary or tertiary faults that might underlie alluvial deposits.

Portland area earthquakes

Intensities: The Portland area has been the epicenter for at least 56 earthquakes with intensities ranging from II to VII. Nine of these were of an intensity of V and above (Berg and Baker, 1962). Earthquakes having intensities of VIII on the modified Mercalli scale were reported in Portland in 1877 and in 1880. An earthquake with an intensity of VII shook the city in 1962, and a quake intensity of VI was reported in Portland in 1953.

Energy release: The cumulative earthquake energy release in the Portland area has been computed by Couch and Lowell (1971). Magnitudes or intensities of all historical earthquakes from 1877 to 1970 were used. Between 1877 and 1950, an average energy release of 1.4×10^{16} ergs per year occurred; between 1950 and 1958, however, the average rate was 1.4×10^{17} ergs per year, ten times as great as before.

The energy release between 1877 and 1950 is considered equivalent to one earthquake of magnitude 4.5 (intensity V) each year. Energy released between 1950 and 1968 was equivalent to one magnitude 4.8 (intensity V-VIII) earthquake each year or one of magnitude 5 (intensity V—VIII) every 5 years (Figure 45) (Table 12).

November 5, 1962: The earthquake occurred at 7:36 p.m., P.S.T., on November 5, 1962; the epicenter was in east Vancouver, Washington, along the Columbia River (Figure 46). A maximum intensity of VII (on the modified Mercalli scale, 1956 version) was felt in Portland, and the shock was felt as far as 150 mi away (Figure 47). This earthquake, estimated magnitude 5, was the largest instrumentally recorded shock ever measured in Oregon, originating probably less than 10 km below the surface. After the main quake, a number of smaller aftershocks occurred. Damage was minor, the greatest occurring in Portland, where numerous chimneys were destroyed, windows were broken, large cracks occurred in plaster, dishes rattled, some furniture was moved, and advertising signs fell off buildings. A thunderlike roar was also reported, and a few individuals reported dizziness or difficulty in remaining standing.

January 27, 1968: The earthquake of January 27, 1968, occurred at 12:28 a.m., P.S.T., near the location of the November 1962 earthquake and was the first sizable disturbance in the immediate area since the damaging shock and accompanying aftershocks of November 5, 1962 (Dehlinger and Berg, 1962; Dehlinger and others, 1963). The magnitude was estimated at 3.7. The source is considered to have been a fault rupture. It is estimated that the source motion lasted no more than a few seconds.

The depth of focus of the earthquake was calculated to have been between 20 and 24 km. The observed initial ground motions were consistent with a right-lateral displacement along a northwesterly-trending strike-slip fault similar to the Portland fault. The epicenter was placed at latitude 45°36.6′ N.,

Figure 45. Cumulative seismic energy release in Portland area.

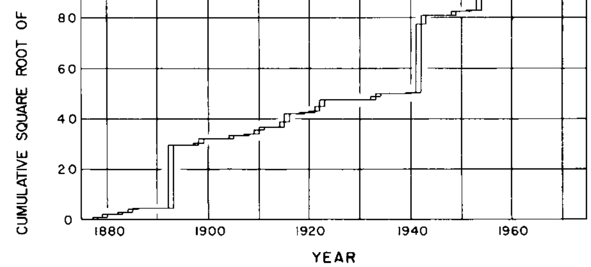


Table 12. *Earthquake frequency vs. energy release in the Portland area*[1]

Physiographic area	Maximum intensity[2]	Maximum acceleration (cm/sec²)	Years of maximum intensity	Average E/yr(E = ERG) 1870-1970	Average E/yr/km² 1870-1970	Estimated seismic activity level
Portland area	VII	68.1	1962	2.6×10^{17}	8.7×10^{13}	One magnitude 4.8† (intensity V) quake per year; or One magnitude 5.3† (intensity VI) quake per ten years
Willamette Valley	VI	31.6	1896 1930 1961	1.3×10^{17}	9.6×10^{12}	One magnitude 5.3† (intensity VI) quake per 30 years

[1]Source: Couch and Lowell, 1971.
[2]Modified Mercalli scale.
†Unified magnitude scale.

122°36.3′ W., on the north bank of the Columbia River (Figure 46). The probable trace of the fault is several miles west of the measured epicenter.

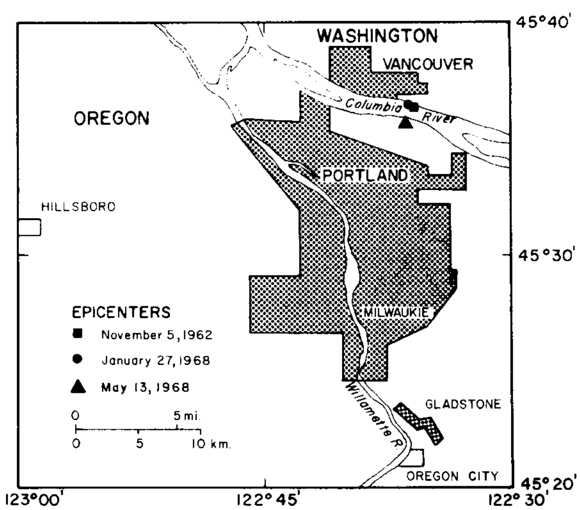
May 13, 1968: The earthquake of May 13, 1968, occurred at 10:52 a.m., P.S.T., between the northeastern edge of the city of Portland and the Columbia River. The estimated magnitude was 3.8, and the estimated depth of focus was 4 to 12 km.

The maximum intensity of this earthquake is placed at IV on the modified Mercalli scale. Although this earthquake rattled windows and caused hanging objects to swing, no damage was reported.

Recommendations

When a destructive earthquake centers in or near a populated area, the results can be catastrophic. It may flatten buildings, collapse dams and bridges, sever communications, cause landslides, and leave gaping cracks in the ground. Since this country was settled, about 1,500 persons have died during earthquakes or earthquake-generated tsunamis and fires. Almost half this number is attributable to the 1906 disaster in San Francisco, California. By comparison, Shenshi, China, experienced an earthquake in 1556 that caused a reported 830,000 fatalities. Even moderate shocks in foreign areas often have caused tremendous loss of life and property because of high population density and poor construction practices.

Figure 46. Map of Portland area, showing location of three earthquake epicenters of 1960's. Portland area historically has experienced at least 56 earthquakes.



Human life and property can be protected from earthquakes in three stages: before, during, and after the quake. Authorities can implement appropriate regulations and public information programs to minimize the potential destructiveness of earthquakes.

Before an earthquake: Earthquake precautions depend largely on local conditions in regard to anticipated epicenter locations and potential damage. The study area has experienced earthquakes of intensity VII, but the observation period so far is quite inadequate for a definitive assessment of earthquake potential. Studies of faulting can serve as additional aids toward a better definition of the earthquake risk in the area, and it may be necessary to study faulting as old as 30,000 years.

Based on the available information, it is recommended that the earthquake provisions of the Uniform Building Code be implemented fully in construction. Provision for refinement should be made, pending more detailed earthquake risk zonation on the basis of structure, anticipated ground response, and slide potential.

During an earthquake: A properly warned public should be able to avoid panic reactions. Many deaths and injuries have occurred when frightened residents ran into the streets just as walls and chimneys were collapsing and parapets, ornamentation, cornices, and other objects were falling.

Indoors, one should take cover immediately under a doorway, table, desk, or any object that will provide protection against a falling ceiling or wall.

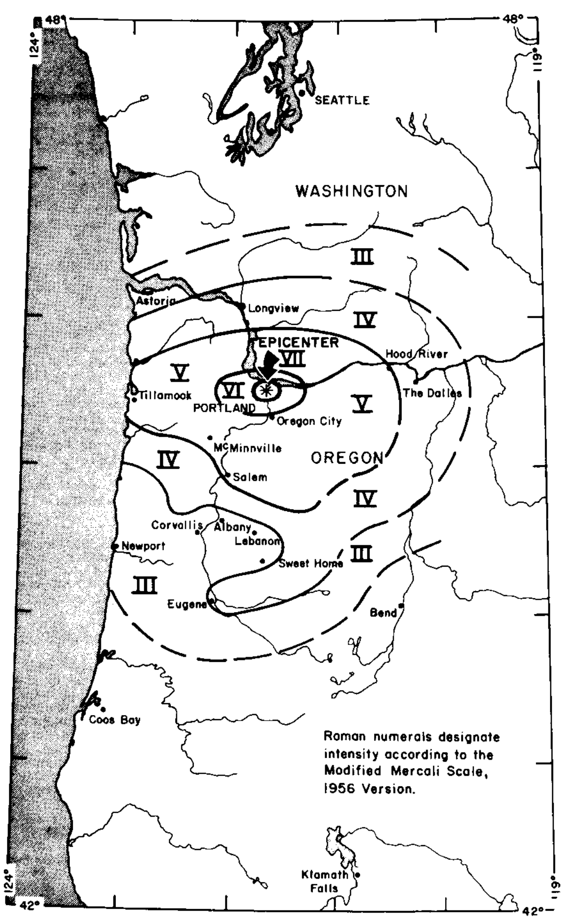
Outdoors, near buildings, one should seek protection in an open doorway or go to the middle of the street, staying clear of utility poles, cornices of buildings, or other objects that might fall.

In open country, one should be aware of trees that can be uprooted or have their tops snapped by shock waves. In areas of unconsolidated ground, shock waves may generate massive landslides, even on moderate slopes. Open, flat country is generally the safest place to experience a strong earthquake. While ground cracks might occur, the chance of being swallowed by such fissures is extremely slight and probably the most unlikely of all earthquake hazards.

When driving a car, one should pull to the center of the street and away from tall structures and then stop until the earthquake has subsided. Remaining inside the automobile will provide additional protection.

After an earthquake: Immediately after a damaging earthquake, fallen or dangling electric wires represent a most direct hazard. Underground pipes are often broken, and leaking gas can be ignited by cigarettes or open fires.

Figure 47. Isoseismal map of Portland earthquake of November 5, 1962 (Dehlinger and Berg, 1962).



Aftershocks normally follow all large earthquakes, usually with decreasing frequency and intensity, and may continue for a day or two, in some cases for weeks or months, after the principal shock. They are generally centered at various points in the epicentral area. For this reason, no seriously damaged structure should be reoccupied without the approval of local authorities. The building or home may have been weakened by the principal shock so that a sharp aftershock could make it collapse.

VOLCANIC HAZARDS

Volcanic history

A large number of small peaks with volcanic vents from which the Boring lava and agglomerate emanated from 1 to 3 million years ago are located in east Portland, Lake Oswego, and other parts of Clackamas County. These volcanoes are considered to be extinct. Volcanic peaks in the High Cascades, however, were active in recent times.

During the past 2,500 years, Mount Saint Helens, located about 50 mi north of Portland in the state of Washington, has erupted repeatedly, producing lava domes, large volumes of pumice, hot pyroclastic flows, lava flows, and mudflows. According to Crandell and Mullineaux (1971), "During an eruption in 1853, clouds of tephra and steam rising above the volcano were seen from a point 150 km to the west and also from Salem, 155 km to the south-southwest." In 1848, large explosions during eruptions at Mount Saint Helens were heard 100 km south, at Oregon City, Oregon (Harris, 1976).

Mount Hood, 45 mi east of Portland, is a late Pleistocene volcano consisting of an older cone buried by a younger cone. Volcanism has continued intermittently almost to the present, according to Crandell and Rubin (1977), who note significant ash flow eruptions and dome development 1,500 to 1,800 years B.P. and 200 to 300 years B.P.

Eruptions during the earlier period produced ash flows and mudflows that extended down the Sandy River to Troutdale; the later eruptions generated mudflows that extended to the Old Maid Flat area and down the Sandy River to Zigzag.

According to Lawrence (1948), an ash eruption occurred around 1800, 300 m below the summit near Cloud Cap Inn. At present, a number of fumaroles with temperatures as high as 85°C are active at Crater Rock (Figure 48).

Figure 48. Fumarolic activity at Crater Rock on Mount Hood, January 1974.

The geothermal potential of Mount Hood is a subject of investigation by the Oregon Department of Geology and Mineral Industries, the U.S. Geological Survey, private utilities, and individuals. The volcanic hazards associated with the Mount Hood volcano are under investigation by Crandell (in press).

In other areas, volcanoes which formerly had been dormant for much longer periods than those in the Cascade Mountains have suddenly become active. The geologists who have studied the Cascade volcanoes in detail believe that a significant eruption could occur at any time. If this is true, the effect of such an event should be seriously considered, and plans should be formulated to protect the public.

Products and associated hazards of of volcanoes

A volcano can erupt in a number of different ways. For example, eruptions which produce fluid lavas are generally relatively quiet. The flows follow canyons and stream channels for varying distances and at varying velocities ranging from a few feet to several miles in an hour. Although normally mobile persons may flee from the path of a lava flow, damage to property cannot be prevented. Hot lavas can cause floods by melting the snow pack, start fires, and pollute or destroy streams, stream channels, and reservoirs.

In other eruptions, the lava at the vent may be viscous, resulting in the formation of a lava dome, which may collapse or explode, hurling rock fragments over great distances.

Mudflows, rock debris avalanches, and pyroclastic flows can develop and cause destruction at a greater distance from the vent. Explosion of gassy magma can produce volcanic ash or tephra which is carried by wind for great distances. This air fall in general may reach several tens of feet in thickness near the vent and thin to 1 ft about 35 to 40 mi downwind. Postulated hazards from Mount Hood are less and are summarized by Newton and Peterson (1978).

Pyroclastic flows move in a cloud of hot gases, travel down gentle glopes at speeds approaching 150 km per hour, and continue on ground level for great distances. Their temperatures can be several hundred degrees Celsius. Mudflows sometimes develop speeds of 80 km per hour and travel for great distances.

Directions and distances which hazards from an erupting volcano can reach may vary considerably. Therefore, it may be difficult to formulate a plan which would fit any given situation. The State Emergency Services Division has developed Part III, Relief and Recovery Plan, which contains a number of features which could apply to volcanic outbreak, including plans to establish public information systems, emergency water supply, emergency energy, debris removal, and disaster recovery planning.

If phenomena that indicate a forthcoming volcanic event are observed, the volcano should be studied by experts. As eruption approaches, a volcano watch should be established. All such precautions as lowering of reservoirs, evacuating persons in hazard areas, and setting up roadblocks should be taken. Warning systems should be used to announce the occurrence and report on its extent.

Crandell (in press) presents volcanic hazard maps of the Mount Hood area, along with a text, all designed to assist planners in addressing volcanic hazards. Planners in the area should allow for plan revision or refinement suggested by the publication when it is released by the U.S. Geological Survey.

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APPENDIX

APPENDIX A. BEDROCK AND SOILS DATA CHART OF NORTHWESTERN CLACKAMAS COUNTY, OREGON

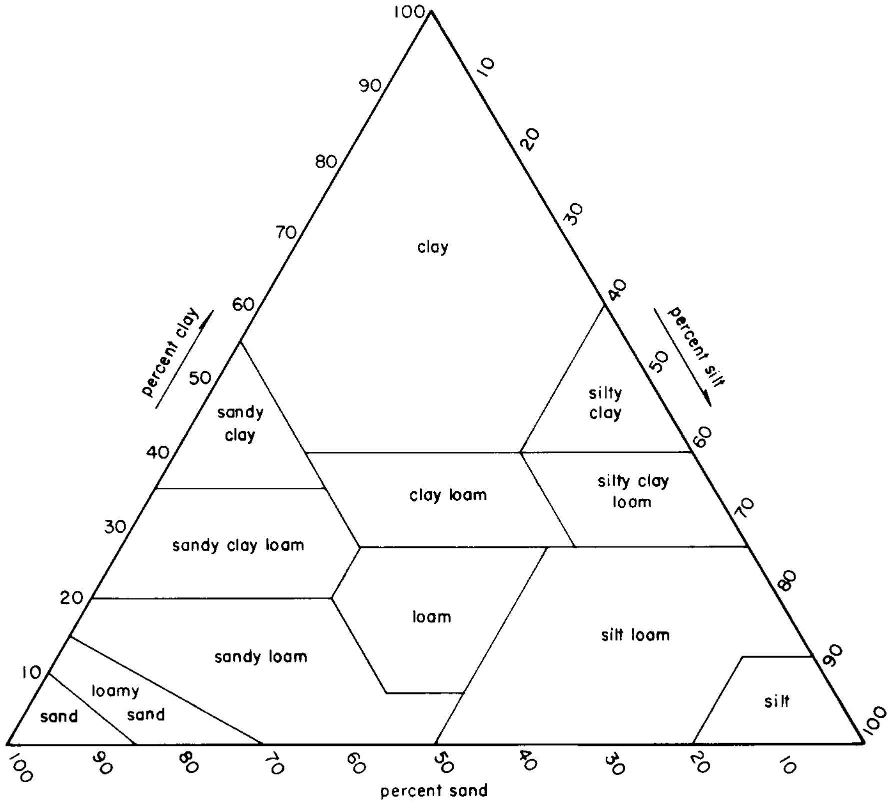
This table presents engineering characteristics of representative soils of each rock unit found in northwest Clackamas County. These soils are the most common and/or the most hazardous (in terms of construction usages) found overlying a particular rock unit. The soils are listed by their locations on particular rock units. If two or more soils with similar characteristics occur at a particular location on a rock unit and if these soils exhibit many common characteristics, the values are averaged so as to give one general set of characteristics for all the soils of this location.

Rock unit	Rock unit symbol and occurrence	Principal soils[7]	Soil depth[1] (in.)	Soil classification Unified	AASHO	Percent of material passing sieve #10	#40	#200	Atterberg limits Liquid limit (%)	Plasticity index	Shrink-swell[3]	Winter water table height[4] (ft)	Permeability (in./hr.)	Corrosivity Steel[3]	Concrete[3]	Septic drain field use[5,6]	Proctor density Opt. moist. (%)	Dry density (pcf)	Shear strength Angle[3]	Cohesion[3] (p/ft²)
SURFICIAL UNITS — Quaternary alluvium	Qal/Pt Poorly drained bottom land	Semiahmoo Muck Peat (Pt),	0-30 30+	Pt	A-8	← Organics →			NP	NP	M	0 -0.5	0.6 -2.0	H	M	SV	-	60+	L	L
		Cove, Labish	0-60	CL-CH-OH	A-6, A-7	100	90-100	75- 95	50-80	15-50	H	0 -1	<0.06-0.2	H	L-H	SV	20-26	96-104	L	H
	Well-drained bottom land	Cloquato, Wapato	0-60	ML-MH	A-4, A-6, A-7	100	90-100	70- 95	30-60	5-20	L-M	0 -3	0.2 -2.0	M-H	M	SV	17-26	99-109	M	M
	Flood plain and low terraces	Briedwell, Latourell	0-30 30-60	ML-GM GC-GM-SM	A-4, A-2 A-1, A-2, A-6	50- 80 20- 60	40- 80 15- 50	30- 80 10- 40	20-40 30-40	NP-10 NP-20	L L	>6 >6	0.6 -2.0 0.6 -2.0	L-M M	M M	SL-SV M-SV	- -	- -	- -	- -
Lacustrine sediments	Qws Well-drained older terraces	Willamette, Woodburn, Aloha	0-60	CL-ML	A-4, A-6, A-7	95-100	95-100	70-100	25-50	2-25	L-M	1.5-3	0.6 -2.0	M-H	M	M-SV	16-22	100-110	M	L
	Poorly drained concave areas and drainage-ways on older terraces	Dayton, Concord, Verboort, Huberly	0-60	CL-MH	A-6, A-7	95-100	95-100	80-100	40-80	15-50	H	0 -1.5	0.6 -2.0	M-H	L-M	M-SV	-	-	-	-
	Qls Terraces	Latourell, Aloha	0-60	ML-GM	A-1, A-4	95-100	90-100	70- 90	20-30	NP- 5	L	>6	0.6 -2.0	L-M	M	M-SV	-	-	-	-
	Qdg Terraces	-	0-60	ML-GM	A-2, A-6	20- 80	20- 75	20- 65	25-40	10-20	L	>6	0.6 -2.0	L-M	M	SV	-	-	-	-
Pleistocene terrace deposits	Qpt Well-drained terraces	Clackamas	0-60	GC-GM GW	A-4, A-6, A-2-6	55-100	10-100	5- 90	25-40	NP-20	L	0.5-1.5	0.2 -2.0	H	M	SV	-	-	-	-
	Poorly drained low terraces	Concord	0-60	CL-ML	A-4, A-7	100	95-100	80- 95	30-40	5-10	L-H	0 -0.5	0.06-0.2	H	L-M	SV	-	-	-	-
	Poorly drained high terraces	Bornstedt[2]	0-60	CL-ML	A-4, A-6, A-7	85-100	85-100	75- 95	30-50	15-20	L	2 -3	0.06-0.2	M	M	SV	-	-	-	-

	Rock unit	Rock unit symbol and occurrence	Principal soils[7]	Soil depth[1] (in.)	Soil classification: Unified	Soil classification: AASHO	Percent of material passing sieve: #10	#40	#200	Atterberg limits: Liquid limit (%)	Plasticity index	Shrink-swell[3]	Winter water table height[4] (ft)	Permeability (in./hr.)	Corrosivity: Steel[3]	Corrosivity: Concrete[3]	Septic drain field use[5,6]	Proctor density: Opt. moist. (%)	Dry density (pcf)	Shear strength: Angle[3]	Cohesion[3] (p/ft²)
SURFICIAL UNITS	Eolian silt	Qes Terrace and gently sloping upland areas	Powell[2], Cascade[2], Kinton[2], Laurelwood, Cornelius[2], Delena[2]	0-60	ML	A-4, A-6	80-100	80-100	70- 95	25-40	NP-20	L-M	1.5-6	0.06-2.0	M-H	M	SV	-	-	-	-
	Plio-Pleistocene gravels	Qpg High terraces and uplands	Cazadero,	0-24	CL-ML	A-6, A-7	70-100	65-100	60- 95	35-45	10-20	L	2 -6	0.6 -2.0	H	M	SV	-	-	-	-
			Cottrell	24-60	MH-CH	A-7	100	95-100	85-100	35-55	15-30	M	2 -6	0.2 -0.6	H	M	SV	-	-	-	-
BEDROCK UNITS	Boring Lava	Qtb Uplands	Jory	0-60	ML-CL	A-7	100	80- 95	65- 90	40-50	15-20	M	>6	0.2 -0.6	H	M-H	SV	-	-	-	-
		Colluvium	Nekia[1],	0-20	ML-CL	A-4, A-6	80-100	75- 95	65- 85	30-45	5-15	L-M	>6	0.2 -2.0	M-H	M	SV	-	-	-	-
			Saum[1]	20-50	GC-MH	A-5, A-7	50-100	55- 95	50- 75	40-55	5-20	M	>6	0.2 -0.6	M-H	M-H	SV	-	-	-	-
	Troutdale Formation	Tpt Terrace and footslopes	Aloha[2]	0-18	ML-CL	A-6	90- 95	85- 95	80- 90	30-40	11-20	M	1 -2	0.6 -2.0	H	M	SV	16-22	102-104	L-M	M
			Hazelair[2]	18-30	CH	A-7	85- 95	75- 85	70- 85	60-80	40-50	H	1 -2	0.06-0.2	H	M	SV	-	-	-	-
	Sandy River Mudstone	Tsr Terrace and slopes	Helvetia[2]	0-48	CL-CH	A-7	95-100	95-100	85- 95	40-55	15-25	M	3 -6	0.2 -0.6	H	M	SV	22-24	102-104	L-M	M
			Hazelair[2]	48-60	ML-CL-CH	A-4, A-6	90-100	85-100	80- 95	25-40	NP-15	L-M	1 -6	0.2 -2.0	H	M	SV	-	-	-	-
	Sardine Formation	Tsa Cascade foothills and high terraces	Alspaugh, Aschoff	0-60	GM-ML-CL	A-4, A-6, A-7	40- 95	35- 95	25- 90	25-50	NP-20	L-M	>6	0.2 -2.0	M	M	SV	-	-	-	-
	Columbia River Basalt	Tcr Highlands	Jory	0-60	ML-CL	A-7	100	80- 95	65- 90	40-50	15-20	M	>6	0.2 -0.6	H	M-H	SV	-	-	-	-
		Colluvium	Witzel[1], Saum[1], Nekia[1]	0-20	GC	A-6	45- 55	40- 50	35- 50	30-45	5-20	L-M	>6	0.2 -0.6	M	M	SV	-	-	-	-

[1]Thin soil = less than 40 in. to bed rock.
[2]Soil has restrictive layer or fragipan.
[3]H = high, M = moderate, L = low.
[4]Water-table height between November and May.
[5]SV = severe, M = moderate, SL = slight.
[6]Hazards include steep slopes, wetness, low strength, percolation rate, depth to bed rock, amount of clay, excessive shrink-swell, flooding, and excess humus.
[7]Source: U.S. Department of Agriculture Soil Conservation Service: OR-Soils-1, Soil Interpretations for Oregon.

APPENDIX B. GUIDE FOR THE TEXTURAL CLASSIFICATION OF SOILS

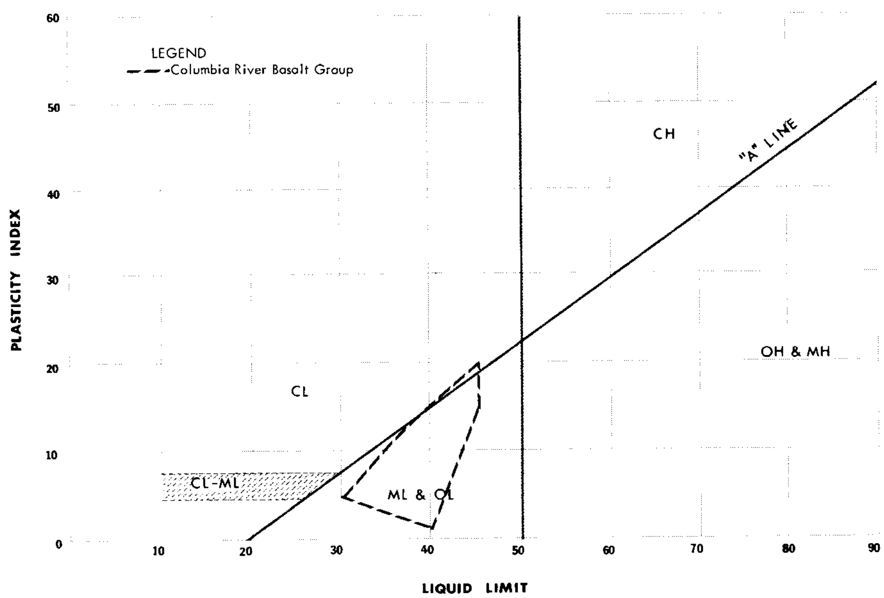


Texture	Dry feel	Moist feel	Moist shine	½"-1" wide, 1/8" thick moist plasticity (ribbon)	Moist 2"+ long plasticity (wire) 1/8"
Sand	Individual grains seen and felt	Individual grains seen and felt	None	Will not ribbon	Will not wire
Sandy loam	Individual grains appear dirty	Individual grains appear dirty	None	Will not ribbon	Will not wire
Loam	Gritty, floury feel	Gritty, smooth slick	Faint dull	Very weak ribbon, broken appearance	Very weak wire in broken segments
Silt loam	Soft and floury	Smooth slick w/ some stickiness	Dull	Ribbon broken appearance	Weak wire easily broken
Clay loam	Slightly hard, little grittiness	Smooth slightly sticky w/some grittiness	Prom-inent dull	Ribbon barely sustains weight	Wire sustains weight
Silty clay loam	Moderately hard, no grittiness	Smooth sticky, feel some plasticity	Faint	Ribbon sustains weight & careful handling	Wire sustains weight & withstands gentle shaking
Silty clay	Hard, no grittiness	Smooth, sticky plastic, faint fingerprints visible	Shine	Ribbon withstands considerable movement & deformation	Wire withstands considerable shaking and rolling
Clay	Very hard, no grittiness	Smooth very sticky - plastic fingerprints	Bright	Long thin ribbon	Wire withstands shaking, rolling, bending, 1/16"

APPENDIX C. PLASTICITY INDEX RANGES FOR SOILS ASSOCIATED WITH GEOLOGIC UNITS IN NORTHWESTERN CLACKAMAS COUNTY, OREGON

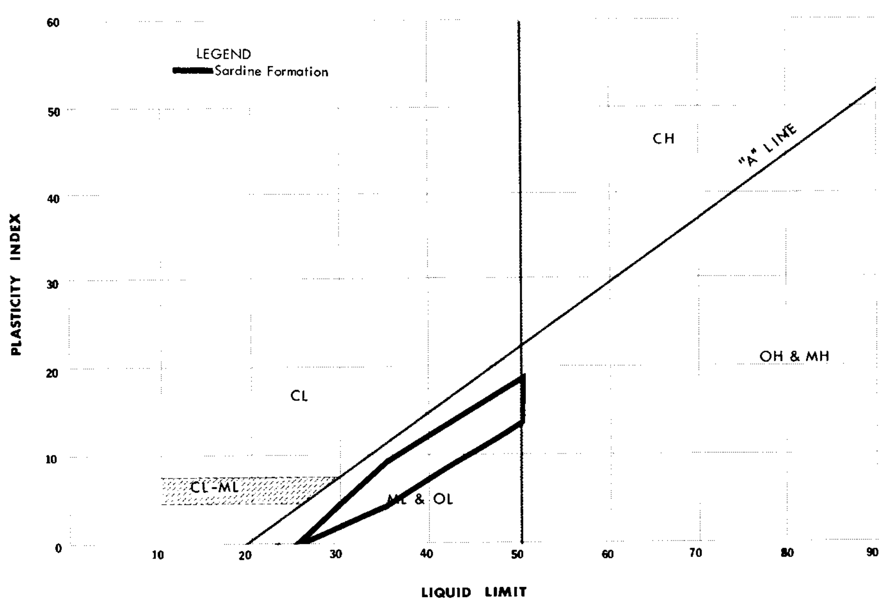
Soils developed on Columbia River Basalt Group (Tcr)

PLASTICITY CHART



Soils developed on Sardine Formation (Tsa)

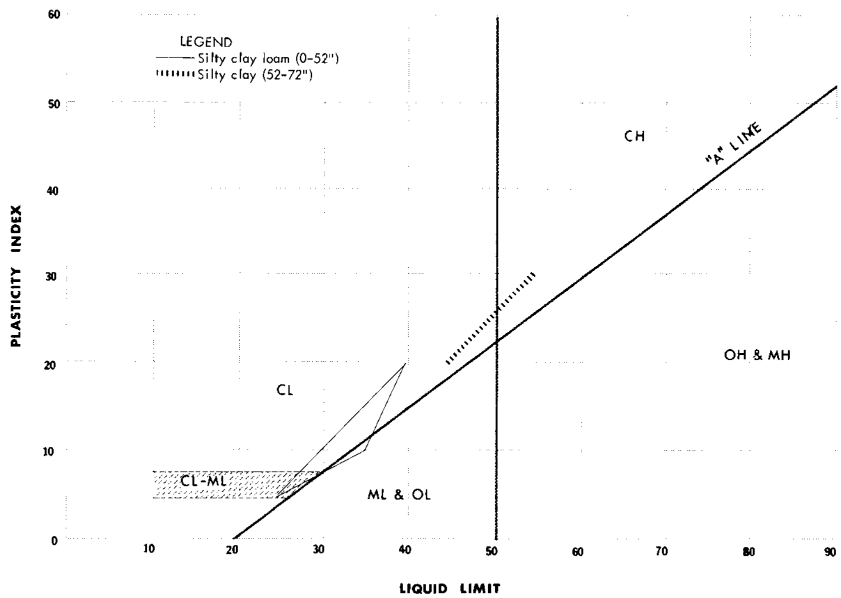
PLASTICITY CHART



APPENDIX C. PLASTICITY INDEX RANGES FOR SOILS ASSOCIATED WITH GEOLOGIC UNITS IN NORTHWESTERN CLACKAMAS COUNTY, OREGON (continued)

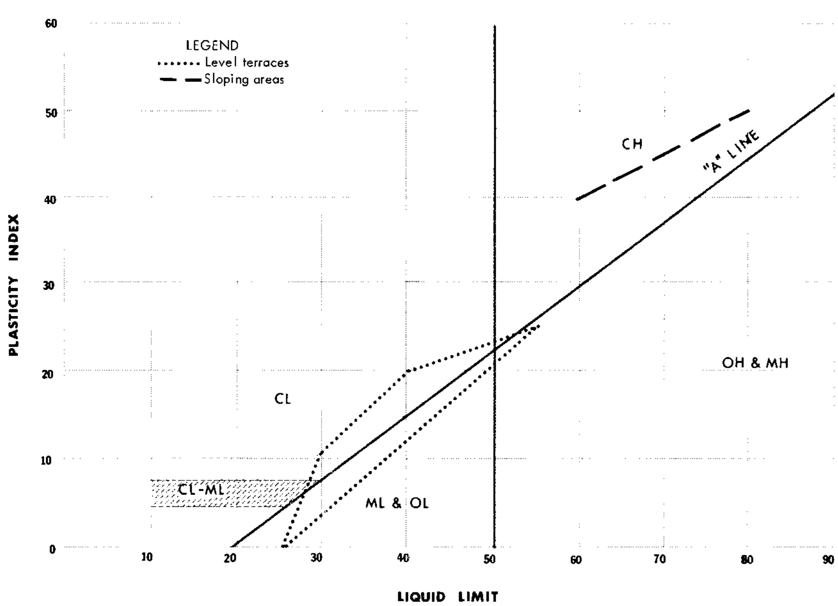
Soils developed on Helvetia Formation (Tph) (limited extent)

PLASTICITY CHART



Soils developed on Sandy River Mudstone (Tsr)

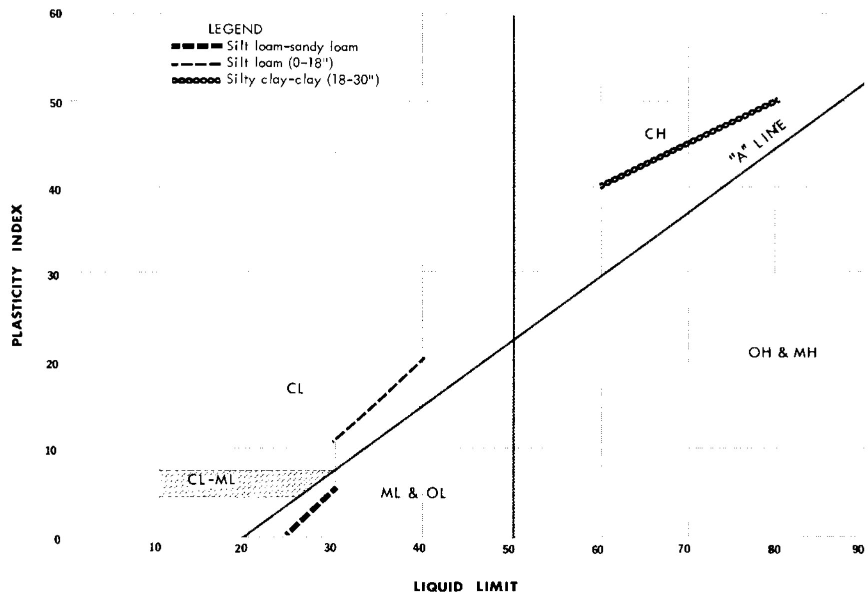
PLASTICITY CHART



APPENDIX C. PLASTICITY INDEX RANGES FOR SOILS ASSOCIATED WITH GEOLOGIC UNITS IN NORTHWESTERN CLACKAMAS COUNTY, OREGON (continued)

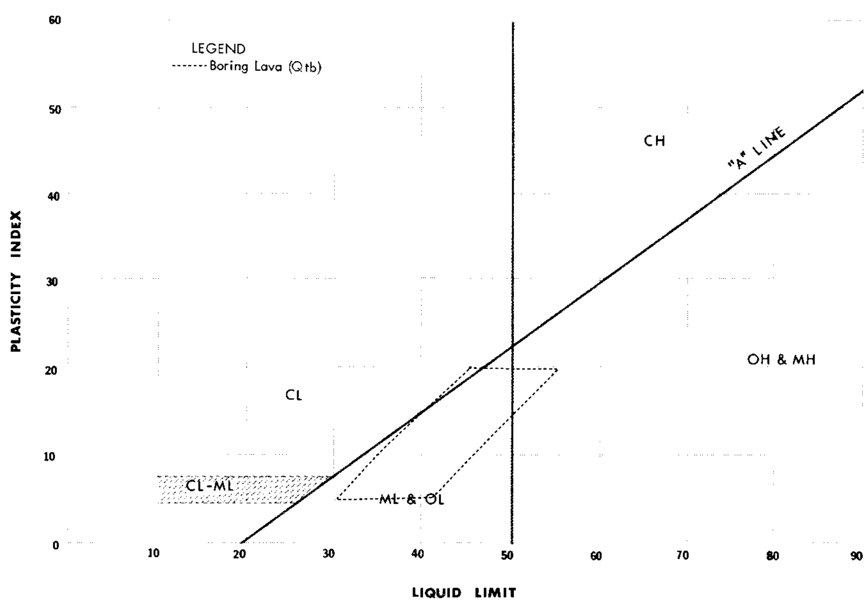
Soils developed on Troutdale Formation (Tpt)

PLASTICITY CHART



Soils developed on Boring Lava (Qtb)

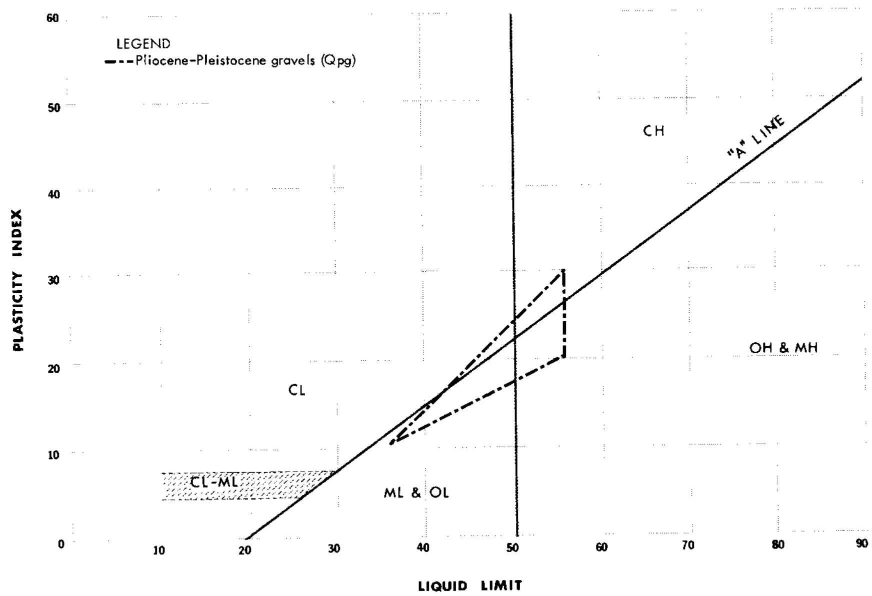
PLASTICITY CHART



APPENDIX C. PLASTICITY INDEX RANGES FOR SOILS ASSOCIATED WITH GEOLOGIC UNITS IN NORTHWESTERN CLACKAMAS COUNTY, OREGON (continued)

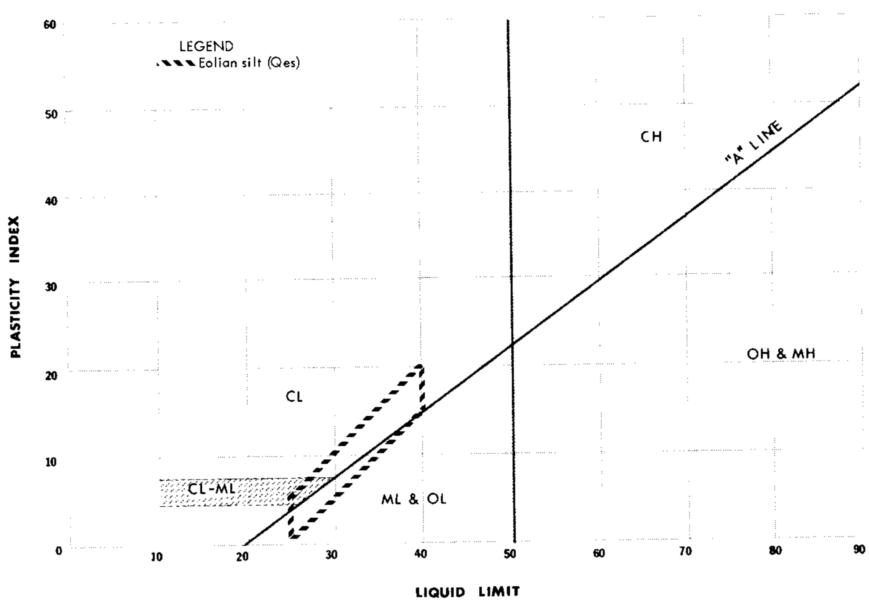
Soils developed on Pliocene-Pleistocene gravels (Qpg)

PLASTICITY CHART



Soils developed on Quaternary eolian silt (Qes)

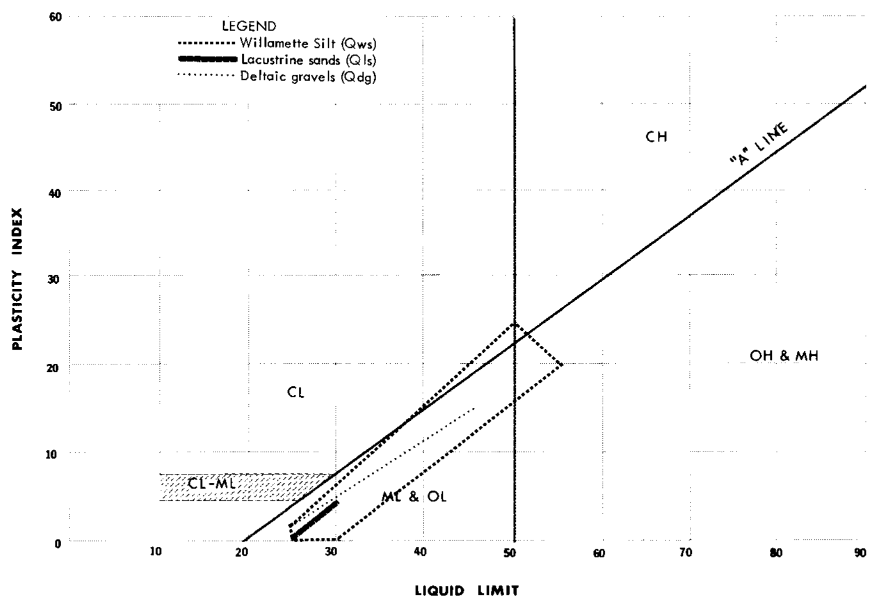
PLASTICITY CHART



APPENDIX C. PLASTICITY INDEX RANGES FOR SOILS ASSOCIATED WITH GEOLOGIC UNITS IN NORTHWESTERN CLACKAMAS COUNTY, OREGON (continued)

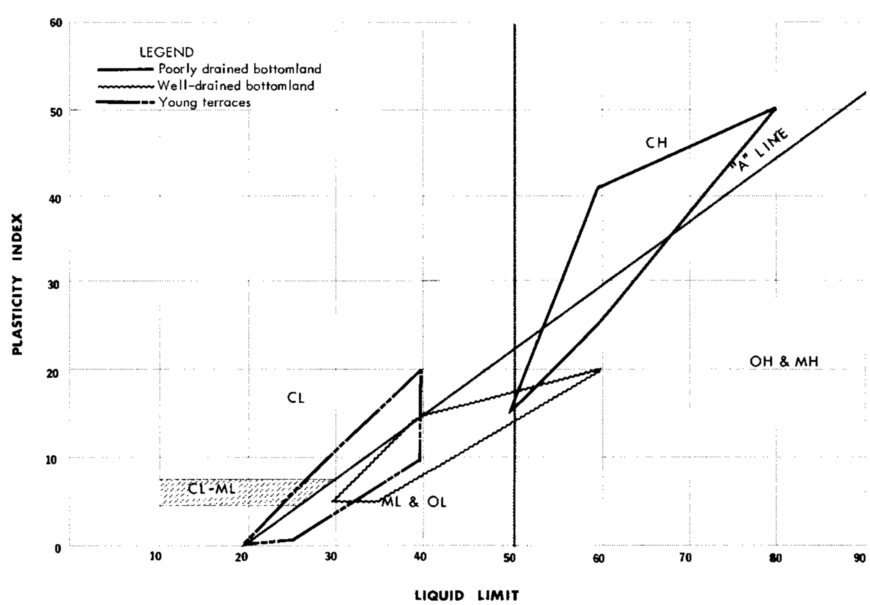
Soils developed on Quaternary lacustrine deposits (Qws, Qls, Qdg)

PLASTICITY CHART



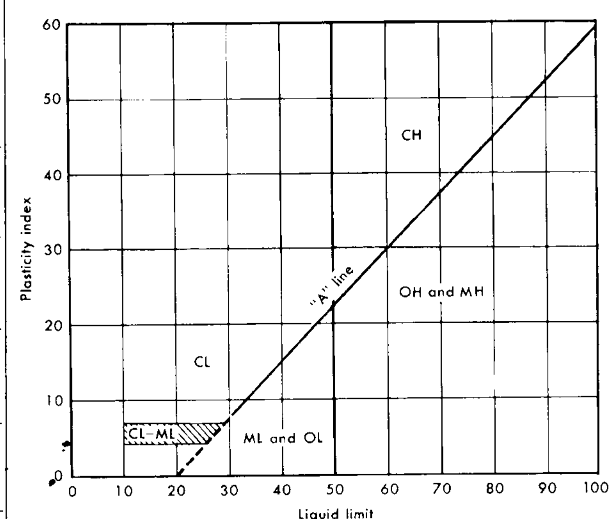
Soils developed on Quaternary alluvium (Qal)

PLASTICITY CHART



APPENDIX D. 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	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**	$C_u = \frac{D_{60}}{D_{10}}$ 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		Atterberg 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		Atterberg 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		Atterberg 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		Atterberg 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	Plasticity Chart (see below)		
			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			



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.

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APPENDIX E. AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS (AASHO) SOILS CLASSIFICATION

General classification			Group symbols	Grain size (sieve)	Atterberg limits for fraction passing No. 40: Liquid limit	Atterberg limits for fraction passing No. 40: Plasticity index*	
Granular materials Less than 35% is smaller than No. 200 sieve	Stone fragments gravel and sand	A-1	A-1-a	50% max. passes No. 10 30% max. passes No. 40 15% max. passes No. 200		Less than 6	Good to excellent subgrade
			A-1-6	50% max. passes No. 40 25% max. passes No. 200			
	Fine sand	A-3	A-3	50% min. passes No. 40 10% max. passes No. 200		N.P.	
	Silty or clayey gravel and sand	A-2	A-2-4	35% max. passes No. 200	Less than 40	Less than 10	
			A-2-5		Greater than 40	Less than 10	
			A-2-6		Less than 40	Greater than 10	
			A-2-7		Greater than 40	Greater than 10	
Silt-clay materials More than 35% is smaller than No. 200 sieve	Silty soils	A-4	A-4	Greater than 35% passes No. 200	Less than 40	Less than 10	Poor to fair subgrade
		A-5	A-5		Greater than 40	Less than 10	
	Clayey soils	A-6	A-6		Less than 40	Greater than 10	
		A-7	A-7-5 and A-7-6		Greater than 40	Greater than 10	

*The difference between liquid limit and plastic limit; the range of water content through which the soil behaves plasticly.

APPENDIX F. COMPARISON OF THREE SYSTEMS OF PARTICLE-SIZE CLASSIFICATION

American Association of State Highway Officials - soil classification	Colloids	Clay	Silt	Fine sand	Coarse sand	Fine gravel	Medium gravel	Coarse gravel	Boulders	
U.S. Department of Agriculture - soil classification	Clay	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Fine gravel	Coarse gravel	Cobbles
Unified soil classification U.S. Army Corps of Engineers Bureau of Reclamation, Dept. of Interior	Fines (silt or clay)	Fine sand	Medium sand	Coarse sand	Fine gravel	Coarse gravel	Cobbles			
Sieve sizes - U.S. standard	270, 200, 140, 60, 40, 20, 10, 4, 1/2", 3/4", 3"									
Particle size - millimeters	.001, .002, .003, .004, .006, .008, .01, .02, .03, .04, .06, .08, .1, .2, .3, .4, .6, .8, 1.0, 2.0, 3.0, 4.0, .0, 8.0, 10, 20, 30, 40, 60, 80									

APPENDIX G. SUGGESTED GUIDELINES FOR GEOLOGIC REPORTS

For Clackamas County, all acceptable geologic reports shall be prepared by qualified engineering geologists licensed by the State of Oregon. The reports shall include:

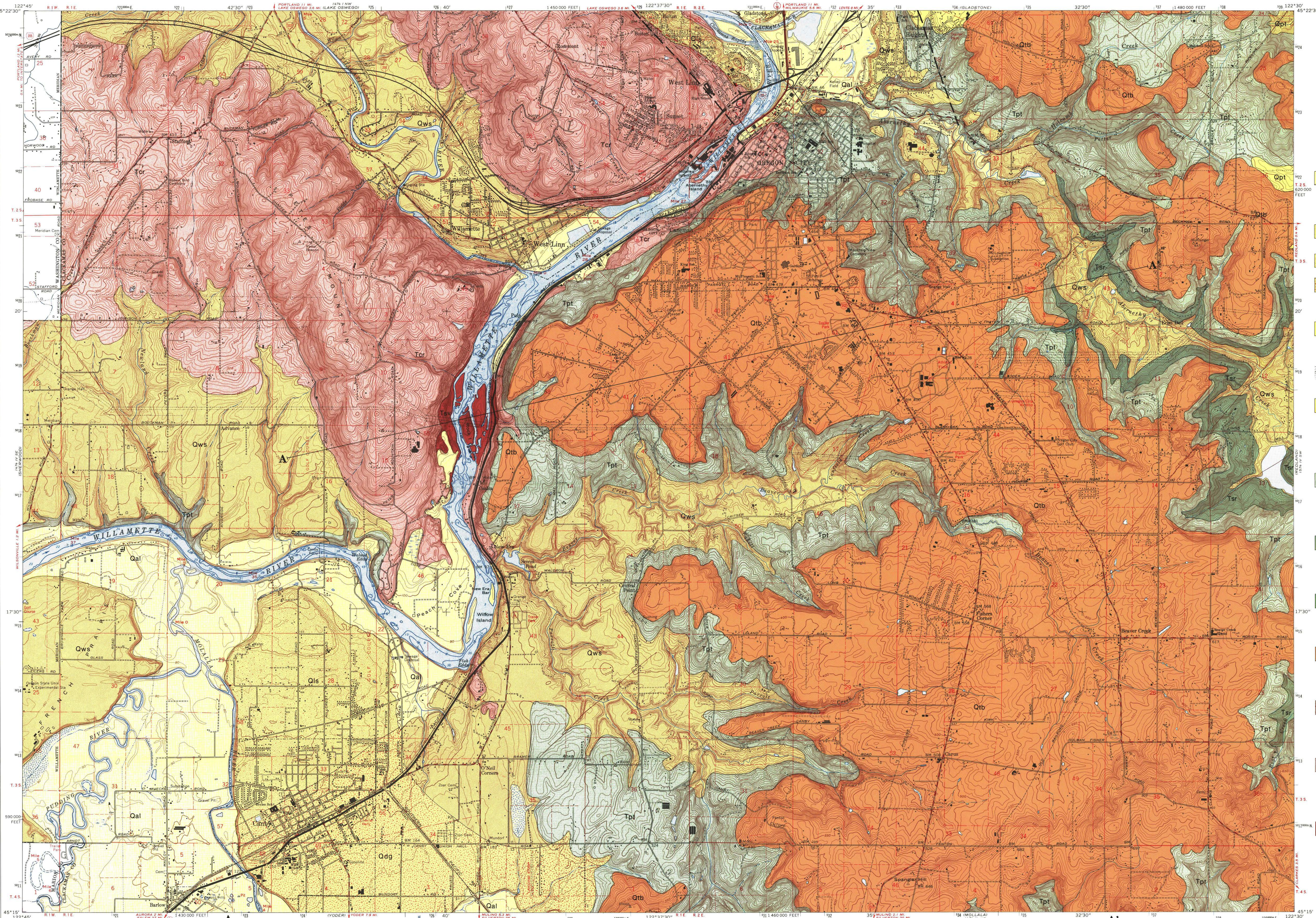
1. Name and certification number of the responsible geologist.
2. An index map showing the regional setting of the study area.
3. A statement regarding methods of study and approximate time spent in the field (to permit meaningful evaluation by the County of the basic data). Note: Methods of study include but are not limited to (1) field traverses and inspections, (2) test pits or trenches, (3) drill holes, (4) geophysical investigations, (5) aerial photo analyses, (6) laboratory tests, and (7) research of previous published or unpublished work.
4. On an appropriate topographic base, an areal geologic map including the site and as much of the surrounding area as practicable. The scale shall be 1:2,000 or larger on the main geologic map. The site map shall be on a scale specified by the County to coincide with the County's available maps.
5. One or more geologic structure cross sections to show actual or probable subsurface relations. Conjectural relations are to be clearly labeled.
6. A statement of conclusions and recommendations regarding the interrelated effects of the proposed development upon existing or potential geologic hazards.
7. A list of references of geologic literature used in evaluation of the site.

These minimum requirements are intended to establish more uniform quality in geologic reports received by the County, but geologists should be encouraged to produce more exhaustive reports when time and circumstances permit.

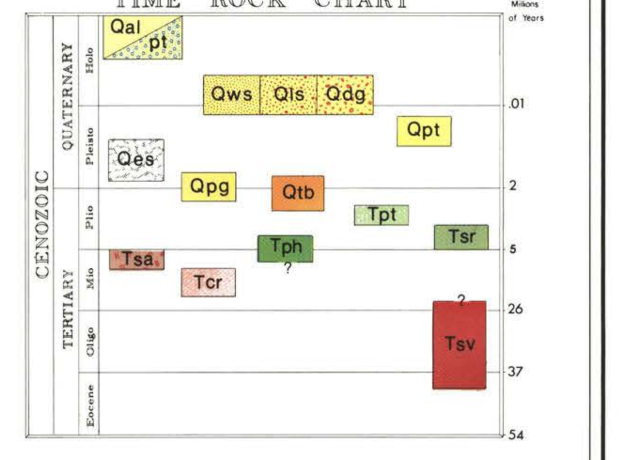
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

Geologic Map of the Canby and Oregon City Quadrangles, Oregon

Geology by Herbert G. Schlicker and Christopher T. Finlayson, modified from Trimble, 1963



TIME ROCK CHART



EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation)

SURFICIAL GEOLOGIC UNITS

Qal / pt

Alluvium: *Unconsolidated sand, gravel, and cobbles within stream channels and on adjacent flood plains; sandy silt up to 10 ft thick overlies gravel on flood plains; approximately equivalent to Qal and Qt (terrace deposits) of Trimble (1963) and Qt (terrace deposits) and Qya (young alluvium) of Schlicker and Deacon (1967);* **pt** *peat soils in local subsurface. Hazards include flooding, near-surface water table, and weak compressible soils; development not normally recommended*

Lacustrine Sediments: *Unconsolidated cross-bedded to graded sedimentary beds deposited by late Pleistocene glacial floods.*

Qws

Qws: *(Willamette Silt Formation): Lacustrine fine sandy silt and clay deposited up to 350 ft elevation. Beds range from a few inches to several feet thick; total thickness about 100 ft (outside of area); equivalent to Qlc (lacustrine silt) of Trimble (1963). Occurs along the valleys of the Tualatin and other tributaries of the Willamette River*

Qls

Qls: *Lacustrine and fluvial unconsolidated stratified to cross-bedded sand in silt and occasional lenses of pebbles to gravel. Occurs along Willamette River in northwest Clackamas County; equivalent to Qls (lacustrine sands) and Qs (sand and silt deposits) of Trimble (1963) and Schlicker and others (1964)*

Qdg

Qdg: *Deltaic deposits of sand, gravel, and boulders up to 8 ft diameter; torrential cross-bedding. Occurs at Lake Oswego, Canby, Wilsonville, and Portland; includes Qlg (lacustrine gravels) of Trimble (1963) and Schlicker and Deacon (1967).* **Qdg** *and* **Qls** *unsuited for septic tank disposal and similarly for* **Qws** *where soils are impermeable or have a high water table;* **Qdg** *is used satisfactorily for aggregate resource.* **Qls** *suitable for high-quality fill material*

Qpt

Pleistocene Terrace Deposits: *Unconsolidated cobble and boulder gravel and silty mudflow deposits up to 200 ft thick along the Clackamas and Sandy Rivers and Rock and Clear Creeks; includes Qg (Gresham Formation) and Qe (Estacada Formation) of Trimble (1963); weathering 10 to 35 ft deep. Hazards include areas of slow permeability and steep unstable terrace escarpments; not suitable for septic tank drainfields; development should not be undertaken without adequate geologic and engineering studies*

Qes

Eolian silt: *Corresponds to Ql (loess) of Trimble (1963) and Qs (upland silt) of Schlicker and Deacon (1967); yellow-brown to buff-colored, fine, micaceous silt. Maximum thickness is 55 ft on uplands above 250 ft elevation. Occurs a few tens of miles south of the Columbia River. Cut slopes are unstable and are susceptible to rapid erosion and frost heave. Overlies other units as indicated*

Qpg

Pliocene-Pleistocene Gravels: *Gravels and mudflows equivalent to the Qtw (Walters Hill Formation) and Qsw (Springwater Formation) of Trimble (1963); weakly indurated, poorly sorted, rounded cobbly and bouldery cobble gravel and associated pyroclastic mudflows; gravels decomposed by extensive weathering; has produced a mottled reddish-brown clayey soil; fanlike deposit extends from the Sandy River west to near Damascus and southeast to near Estacada. Up to 400 ft thick. Hazards include poor drainage; restrictive soil layers; low foundation strength in weathered areas; not suitable for aggregate*

BEDROCK GEOLOGIC UNITS

Sedimentary rocks

Tpt

Troutdale Formation: *Pliocene sandstone and conglomerate; indurated beds and lenses of well-sorted sand and cobbly gravel with up to 30% quartzite clasts. Equivalent to upper Troutdale Formation of Treasher (1942) and the Troutdale Formation of Trimble (1963); some sand originally composed of volcanic glass altered to an impermeable high shrink-swell clay. Occurs in valleys of Willamette, Clackamas, and Sandy Rivers and many of their tributary streams. Clay is unstable and causes overlying competent units to fail by landslide. Aggregate produced from Troutdale gravel is used mainly for fill and base rock; use in concrete may not prove satisfactory without special treatment; in areas of low permeability or where gravels are open, septic tank drainfields are not recommended*

Tsr

Sandy River Mudstone: *Pliocene mudstone corresponds to lower Troutdale Formation of Treasher (1942) and the Sandy River Mudstone of Trimble (1963); siltstone, claystone, very fine sandstone, and some lapilli tuff; laid down in fresh water; uniform parallel bedding; well-sorted and moderately indurated; maximum known thickness about 725 ft. Underlies Troutdale Formation along Clear, Abernathy, Tickle, Deep, and Eagle Creeks and along Clackamas and Sandy Rivers. Hazards include low-strength clays, earthflows, and slump failure of overlying units because downward flow of ground water is slowed by impermeable layers in this unit; not suitable for septic tank drainfields*

Tph

Helvetia Formation: *Pliocene pebbly sand, silt, and clay; light-brown to reddish-brown; minerals mainly quartz and muscovite; local inclusions include granitic, basaltic, and quartzite pebbles; gibbsite nodules also common; laterized. Exposures limited to flanks of hills such as Parrett and Bull Mountains in Tualatin area; found only overlying Columbia River Basalt. Hazards include low permeability, erosion by gullying, some potential for earthflow and slump; marginally suitable for septic tank effluent disposal*

Volcanic rocks

Qtb / Wx

Boring Lavas: *Pliocene-Pleistocene lavas, light-gray, open-textured olivine basalt; flow structures common; includes some pyroclastic material of local extent; widely spaced joint pattern. Occurs in wide spread exposures in the central portion of northwest Clackamas County.* **Wx,** *lavas and breccias weathered to red clay, interspersed with large boulders that pose excavation and disposal problems; wide spaced pattern discourages aggregate production as large blocks produced require secondary shooting; vertical exposures susceptible to mass movement and deep bedrock sliding because of failure of underlying material*

Tsa

Sardine Formation: *Miocene andesitic lavas and indurated pyroclastics; partly equivalent to the Sardine Formation of Thayer (1963) and Peck and others (1964), Rhododendron of Hodge (1933) and Trimble (1963), and Boring agglomerate of Treasher (1942). Mudflow breccias are abundant within this unit, and deep weathering has produced a reddish brown laterite; maximum thickness in area is 600 ft but thickens to east. Occurs principally in Eagle Creek and Clear Creek Valleys and Clackamas River gorge east of Estacada. Hazards include impermeable layers, earthflows and slumps in weathered pyroclastics, and difficult excavation in coarse jointed mudflows*

Tcr

Columbia River Basalt Group: *Miocene flood basalt; composed of gray to black, dense, fine-grained, low-olivine basalt; locally porphyritic; locally deeply weathered and laterized; saprolite developed on some interbeds occurring between basalt flows; thick saprolite on Vantage horizon is responsible for major landslides; maximum thickness of basalt in map area is about 975 ft. Unit is extensive in western part of map area. Hazards include high potential for deep bedrock slides in dipping saprolitic interbeds and potential for rockfall in areas of nearly vertical exposures. Other engineering features include high foundation strength, good construction-rock source, and abundant ground water where structure is favorable*

Tsv

Skamania Volcanics: *Eocene basalt and basaltic andesite flows and beds of tuff breccia; lower exposures highly altered with veins of quartz, zeolite, calcite, opal, and chlorite; upper less-altered flows are porphyritic basalt with columnar jointing. Thickness unknown but probably several thousand feet. Only known exposures in northwest Clackamas County are small islands in Willamette River and in roadcuts at Coalca between Canby and Oregon City; rock is poor quality for aggregate because of alteration and abundant zeolites*

GEOLOGIC SYMBOLS

Contacts

syncline *(showing plunge of axis)*

Faults

Lineament

Normal fault *(ball and bar on downthrown side)*

Inferred fault

Base Map from USGS 7½' series

Control by USGS

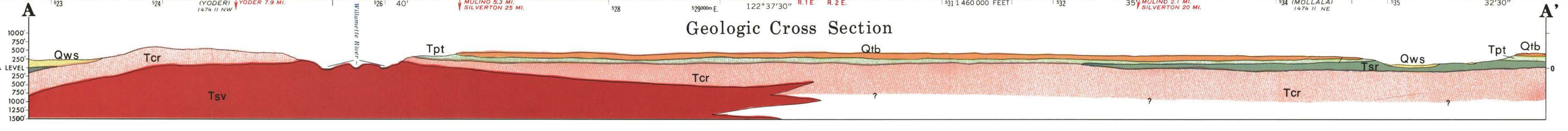
Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1952. Field check 1954
Revised from aerial photographs taken 1960. Field check 1961

Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

PHOTOREVISED 1970 AND 1975

CARTOGRAPHY by Paul E. Staub, 1979.

Geologic Cross Section



SCALE 1:24 000

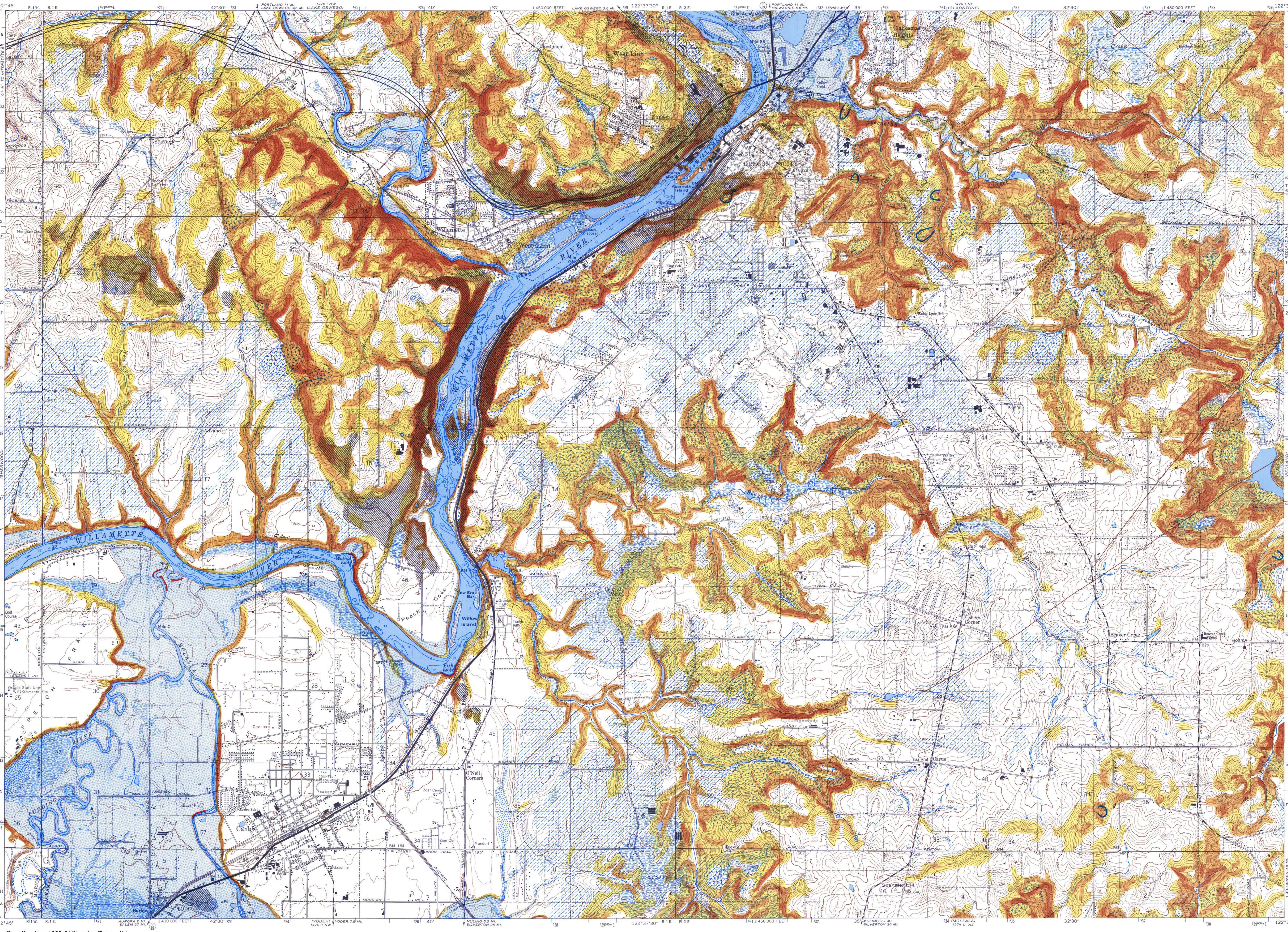
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

BULLETIN 99 - GEOLOGY AND GEOLOGIC HAZARDS OF NORTHWESTERN CLACKAMAS COUNTY, OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

GEOLOGIC HAZARDS MAP OF THE CANBY AND OREGON CITY QUADRANGLES, OREGON



Geologic Hazards by Herbert G. Schlicker and Christopher T. Finlayson

EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation.)

GEOLOGIC HAZARDS

Mass Movement

Rockfall: *Precise delineation requires detailed mapping on larger scale than that of this study. Rockfall hazard is associated with volcanic or coarse clastic sedimentary units with slopes in excess of 100 percent (45°). Rockfall occurs when rock or soil is dislodged and tumbles, slides, or falls down the slope, commonly where rivers or streams undercut toes of steep slopes producing overhangs. Small rockfalls frequently occur in steep, high roadcuts in combination with bedding-plane and slump-type slides. Rockfall is often associated with frost heave which can dislodge individual rock fragments*

Landslide topography: *Large areas of bedrock failure characterized by irregular topography, disrupted stratigraphy, overall anomalous moderate to shallow slope, and disrupted drainage pattern; deposit often fan shaped or with multiple coalescing fans covering area up to several square miles. Numerous sags and ponded areas. Trees bowed or tipped; scarps and cracks still present if movement is recent. Stream-bank erosion at toe; drainage diverted into slide mass or other causes may be responsible for continued instability. Areas having recent movement are not recommended for development. Apparently stable areas require careful study and appropriate design and construction methods*

Local slump and earthflow: *Rotational slides upslope generally in combination with earthflow downslope. Terrace escarpments oversteepened by stream erosion or modified by man. Slide usually arcuate at top. Trees bent or tipped; ground surface and drainage disrupted. Engineering projects in landslide areas will suffer damage from movement of foundation rock or soil. Inactive slides may be reactivated by redistribution of loads or change in drainage patterns during or following construction*

Mudflow and debris flow: *Lobate mass composed either of uncemented, fine-grained material (mudflow) or of more than 50 percent of solid content larger than sand size (debris flow) which moved slowly to rapidly, depending upon degree of slope and water content. Also contains variable amounts of organic material. Slopes adjacent to mudflow and debris flow are considered likely to fail with changing land use unless geological and engineering studies show otherwise*

Soil Hazards

Organic soils: *Areas of peat and areas likely to contain organic muds, muck, and peat either at surface or in subsurface. Most are water saturated and will compress excessively under moderate loads. Where possible, material should be removed and excavation backfilled with select embankment prior to construction. Elsewhere preloading or piling of sufficient length to reach competent rock or soil can provide adequate foundations. In artificial fills, drainage needed to prevent rise in water level. Embankments or structures that impede flood drainage will cause flood waters to rise*

High shrink-swell soils: *Clay soil with high shrink-swell ratio occurs in Sandy River Mudstone, Troutdale Formation, and younger units. Bentonitic material in soil expands or shrinks with seasonal changes in moisture content, producing cracks in foundations and plaster. Movement can be stabilized by controlling moisture content or by excavating high shrink-swell soil and backfilling with select embankment material*

Thin soils: *Areas mapped as thin soils overlie hard bed rock at depths of 2 ft or less. Unit includes soil developed from basalt residuum, thin soil deposited on bed rock, and bare outcrop areas. Associated hazards include inadequate septic tank drainage and high runoff. Excavation for utilities, underground storage tanks, and basements is difficult, especially in residential areas where blasting is not compatible*

Wet soils — high water table: *Areas in which the water table rises to within 1.5 ft of the ground surface. Area extent interpreted from geology, soil maps, topography, and engineering borings. High water table causes water to stand at the surface or in shallow excavations. Pumping of water from excavations may cause sides to cave unless properly shored. High water table can cause basement floors and walls to crack, force empty storage tanks to rise to the ground surface, and prevent subsurface disposal of septic tank effluent*

Flooding

Flood boundaries compiled from various sources including 1964 flood. Sources include U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Soil Conservation Service, and consultants to Clackamas County. Boundaries based variously on observations, predictions of 50-100-500 years, and standard projected flood. Because mapped flood boundaries vary with flood definition and with intent, scope, and method of study, original references should be consulted

Stream-Bank Erosion

Caused by deflection of stream flow naturally or by man-made obstruction; especially severe during high-volume flow. Rapid where stream banks are vertical, particularly along outside of meander curve. High vertical banks erode by undercutting and caving and may cause landslides. Areas of ongoing or potential stream-bank erosion should be studied to determine rates of erosion and overall safety relative to proposed structure or development. Corrective measures include weirs, concrete facing, piling, cribbing, and channel changes. Channel modification may yield beneficial or adverse impacts as a function of local hydraulics at site and downstream

Faulting

Faulting inferred from large-scale bedrock displacement, detailed mapping, radar imagery lineaments, and extensions of faults shown on published maps of adjacent areas. Faulting in northwestern Oregon is very poorly understood, and knowledge is inadequate for making predictions. Response of surficial geologic units and soils to earthquake movement varies considerably depending on thickness and consistency of unit, magnitude of event, and distance from epicenter

Fault — Stratigraphic offset determined by direct and indirect methods; dashed where approximate; indirect methods include gravity, magnetics, and geochemistry of basalt flows (Beeson, Johnson, and Moran, 1975) (ball and bar on downthrown side)

Lineament — Major lineaments identified from side looking airborne radar imagery. and/or topographic maps; radar imagery by Westinghouse Electric Corporation for WPPSS, July 1973

Average Regional Slope

Slopes have been categorized according to general severity of hazard relative to various land uses. Landslide and earthflow reduce slope angle, however, and gentle slopes adjacent to steeper terrain are not necessarily stable

0 - 10% — *Stream terraces, dissected valley terraces, channels, and flood plains of major streams. Hazards include poor drainage, ponded areas, high water table, clay and peat bottom-land soils, and flooding. Upland areas with adequate engineering and geologic information can be developed. Lowlands associated with high water table and flooding may better be used for agriculture*

10 - 20% — *Gently sloping foothill areas and rolling uplands. Drainage usually good, but steeper parts may not be satisfactory for septic tank drainage except in best soils. Where clay or hardpan layers are present, effluent may exit at surface*

20 - 35% — *Moderate slopes of gentle terrace escarpments, foothills, pediments, and alluvial fans. Slopes generally excessive for septic tank drainage. Stream and ditch erosion moderate to severe and severe where gullying can take place in plowed fields devoid of vegetation. Some earthflow and slump landslides have reduced steeper slopes to this category*

35 - 50% — *Rolling and steeper hill slopes, steep terrace escarpments, and recent and active earthflow and slump landslide areas. Excavation and drainage in this terrain require extensive geologic input and engineering design. Areas of critical slope stability can be activated by improper land use*

>50% — *Bedrock exposures, steep terrace escarpments, areas of severe stream erosion, talus slopes, and debris flow and debris avalanche landslide areas. Steepest slopes in this category may be subject to rockfall. Geological input necessary for engineering design of roads, cuts, embankments, and drainage in these areas. Development should be limited to certain categories such as roads, recreation, and timber harvest, except for small properly engineered projects shown to be safe*

CARTOGRAPHY by Paul E. Staub, 1979.

Base Map from USGS 71/2' series (Topographic)

Control by USGS

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1952. Field check 1954
Revised from aerial photographs taken 1960. Field check 1961

Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks,
zone 10, shown in blue

PHOTOREVISED 1970 AND 1975

UTM GRID AND 1970 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

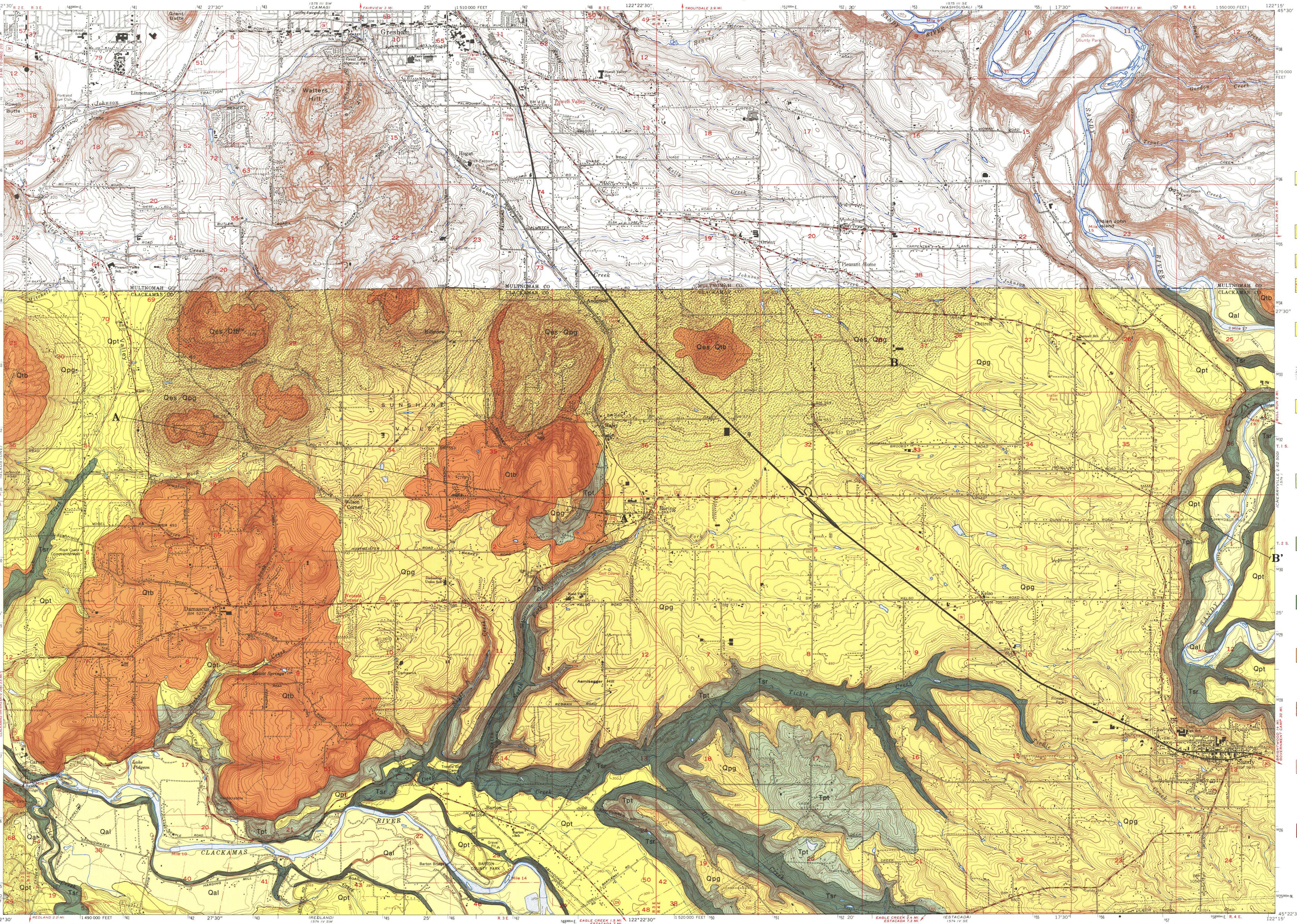
QUADRANGLE LOCATION

Index to Map Series

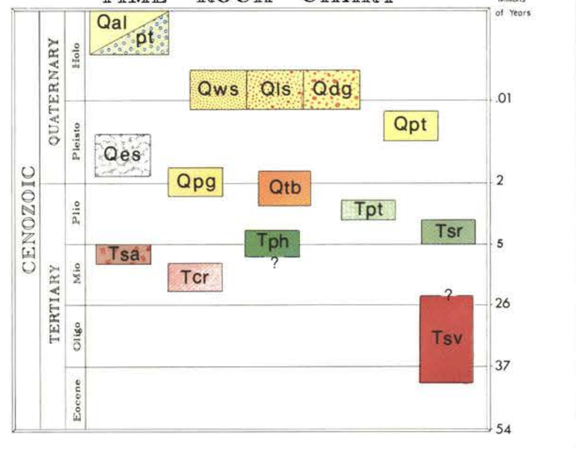
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

Geologic Map of the Damascus and Sandy Quadrangles, Oregon

Geology by Herbert G. Schlicker and Christopher T. Finlayson, modified from Trimble, 1963



TIME ROCK CHART



EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation)

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BEDROCK GEOLOGIC UNITS

Sedimentary rocks

Tpt — **Troutdale Formation:** *Pliocene sandstone and conglomerate; indurated beds and lenses of well-sorted sand and cobbly gravel with up to 30% quartzite clasts. Equivalent to upper Troutdale Formation of Treasher (1942) and the Troutdale Formation of Trimble (1963); some sand originally composed of volcanic glass altered to an impermeable high shrink-swell clay. Occurs in valleys of Willamette, Clackamas, and Sandy Rivers and many of their tributary streams. Clay is unstable and causes overlying competent units to fail by landslide. Aggregate produced from Troutdale gravel is used mainly for fill and base rock; use in concrete may not prove satisfactory without special treatment; in areas of low permeability or where gravels are open, septic tank drainfields are not recommended*

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Volcanic rocks

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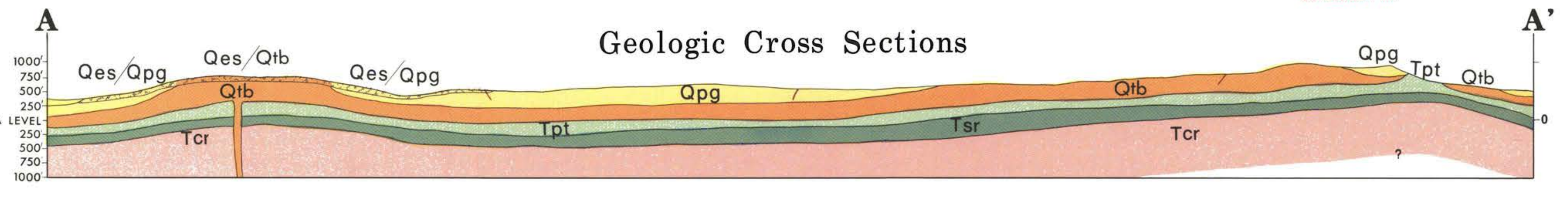
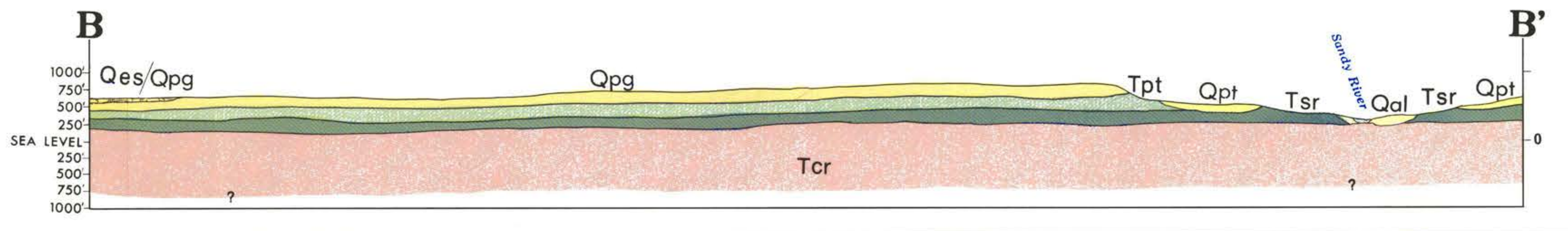
- Normal fault *(ball and bar on downthrown side)*
- Inferred fault
- syncline *(showing plunge of axis)*
- Lineament

Geologic Cross Sections





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1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue
PHOTOREVISED 1970 AND 1975
CARTOGRAPHY by Paul E. Staub, 1979.

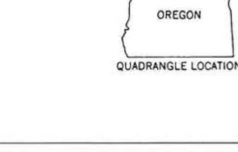
SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

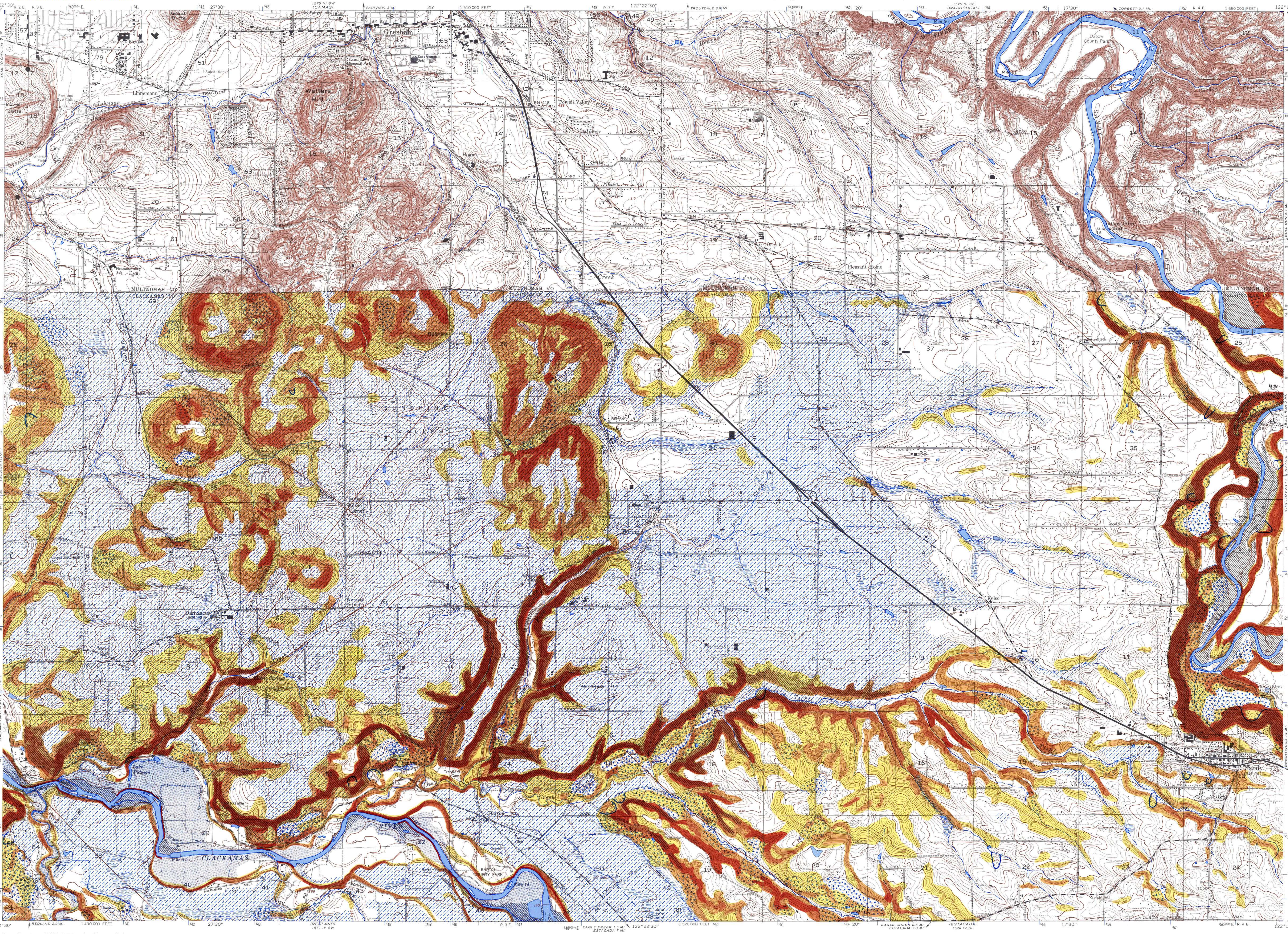
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL



QUADRANGLE LOCATION

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

GEOLOGIC HAZARDS MAP OF THE DAMASCUS AND SANDY QUADRANGLES, OREGON



Geologic Hazards by Herbert G. Schlicker and Christopher T. Finlayson

EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation.)

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Mass Movement

Rockfall: *Precise delineation requires detailed mapping on larger scale than that of this study. Rockfall hazard is associated with volcanic or coarse clastic sedimentary units with slopes in excess of 100 percent (45°). Rockfall occurs when rock or soil is dislodged and tumbles, slides, or falls down the slope, commonly where rivers or streams undercut toes of steep slopes producing overhangs. Small rockfalls frequently occur in steep, high roadcuts in combination with bedding-plane and slump-type slides. Rockfall is often associated with frost heave which can dislodge individual rock fragments*

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Slopes have been categorized according to general severity of hazard relative to various land uses. Landslide and earthflow reduce slope angle, however, and gentle slopes adjacent to steeper terrain are not necessarily stable

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10 - 20% *Gently sloping foothill areas and rolling uplands. Drainage usually good, but steeper parts may not be satisfactory for septic tank drainage except in best soils. Where clay or hardpan layers are present, effluent may exit at surface*

20 - 35% *Moderate slopes of gentle terrace escarpments, foothills, pediments, and alluvial fans. Slopes generally excessive for septic tank drainage. Stream and ditch erosion moderate to severe and severe where gullying can take place in plowed fields devoid of vegetation. Some earthflow and slump landslides have reduced steeper slopes to this category*

35 - 50% *Rolling and steeper hill slopes, steep terrace escarpments, and recent and active earthflow and slump landslide areas. Excavation and drainage in this terrain require extensive geologic input and engineering design. Areas of critical slope stability can be activated by improper land use*

>50% *Bedrock exposures, steep terrace escarpments, areas of severe stream erosion, talus slopes, and debris flow and debris avalanche landslide areas. Steepest slopes in this category may be subject to rockfall. Geological input necessary for engineering design of roads, cuts, embankments, and drainage in these areas. Development should be limited to certain categories such as roads, recreation, and timber harvest, except for small properly engineered projects shown to be safe*

CARTOGRAPHY by Paul E. Staub, 1979.

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Index to Map Series

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

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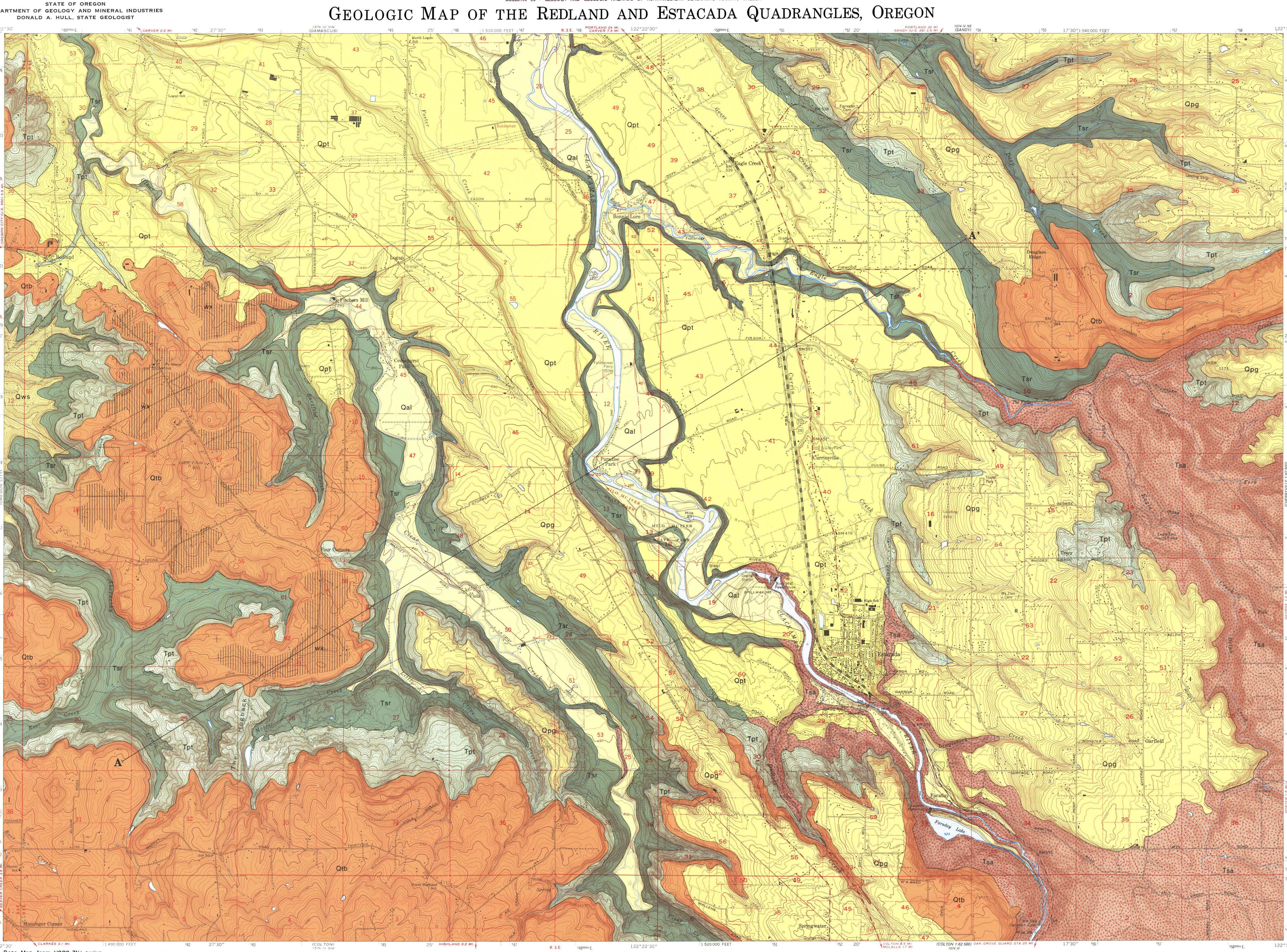
Geology by Herbert G. Schlicker and Christopher T. Finlayson, modified from Trimble, 1963



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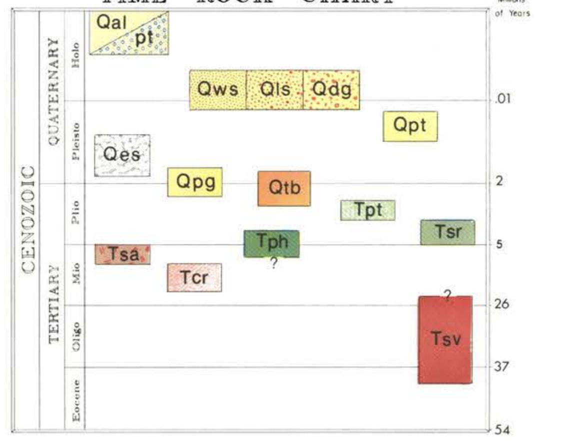

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SURFICIAL GEOLOGIC UNITS

Qal / pt — **Alluvium:** *Unconsolidated sand, gravel, and cobbles within stream channels and on adjacent flood plains; sandy silt up to 10 ft thick overlies gravel on flood plains; approximately equivalent to Qal and Qt (terrace deposits) of Trimble (1963) and Qt (terrace deposits) and Qya (young alluvium) of Schlicker and Deacon (1967);* **pt** *peat soils in local subsurface. Hazards include flooding, near-surface water table, and weak compressible soils; development not normally recommended*

Lacustrine Sediments: *Unconsolidated cross-bedded to graded sedimentary beds deposited by late Pleistocene glacial floods.*

Qws: *(Willamette Silt Formation): Lacustrine fine sandy silt and clay deposited up to 350 ft elevation. Beds range from a few inches to several feet thick; total thickness about 100 ft (outside of area); equivalent to Qlc (lacustrine silt) of Trimble (1963). Occurs along the valleys of the Tualatin and other tributaries of the Willamette River*

Qls: *Lacustrine and fluvial unconsolidated stratified to cross-bedded sand in silt and occasional lenses of pebbles to gravel. Occurs along Willamette River in northwest Clackamas County; equivalent to Qls (lacustrine sands) and Qs (sand and silt deposits) of Trimble (1963) and Schlicker and others (1964)*

Qdg: *Deltaic deposits of sand, gravel, and boulders up to 8 ft diameter; torrential cross-bedding. Occurs at Lake Oswego, Canby, Wilsonville, and Portland; includes Qlg (lacustrine gravels) of Trimble (1963) and Schlicker and Deacon (1967).* **Qdg** *and* **Qls** *unsuited for septic tank disposal and similarly for* **Qws** *where soils are impermeable or have a high water table;* **Qdg** *is used satisfactorily for aggregate resource.* **Qls** *suitable for high-quality fill material*

Qpt — **Pleistocene Terrace Deposits:** *Unconsolidated cobble and boulder gravel and silty mudflow deposits up to 200 ft thick along the Clackamas and Sandy Rivers and Rock and Clear Creeks; includes Qg (Gresham Formation) and Qe (Estacada Formation) of Trimble (1963); weathering 10 to 35 ft deep. Hazards include areas of slow permeability and steep unstable terrace escarpments; not suitable for septic tank drainfields; development should not be undertaken without adequate geologic and engineering studies*

Qes — **Eolian silt:** *Corresponds to Ql (loess) of Trimble (1963) and Qs (upland silt) of Schlicker and Deacon (1967); yellow-brown to buff-colored, fine, micaceous silt. Maximum thickness is 55 ft on uplands above 250 ft elevation. Occurs a few tens of miles south of the Columbia River. Cut slopes are unstable and are susceptible to rapid erosion and frost heave. Overlies other units as indicated*

Qpg — **Pliocene-Pleistocene Gravels:** *Gravels and mudflows equivalent to the Qtw (Walters Hill Formation) and Qsw (Springwater Formation) of Trimble (1963); weakly indurated, poorly sorted, rounded cobbly and bouldery cobble gravel and associated pyroclastic mudflows; gravels decomposed by extensive weathering; has produced a mottled reddish-brown clayey soil; fanlike deposit extends from the Sandy River west to near Damascus and southeast to near Estacada. Up to 400 ft thick. Hazards include poor drainage; restrictive soil layers; low foundation strength in weathered areas; not suitable for aggregate*

BEDROCK GEOLOGIC UNITS

Sedimentary rocks

Tpt — **Troutdale Formation:** *Pliocene sandstone and conglomerate; indurated beds and lenses of well-sorted sand and cobbly gravel with up to 30% quartzite clasts. Equivalent to upper Troutdale Formation of Treasher (1942) and the Troutdale Formation of Trimble (1963); some sand originally composed of volcanic glass altered to an impermeable high shrink-swell clay. Occurs in valleys of Willamette, Clackamas, and Sandy Rivers and many of their tributary streams. Clay is unstable and causes overlying competent units to fail by landslide. Aggregate produced from Troutdale gravel is used mainly for fill and base rock; use in concrete may not prove satisfactory without special treatment; in areas of low permeability or where gravels are open, septic tank drainfields are not recommended*

Tsr — **Sandy River Mudstone:** *Pliocene mudstone corresponds to lower Troutdale Formation of Treasher (1942) and the Sandy River Mudstone of Trimble (1963); siltstone, claystone, very fine sandstone, and some lapilli tuff; laid down in fresh water; uniform parallel bedding; well-sorted and moderately indurated; maximum known thickness about 725 ft. Underlies Troutdale Formation along Clear, Abernathy, Tickle, Deep, and Eagle Creeks and along Clackamas and Sandy Rivers. Hazards include low-strength clays, earthflows, and slump failure of overlying units because downward flow of ground water is slowed by impermeable layers in this unit; not suitable for septic tank drainfields*

Tph — **Helvetia Formation:** *Pliocene pebbly sand, silt, and clay; light-brown to reddish-brown; minerals mainly quartz and muscovite; local inclusions include granitic, basaltic, and quartzite pebbles; gibbsite nodules also common; laterized. Exposures limited to flanks of hills such as Parrett and Bull Mountains in Tualatin area; found only overlying Columbia River Basalt. Hazards include low permeability, erosion by gullying, some potential for earthflow and slump; marginally suitable for septic tank effluent disposal*

Volcanic rocks

Qtb / Wx — **Boring Lavas:** *Pliocene-Pleistocene lavas, light-gray, open-textured olivine basalt; flow structures common; includes some pyroclastic material of local extent; widely spaced joint pattern. Occurs in wide spread exposures in the central portion of northwest Clackamas County.* **Wx**, *lavas and breccias weathered to red clay, interspersed with large boulders that pose excavation and disposal problems; wide spaced pattern discourages aggregate production as large blocks produced require secondary shooting; vertical exposures susceptible to mass movement and deep bedrock sliding because of failure of underlying material*

Tsa — **Sardine Formation:** *Miocene andesitic lavas and indurated pyroclastics; partly equivalent to the Sardine Formation of Thayer (1963) and Peck and others (1964), Rhododendron of Hodge (1933) and Trimble (1963), and Boring agglomerate of Treasher (1942). Mudflow breccias are abundant within this unit, and deep weathering has produced a reddish brown laterite; maximum thickness in area is 600 ft but thickens to east. Occurs principally in Eagle Creek and Clear Creek Valleys and Clackamas River gorge east of Estacada. Hazards include impermeable layers, earthflows and slumps in weathered pyroclastics, and difficult excavation in coarse jointed mudflows*

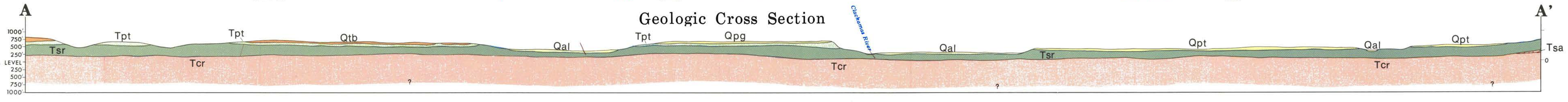
Tcr — **Columbia River Basalt Group:** *Miocene flood basalt; composed of gray to black, dense, fine-grained, low-olivine basalt; locally porphyritic; locally deeply weathered and laterized; saprolite developed on some interbeds occurring between basalt flows; thick saprolite on Vantage horizon is responsible for major landslides; maximum thickness of basalt in map area is about 975 ft. Unit is extensive in western part of map area. Hazards include high potential for deep bedrock slides in dipping saprolitic interbeds and potential for rockfall in areas of nearly vertical exposures. Other engineering features include high foundation strength, good construction-rock source, and abundant ground water where structure is favorable*

Tsv — **Skamania Volcanics:** *Eocene basalt and basaltic andesite flows and beds of tuff breccia; lower exposures highly altered with veins of quartz, zeolite, calcite, opal, and chlorite; upper less-altered flows are porphyritic basalt with columnar jointing. Thickness unknown but probably several thousand feet. Only known exposures in northwest Clackamas County are small islands in Willamette River and in roadcuts at Coalca between Canby and Oregon City; rock is poor quality for aggregate because of alteration and abundant zeolites*

GEOLOGIC SYMBOLS

- **Contacts**
- syncline *(showing plunge of axis)*
- **Faults**
- Lineament
- **Normal fault** *(ball and bar on downthrown side)*
- **Inferred fault**

Geologic Cross Section



SCALE 1:24 000

1 MILE — 7000 FEET — 1 KILOMETER

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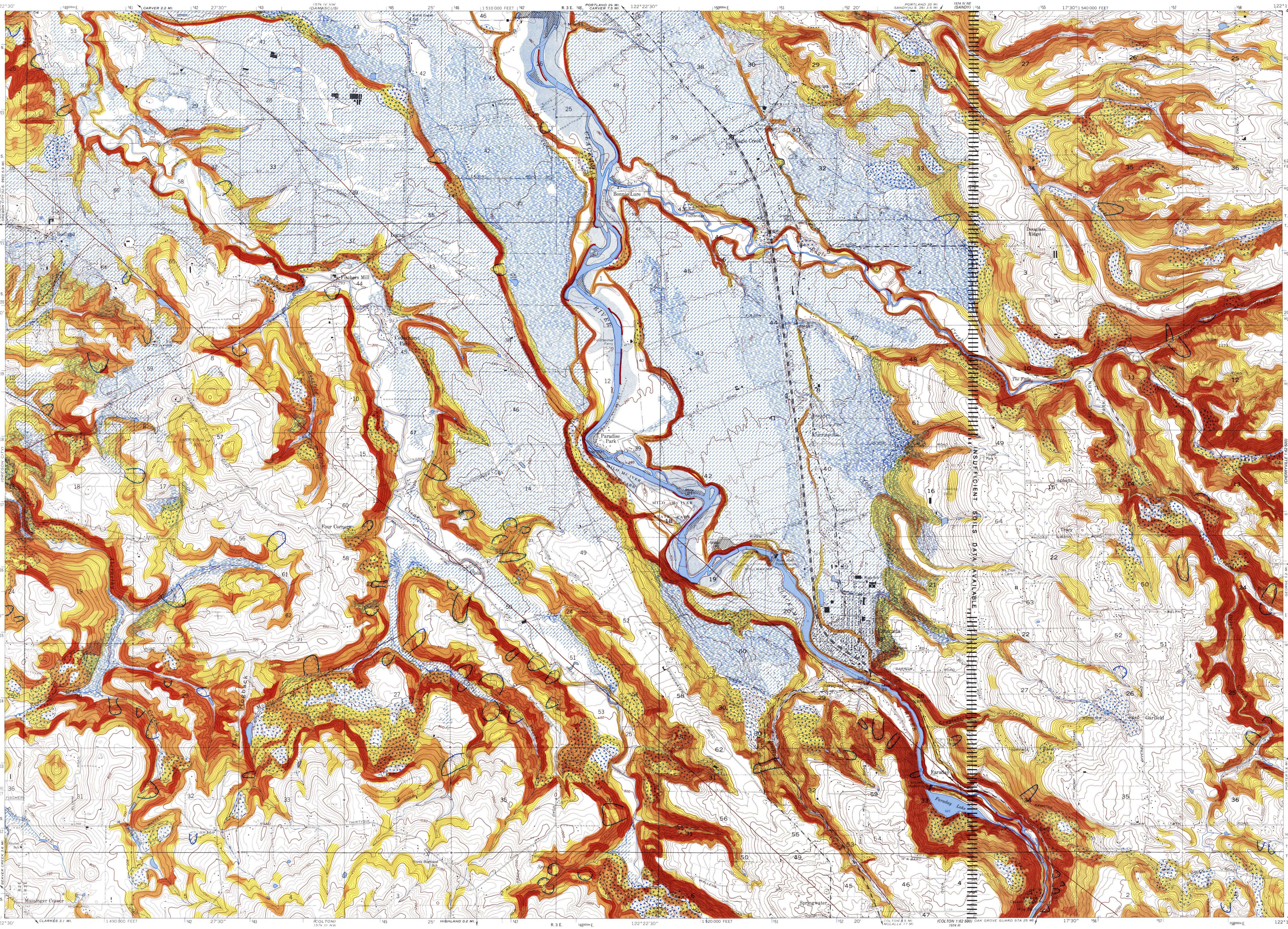

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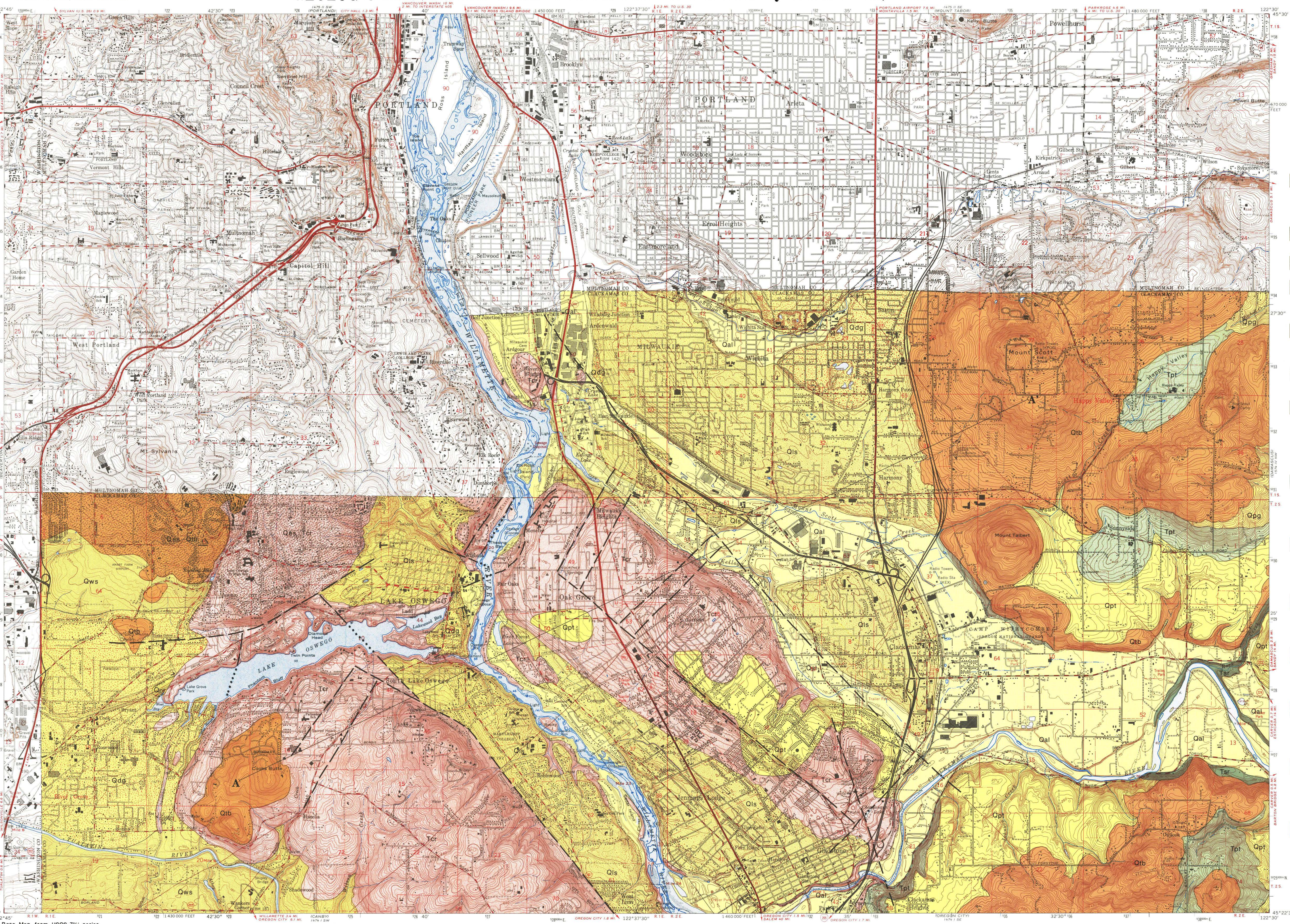

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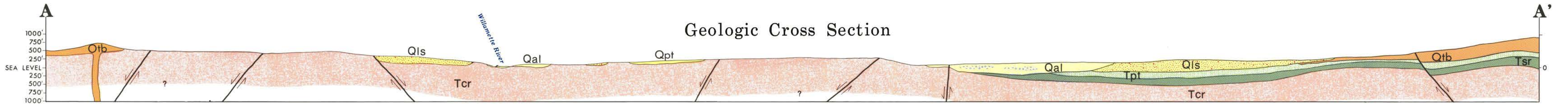

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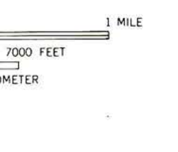

QUADRANGLE LOCATION

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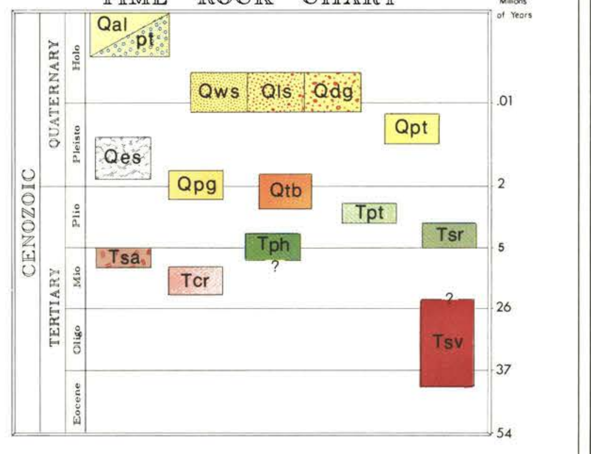

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Qdg

Qdg: *Deltaic deposits of sand, gravel, and boulders up to 8 ft diameter; torrential cross-bedding. Occurs at Lake Oswego, Canby, Wilsonville, and Portland; includes Qlg (lacustrine gravels) of Trimble (1963) and Schlicker and Deacon (1967).* **Qdg** *and* **Qls** *unsuited for septic tank disposal and similarly for* **Qws** *where soils are impermeable or have a high water table;* **Qdg** *is used satisfactorily for aggregate resource.* **Qls** *suitable for high-quality fill material*

Qpt

Pleistocene Terrace Deposits: *Unconsolidated cobble and boulder gravel and silty mudflow deposits up to 200 ft thick along the Clackamas and Sandy Rivers and Rock and Clear Creeks; includes Qg (Gresham Formation) and Qe (Estacada Formation) of Trimble (1963); weathering 10 to 35 ft deep. Hazards include areas of slow permeability and steep unstable terrace escarpments; not suitable for septic tank drainfields; development should not be undertaken without adequate geologic and engineering studies*

Qes

Eolian silt: *Corresponds to Ql (loess) of Trimble (1963) and Qs (upland silt) of Schlicker and Deacon (1967); yellow-brown to buff-colored, fine, micaceous silt. Maximum thickness is 55 ft on uplands above 250 ft elevation. Occurs a few tens of miles south of the Columbia River. Cut slopes are unstable and are susceptible to rapid erosion and frost heave. Overlies other units as indicated*

Qpg

Pliocene-Pleistocene Gravels: *Gravels and mudflows equivalent to the Qtw (Walters Hill Formation) and Qsw (Springwater Formation) of Trimble (1963); weakly indurated, poorly sorted, rounded cobbly and bouldery cobble gravel and associated pyroclastic mudflows; gravels decomposed by extensive weathering; has produced a mottled reddish-brown clayey soil; fanlike deposit extends from the Sandy River west to near Damascus and southeast to near Estacada. Up to 400 ft thick. Hazards include poor drainage; restrictive soil layers; low foundation strength in weathered areas; not suitable for aggregate*

BEDROCK GEOLOGIC UNITS

Sedimentary rocks

Tpt

Troutdale Formation: *Pliocene sandstone and conglomerate; indurated beds and lenses of well-sorted sand and cobbly gravel with up to 30% quartzite clasts. Equivalent to upper Troutdale Formation of Treasher (1942) and the Troutdale Formation of Trimble (1963); some sand originally composed of volcanic glass altered to an impermeable high shrink-swell clay. Occurs in valleys of Willamette, Clackamas, and Sandy Rivers and many of their tributary streams. Clay is unstable and causes overlying competent units to fail by landslide. Aggregate produced from Troutdale gravel is used mainly for fill and base rock; use in concrete may not prove satisfactory without special treatment; in areas of low permeability or where gravels are open, septic tank drainfields are not recommended*

Tsr

Sandy River Mudstone: *Pliocene mudstone corresponds to lower Troutdale Formation of Treasher (1942) and the Sandy River Mudstone of Trimble (1963); siltstone, claystone, very fine sandstone, and some lapilli tuff; laid down in fresh water; uniform parallel bedding; well-sorted and moderately indurated; maximum known thickness about 725 ft. Underlies Troutdale Formation along Clear, Abernathy, Tickle, Deep, and Eagle Creeks and along Clackamas and Sandy Rivers. Hazards include low-strength clays, earthflows, and slump failure of overlying units because downward flow of ground water is slowed by impermeable layers in this unit; not suitable for septic tank drainfields*

Tph

Helvetia Formation: *Pliocene pebbly sand, silt, and clay; light-brown to reddish-brown; minerals mainly quartz and muscovite; local inclusions include granitic, basaltic, and quartzite pebbles; gibbsite nodules also common; laterized. Exposures limited to flanks of hills such as Parrett and Bull Mountains in Tualatin area; found only overlying Columbia River Basalt. Hazards include low permeability, erosion by gullying, some potential for earthflow and slump; marginally suitable for septic tank effluent disposal*

Volcanic rocks

Qtb / Wx

Boring Lavas: *Pliocene-Pleistocene lavas, light-gray, open-textured olivine basalt; flow structures common; includes some pyroclastic material of local extent; widely spaced joint pattern. Occurs in wide spread exposures in the central portion of northwest Clackamas County.* **Wx,** *lavas and breccias weathered to red clay, interspersed with large boulders that pose excavation and disposal problems; wide spaced pattern discourages aggregate production as large blocks produced require secondary shooting; vertical exposures susceptible to mass movement and deep bedrock sliding because of failure of underlying material*

Tsa

Sardine Formation: *Miocene andesitic lavas and indurated pyroclastics; partly equivalent to the Sardine Formation of Thayer (1963) and Peck and others (1964), Rhododendron of Hodge (1933) and Trimble (1963), and Boring agglomerate of Treasher (1942). Mudflow breccias are abundant within this unit, and deep weathering has produced a reddish brown laterite; maximum thickness in area is 600 ft but thickens to east. Occurs principally in Eagle Creek and Clear Creek Valleys and Clackamas River gorge east of Estacada. Hazards include impermeable layers, earthflows and slumps in weathered pyroclastics, and difficult excavation in coarse jointed mudflows*

Tcr

Columbia River Basalt Group: *Miocene flood basalt; composed of gray to black, dense, fine-grained, low-olivine basalt; locally porphyritic; locally deeply weathered and laterized; saprolite developed on some interbeds occurring between basalt flows; thick saprolite on Vantage horizon is responsible for major landslides; maximum thickness of basalt in map area is about 975 ft. Unit is extensive in western part of map area. Hazards include high potential for deep bedrock slides in dipping saprolitic interbeds and potential for rockfall in areas of nearly vertical exposures. Other engineering features include high foundation strength, good construction-rock source, and abundant ground water where structure is favorable*

Tsv

Skamania Volcanics: *Eocene basalt and basaltic andesite flows and beds of tuff breccia; lower exposures highly altered with veins of quartz, zeolite, calcite, opal, and chlorite; upper less-altered flows are porphyritic basalt with columnar jointing. Thickness unknown but probably several thousand feet. Only known exposures in northwest Clackamas County are small islands in Willamette River and in roadcuts at Coalca between Canby and Oregon City; rock is poor quality for aggregate because of alteration and abundant zeolites*

GEOLOGIC SYMBOLS

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Faults

Normal fault *(ball and bar on downthrown side)*

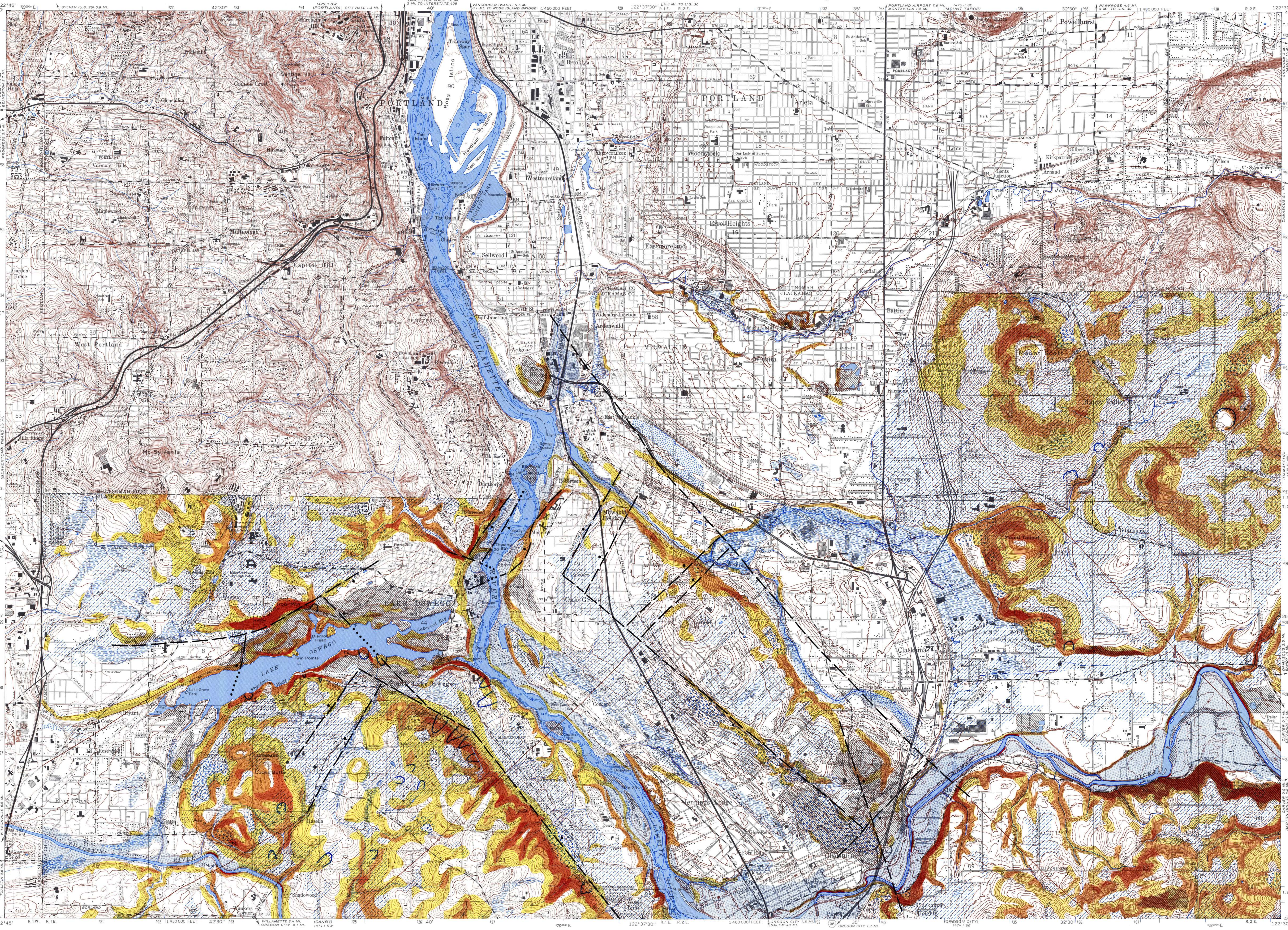
Inferred fault

syncline *(showing plunge of axis)*

Lineament

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

GEOLOGIC HAZARDS MAP OF THE LAKE OSWEGO AND GLADSTONE QUADRANGLES, OREGON



Geologic Hazards by Herbert G. Schlicker and Christopher T. Finlayson

EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation.)

GEOLOGIC HAZARDS

Mass Movement

Rockfall: *Precise delineation requires detailed mapping on larger scale than that of this study. Rockfall hazard is associated with volcanic or coarse clastic sedimentary units with slopes in excess of 100 percent (45°). Rockfall occurs when rock or soil is dislodged and tumbles, slides, or falls down the slope, commonly where rivers or streams undercut toes of steep slopes producing overhangs. Small rockfalls frequently occur in steep, high roadcuts in combination with bedding-plane and slump-type slides. Rockfall is often associated with frost heave which can dislodge individual rock fragments*

Landslide topography: *Large areas of bedrock failure characterized by irregular topography, disrupted stratigraphy, overall anomalous moderate to shallow slope, and disrupted drainage pattern; deposit often fan shaped or with multiple coalescing fans covering area up to several square miles. Numerous sags and ponded areas. Trees bowed or tipped; scarps and cracks still present if movement is recent. Stream-bank erosion at toe; drainage diverted into slide mass or other causes may be responsible for continued instability. Areas having recent movement are not recommended for development. Apparently stable areas require careful study and appropriate design and construction methods*

Local slump and earthflow: *Rotational slides upslope generally in combination with earthflow downslope. Terrace escarpments oversteepened by stream erosion or modified by man. Slide usually arcuate at top. Trees bent or tipped; ground surface and drainage disrupted. Engineering projects in landslide areas will suffer damage from movement of foundation rock or soil. Inactive slides may be reactivated by redistribution of loads or change in drainage patterns during or following construction*

Mudflow and debris flow: *Lobate mass composed either of uncemented, fine-grained material (mudflow) or of more than 50 percent of solid content larger than sand size (debris flow) which moved slowly to rapidly, depending upon degree of slope and water content. Also contains variable amounts of organic material. Slopes adjacent to mudflow and debris flow are considered likely to fail with changing land use unless geological and engineering studies show otherwise*

Soil Hazards

Organic soils: *Areas of peat and areas likely to contain organic muds, muck, and peat either at surface or in subsurface. Most are water saturated and will compress excessively under moderate loads. Where possible, material should be removed and excavation backfilled with select embankment prior to construction. Elsewhere preloading or piling of sufficient length to reach competent rock or soil can provide adequate foundations. In artificial fills, drainage needed to prevent rise in water level. Embankments or structures that impede flood drainage will cause flood waters to rise*

High shrink-swell soils: *Clay soil with high shrink-swell ratio occurs in Sandy River Mudstone, Troutdale Formation, and younger units. Bentonitic material in soil expands or shrinks with seasonal changes in moisture content, producing cracks in foundations and plaster. Movement can be stabilized by controlling moisture content or by excavating high shrink-swell soil and backfilling with select embankment material*

Thin soils: *Areas mapped as thin soils overlie hard bed rock at depths of 2 ft or less. Unit includes soil developed from basalt residuum, thin soil deposited on bed rock, and bare outcrop areas. Associated hazards include inadequate septic tank drainage and high runoff. Excavation for utilities, underground storage tanks, and basements is difficult, especially in residential areas where blasting is not compatible*

Wet soils — high water table: *Areas in which the water table rises to within 1.5 ft of the ground surface. Area extent interpreted from geology, soil maps, topography, and engineering borings. High water table causes water to stand at the surface or in shallow excavations. Pumping of water from excavations may cause sides to cave unless properly shored. High water table can cause basement floors and walls to crack, force empty storage tanks to rise to the ground surface, and prevent subsurface disposal of septic tank effluent*

Flooding

Flood boundaries compiled from various sources including 1964 flood. Sources include U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Soil Conservation Service, and consultants to Clackamas County. Boundaries based variously on observations, predictions of 50-100-500 years, and standard projected flood. Because mapped flood boundaries vary with flood definition and with intent, scope, and method of study, original references should be consulted

Stream-Bank Erosion

Caused by deflection of stream flow naturally or by man-made obstruction; especially severe during high-volume flow. Rapid where stream banks are vertical, particularly along outside of meander curve. High vertical banks erode by undercutting and caving and may cause landslides. Areas of ongoing or potential stream-bank erosion should be studied to determine rates of erosion and overall safety relative to proposed structure or development. Corrective measures include weirs, concrete facing, piling, cribbing, and channel changes. Channel modification may yield beneficial or adverse impacts as a function of local hydraulics at site and downstream

Faulting

Faulting inferred from large-scale bedrock displacement, detailed mapping, radar imagery lineaments, and extensions of faults shown on published maps of adjacent areas. Faulting in northwestern Oregon is very poorly understood, and knowledge is inadequate for making predictions. Response of surficial geologic units and soils to earthquake movement varies considerably depending on thickness and consistency of unit, magnitude of event, and distance from epicenter

Fault — Stratigraphic offset determined by direct and indirect methods; dashed where approximate; indirect methods include gravity, magnetics, and geochemistry of basalt flows (Beeson, Johnson, and Moran, 1975) (ball and bar on downthrown side)

Lineament — Major lineaments identified from side looking airborne radar imagery and/or topographic maps; radar imagery by Westinghouse Electric Corporation for WPPSS, July 1973

Average Regional Slope

Slopes have been categorized according to general severity of hazard relative to various land uses. Landslide and earthflow reduce slope angle, however, and gentle slopes adjacent to steeper terrain are not necessarily stable

0 - 10% *Stream terraces, dissected valley terraces, channels, and flood plains of major streams. Hazards include poor drainage, ponded areas, high water table, clay and peat bottom-land soils, and flooding. Upland areas with adequate engineering and geologic information can be developed. Lowlands associated with high water table and flooding may better be used for agriculture*

10 - 20% *Gently sloping foothill areas and rolling uplands. Drainage usually good, but steeper parts may not be satisfactory for septic tank drainage except in best soils. Where clay or hardpan layers are present, effluent may exit at surface*

20 - 35% *Moderate slopes of gentle terrace escarpments, foothills, pediments, and alluvial fans. Slopes generally excessive for septic tank drainage. Stream and ditch erosion moderate to severe and severe where gullying can take place in plowed fields devoid of vegetation. Some earthflow and slump landslides have reduced steeper slopes to this category*

35 - 50% *Rolling and steeper hill slopes, steep terrace escarpments, and recent and active earthflow and slump landslide areas. Excavation and drainage in this terrain require extensive geologic input and engineering design. Areas of critical slope stability can be activated by improper land use*

>50% *Bedrock exposures, steep terrace escarpments, areas of severe stream erosion, talus slopes, and debris flow and debris avalanche landslide areas. Steepest slopes in this category may be subject to rockfall. Geological input necessary for engineering design of roads, cuts, embankments, and drainage in these areas. Development should be limited to certain categories such as roads, recreation, and timber harvest, except for small properly engineered projects shown to be safe*

Base Map from USGS 71/2' series (Topographic)

Control by USGS

Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1952. Field check 1954
Revised from aerial photographs taken 1960. Field check 1961

Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks,
zone 10, shown in blue

PHOTOREVISED 1970 AND 1975

UTM GRID AND 1970 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

Index to Map Series

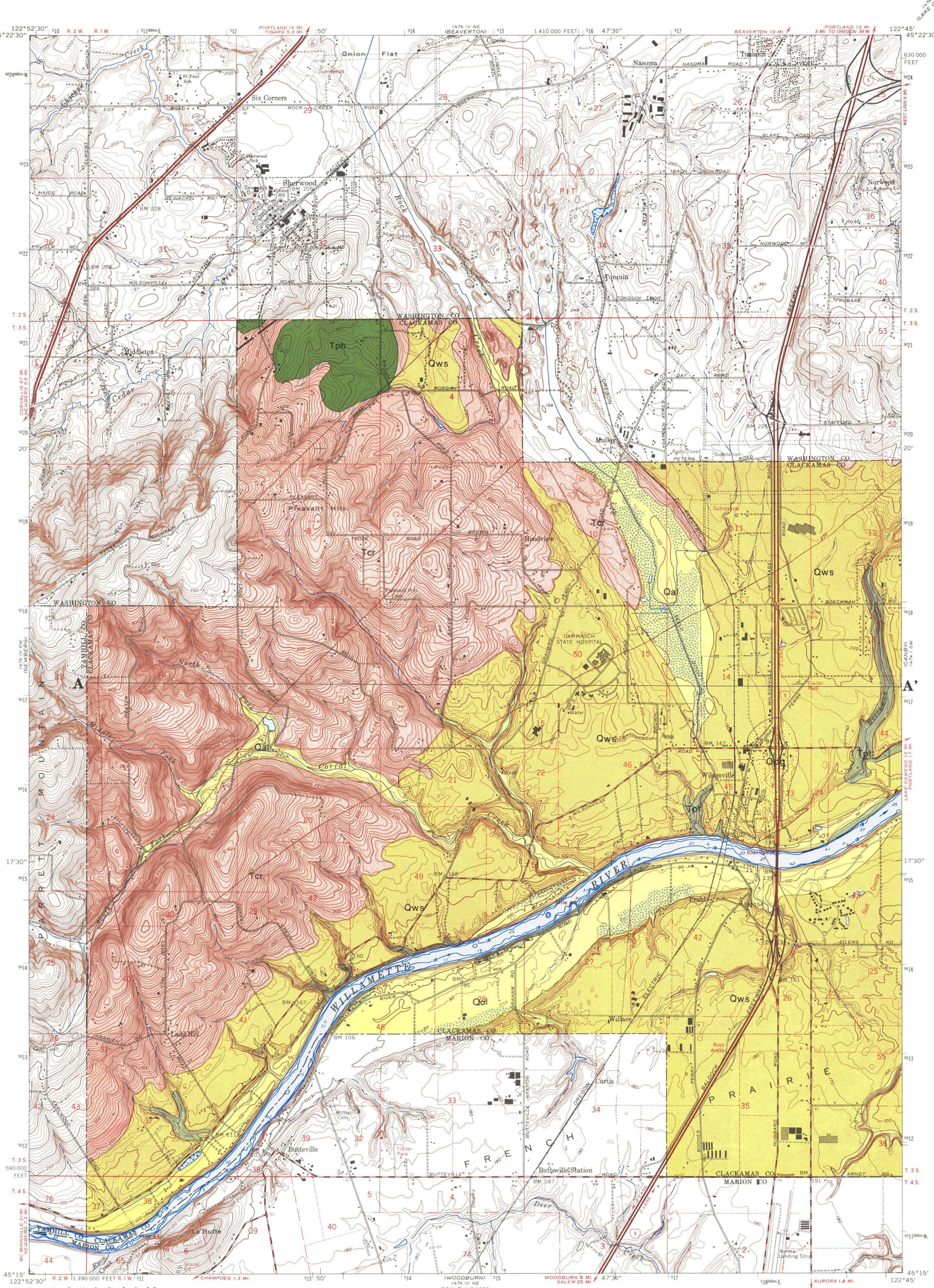
	LAKE OSWEGO	GLADSTONE	DAMASCUS	SANDY
SHERWOOD	CANBY	OREGON CITY	REDLAND	ESTACADA

CARTOGRAPHY by Paul E. Staub, 1979.

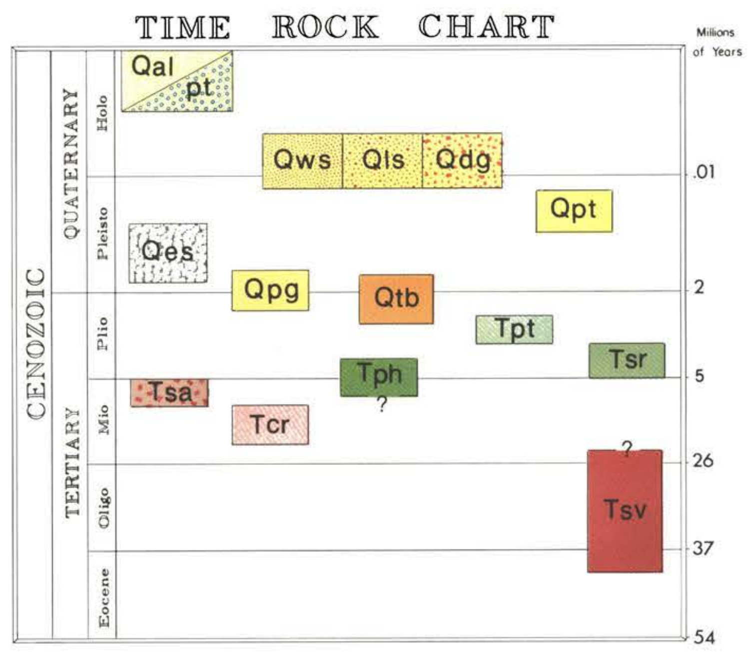
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

Geologic Map of the Sherwood Quadrangle, Oregon

Geology by Herbert G. Schlicker and Christopher T. Finlayson, modified from Trimble, 1963



TIME ROCK CHART



EXPLANATION

(Boundaries are approximate; statements are general; specific evaluations require on-site investigation)

SURFICIAL GEOLOGIC UNITS

Qal / pt — **Alluvium:** *Unconsolidated sand, gravel, and cobbles within stream channels and on adjacent flood plains; sandy silt up to 10 ft thick overlies gravel on flood plains; approximately equivalent to Qal and Qt (terrace deposits) of Trimble (1963) and Qt (terrace deposits) and Qya (young alluvium) of Schlicker and Deacon (1967);* **pt** *peat soils in local subsurface. Hazards include flooding, near-surface water table, and weak compressible soils; development not normally recommended*

Lacustrine Sediments: *Unconsolidated cross-bedded to graded sedimentary beds deposited by late Pleistocene glacial floods.*

Qws — **Qws:** *(Willamette Silt Formation): Lacustrine fine sandy silt and clay deposited up to 350 ft elevation. Beds range from a few inches to several feet thick; total thickness about 100 ft (outside of area); equivalent to Qlc (lacustrine silt) of Trimble (1963). Occurs along the valleys of the Tualatin and other tributaries of the Willamette River*

Qls — **Qls:** *Lacustrine and fluvial unconsolidated stratified to cross-bedded sand in silt and occasional lenses of pebbles to gravel. Occurs along Willamette River in northwest Clackamas County; equivalent to Qls (lacustrine sands) and Qs (sand and silt deposits) of Trimble (1963) and Schlicker and others (1964)*

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Qpg — **Pliocene-Pleistocene Gravels:** *Gravels and mudflows equivalent to the Qtw (Walters Hill Formation) and Qsw (Springwater Formation) of Trimble (1963); weakly indurated, poorly sorted, rounded cobbly and bouldery cobble gravel and associated pyroclastic mudflows; gravels decomposed by extensive weathering; has produced a mottled reddish-brown clayey soil; fanlike deposit extends from the Sandy River west to near Damascus and southeast to near Estacada. Up to 400 ft thick. Hazards include poor drainage; restrictive soil layers; low foundation strength in weathered areas; not suitable for aggregate*

BEDROCK GEOLOGIC UNITS

Sedimentary rocks

Tpt — **Troutdale Formation:** *Pliocene sandstone and conglomerate; indurated beds and lenses of well-sorted sand and cobbly gravel with up to 30% quartzite clasts. Equivalent to upper Troutdale Formation of Treasher (1942) and the Troutdale Formation of Trimble (1963); some sand originally composed of volcanic glass altered to an impermeable high shrink-swell clay. Occurs in valleys of Willamette, Clackamas, and Sandy Rivers and many of their tributary streams. Clay is unstable and causes overlying competent units to fail by landslide. Aggregate produced from Troutdale gravel is used mainly for fill and base rock; use in concrete may not prove satisfactory without special treatment; in areas of low permeability or where gravels are open, septic tank drainfields are not recommended*

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Volcanic rocks

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Tsa — **Sardine Formation:** *Miocene andesitic lavas and indurated pyroclastics; partly equivalent to the Sardine Formation of Thayer (1963) and Peck and others (1964), Rhododendron of Hodge (1933) and Trimble (1963), and Boring agglomerate of Treasher (1942). Mudflow breccias are abundant within this unit, and deep weathering has produced a reddish brown laterite; maximum thickness in area is 600 ft but thickens to east. Occurs principally in Eagle Creek and Clear Creek Valleys and Clackamas River gorge east of Estacada. Hazards include impermeable layers, earthflows and slumps in weathered pyroclastics, and difficult excavation in coarse jointed mudflows*

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- Contacts
- Faults
- Normal fault *(ball and bar on downthrown side)*
- Inferred fault
- syncline *(showing plunge of axis)*
- Lineament

Base Map by U. S. Geological Survey
Control by USGS, NOS/NOAA, USCE, and State of Oregon
Topography by photogrammetric methods from aerial photographs taken 1952. Field check 1954.
Revised from aerial photographs taken 1960. Field check 1961
Selected hydrographic data compiled from NOS/NOAA Chart 6172 (1958)
This information not intended for navigational purposes
Projection and 10,000-foot grid ticks: Oregon coordinate system, north zone (Lambert conformal conic)
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue. 1927 North American datum
Fine red dashed lines indicate selected fencelines
CARTOGRAPHY by Paul E. Staub

UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
0°08' 2 MILS; 20½° 364 MILS

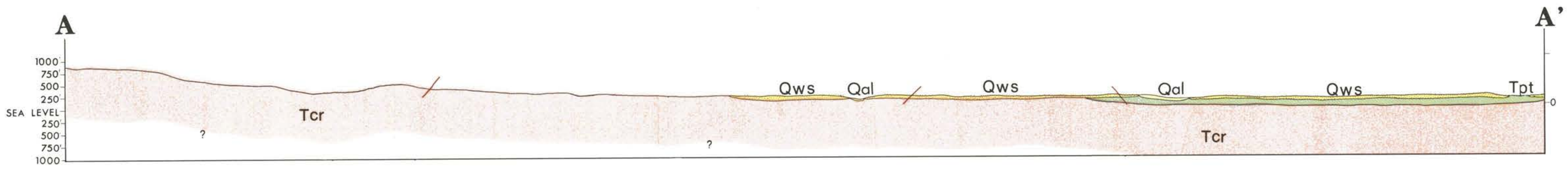
SCALE 1:24 000
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES AND SOUNDINGS IN FEET—WILLAMETTE RIVER DATUM

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Heavy-duty; Light-duty; Medium-duty; Unimproved dirt; Interstate Route; U. S. Route; State Route

SHERWOOD, OREG.
SE/4 BEAVERTON 15' QUADRANGLE
N4515—W12245/7.5
1961

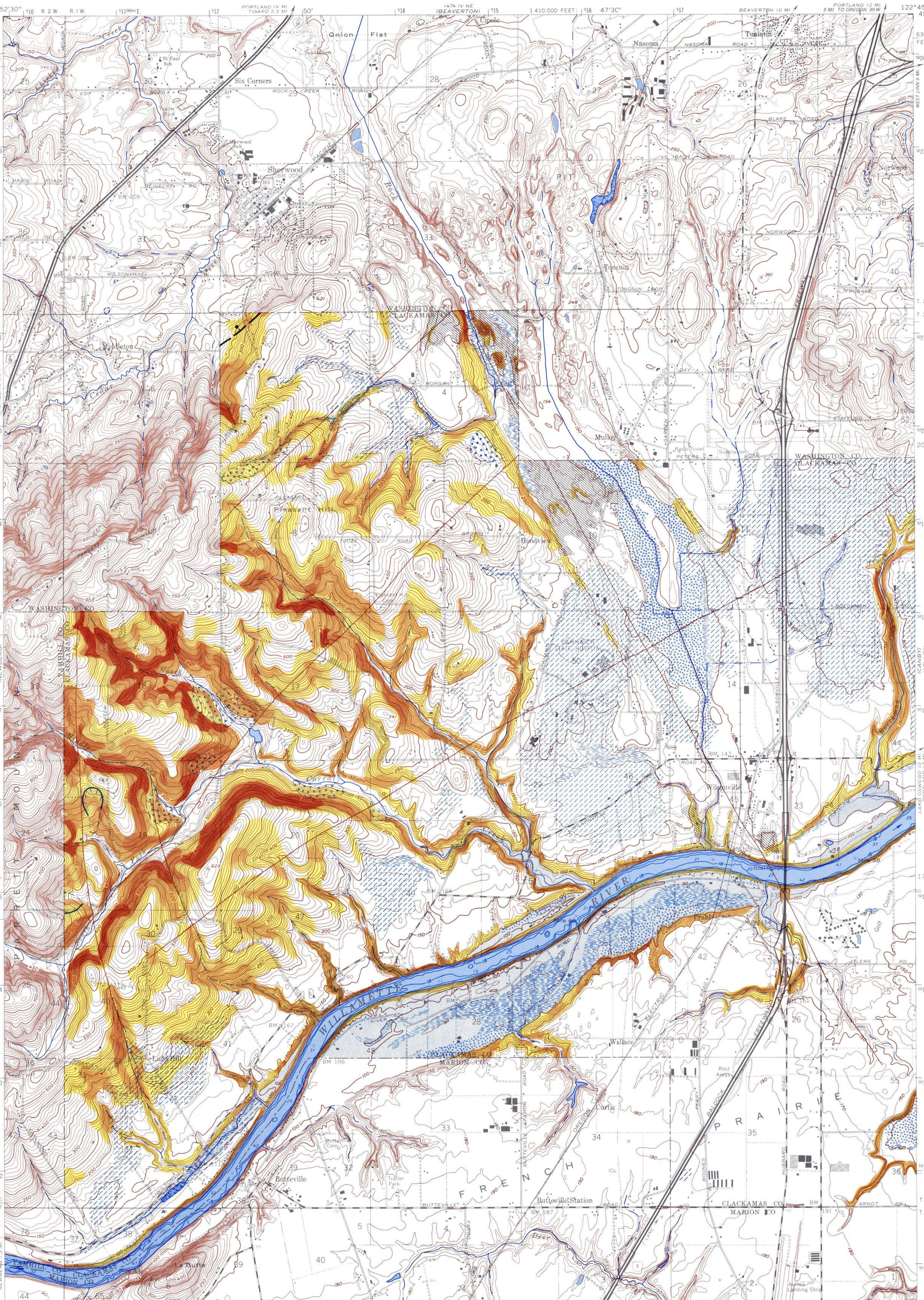
Geologic Cross Section



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

GEOLOGIC HAZARDS MAP OF THE SHERWOOD QUADRANGLE, OREGON

Geologic Hazards by Herbert G. Schlicker and Christopher T. Finlayson



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PHOTOREVISED 1970 and 1975

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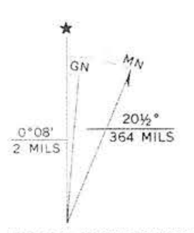

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AMS 1474 IV SE—SERIES V892

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Soil Hazards

Organic soils: *Areas of peat and areas likely to contain organic muds, muck, and peat either at surface or in subsurface. Most are water saturated and will compress excessively under moderate loads. Where possible, material should be removed and excavation backfilled with select embankment prior to construction. Elsewhere preloading or piling of sufficient length to reach competent rock or soil can provide adequate foundations. In artificial fills, drainage needed to prevent rise in water level. Embankments or structures that impede flood drainage will cause flood waters to rise*

High shrink-swell soils: *Clay soil with high shrink-swell ratio occurs in Sandy River Mudstone, Troutdale Formation, and younger units. Bentonitic material in soil expands or shrinks with seasonal changes in moisture content, producing cracks in foundations and plaster. Movement can be stabilized by controlling moisture content or by excavating high shrink-swell soil and backfilling with select embankment material*

Thin soils: *Areas mapped as thin soils overlie hard bed rock at depths of 2 ft or less. Unit includes soil developed from basalt residuum, thin soil deposited on bed rock, and bare outcrop areas. Associated hazards include inadequate septic tank drainage and high runoff. Excavation for utilities, underground storage tanks, and basements is difficult, especially in residential areas where blasting is not compatible*

Wet soils — high water table: *Areas in which the water table rises to within 1.5 ft of the ground surface. Area extent interpreted from geology, soil maps, topography, and engineering borings. High water table causes water to stand at the surface or in shallow excavations. Pumping of water from excavations may cause sides to cave unless properly shored. High water table can cause basement floors and walls to crack, force empty storage tanks to rise to the ground surface, and prevent subsurface disposal of septic tank effluent*

Flooding

Flood boundaries compiled from various sources including 1964 flood. Sources include U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Soil Conservation Service, and consultants to Clackamas County. Boundaries based variously on observations, predictions of 50-100-500 years, and standard projected flood. Because mapped flood boundaries vary with flood definition and with intent, scope, and method of study, original references should be consulted

Stream-Bank Erosion

Caused by deflection of stream flow naturally or by man-made obstruction; especially severe during high-volume flow. Rapid where stream banks are vertical, particularly along outside of meander curve. High vertical banks erode by undercutting and caving and may cause landslides. Areas of ongoing or potential stream-bank erosion should be studied to determine rates of erosion and overall safety relative to proposed structure or development. Corrective measures include weirs, concrete facing, piling, cribbing, and channel changes. Channel modification may yield beneficial or adverse impacts as a function of local hydraulics at site and downstream

Faulting

Faulting inferred from large-scale bedrock displacement, detailed mapping, radar imagery lineaments, and extensions of faults shown on published maps of adjacent areas. Faulting in northwestern Oregon is very poorly understood, and knowledge is inadequate for making predictions. Response of surficial geologic units and soils to earthquake movement varies considerably depending on thickness and consistency of unit, magnitude of event, and distance from epicenter

Fault — Stratigraphic offset determined by direct and indirect methods; dashed where approximate; indirect methods include gravity, magnetics, and geochemistry of basalt flows (Beeson, Johnson, and Moran, 1975) (ball and bar on downthrown side)

Lineament — Major lineaments identified from side looking airborne radar imagery and/or topographic maps; radar imagery by Westinghouse Electric Corporation for WPPSS, July 1973

Average Regional Slope

Slopes have been categorized according to general severity of hazard relative to various land uses. Landslide and earthflow reduce slope angle, however, and gentle slopes adjacent to steeper terrain are not necessarily stable

0 - 10%: *Stream terraces, dissected valley terraces, channels, and flood plains of major streams. Hazards include poor drainage, ponded areas, high water table, clay and peat bottom-land soils, and flooding. Upland areas with adequate engineering and geologic information can be developed. Lowlands associated with high water table and flooding may better be used for agriculture*

10 - 20%: *Gently sloping foothill areas and rolling uplands. Drainage usually good, but steeper parts may not be satisfactory for septic tank drainage except in best soils. Where clay or hardpan layers are present, effluent may exit at surface*

20 - 35%: *Moderate slopes of gentle terrace escarpments, foothills, pediments, and alluvial fans. Slopes generally excessive for septic tank drainage. Stream and ditch erosion moderate to severe and severe where gullying can take place in plowed fields devoid of vegetation. Some earthflow and slump landslides have reduced steeper slopes to this category*

35 - 50%: *Rolling and steeper hill slopes, steep terrace escarpments, and recent and active earthflow and slump landslide areas. Excavation and drainage in this terrain require extensive geologic input and engineering design. Areas of critical slope stability can be activated by improper land use*

>50%: *Bedrock exposures, steep terrace escarpments, areas of severe stream erosion, talus slopes, and debris flow and debris avalanche landslide areas. Steepest slopes in this category may be subject to rockfall. Geological input necessary for engineering design of roads, cuts, embankments, and drainage in these areas. Development should be limited to certain categories such as roads, recreation, and timber harvest, except for small properly engineered projects shown to be safe*

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