



**GEOLOGIC HAZARDS
OF
EASTERN BENTON
COUNTY, OREGON
1979**

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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BULLETIN 98

**GEOLOGIC HAZARDS OF EASTERN
BENTON COUNTY, OREGON**

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Oregon Department of Geology and Mineral Industries
1979

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Commission to Benton County and in cooperation with
the Benton County Board of Commissioners



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ERRATA SHEET

Map showing geology and geologic hazards of eastern Benton County, Oregon
(scale 1:62,500)

NW $\frac{1}{4}$ sec. 12 T. 11 S. R. 5 W - Tsr-p should appear next to Corvallis Fault
just west of Lewisburg instead of Qth (see Lewisburg 7 $\frac{1}{2}$ ' Quadrangle).

SE $\frac{1}{4}$ sec. 11 T. 11 S. R. 5 W. - Some Qth should appear east of concealed
trace of Corvallis Fault just west of Locke Cemetery.

E $\frac{1}{2}$ sec. 20 T. 10 S. R. 4 W. - Ts-p symbol should read Ts-p\Qth northeast
of Adair Village (see Lewisburg 7 $\frac{1}{2}$ ' Quadrangle) to indicate both units
may be present.

SE $\frac{1}{4}$ sec. 12 T. 11 S. R. 5 W. and N $\frac{1}{2}$ sec. 13 T. 11 S. R. 5 W. - Ts-p
(shown by cross-hatching) should be Ts-p\Qth (see Lewisburg 7 $\frac{1}{2}$ ' Quad-
rangle) to indicate both units may be present.

T. 14 S. R 6 W. - Wide blue band shown is a logging road, not stream drainage.

Sec. 30 and sec. 31 T. 14 S. R. 5 W.; and E $\frac{1}{2}$ sec. 25 T. 14 S. R. 6 W. -
Tf-p in semicircular arc from Alpine to southwest end of the fault just
west of Monroe (see Monroe 7 $\frac{1}{2}$ ' Quadrangle) should be shown as Ts-p.

Willamette River (by river mile)

120: Yellow showing major bar growth (post 1969) should be omitted.

132: Major stream-bank erosion is missing at mouth of Marys River,
as correctly shown on Corvallis 7 $\frac{1}{2}$ ' Quadrangle.

154.5: Existing island is shown north of major bar growth; existing
island should be displaced southward to boundary of yellow
major bar growth. Surrounding area is then correct area of
major bar growth.

City of Alpine (left margin, center) is located on Ts-p instead of Tf-p,
as shown.

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Maps in envelope

Map showing geology and geologic hazards of eastern Benton County, Oregon

Maps showing geology and geologic hazards of the following quadrangles:

 Corvallis
 Greenberry

Maps showing geology of the Benton County parts of the following quadrangles:

 Lewisburg
 Monroe

GEOLOGIC HAZARDS OF EASTERN BENTON COUNTY, OREGON

INTRODUCTION

Purpose

Effective land use planning and land management require an adequate data base with regard to the potential uses and limitations of the land. The purpose of this study is to provide practical information on specified geologic hazards and engineering geology conditions of eastern Benton County.

The need for comprehensive, systematic, and reliable information of this sort has gained wide recognition by State officials, County officials, planners, private citizens, and resource specialists. Legal trends in recent years have been toward placing increasing emphasis on comprehensive plans in land use decisions in Oregon (Fasano; Baker v. Milwaukee; Green v. Hayward, Salishan). The nationwide trend is also toward the placing of greater responsibilities on permit-granting agencies.

Acknowledgments

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Staff members of the Oregon Department of Geology and Mineral Industries assisting in the project included John Beaulieu, Norman Peterson, Herbert Schlicker, geologists; Charles Schumacher and Paul Staub, cartographers; Beverly Vogt, geologist-editor; Ainslie Bricker, editor; Ruth Pavlat, typist; Laura di Trapani, art work; and Darolyn Burch, pasteup.

How to Use

General

Proper land management and land use planning address the characteristics of the land. In addition to County and city planners, the category of land use planners and managers to some degree also includes developers; policy formulators on the national, State, and local levels; land holders; architects; engineers; and natural resource specialists.

This bulletin provides planners in Benton County with a synthesis of present thinking on geologic hazards and engineering geologic conditions in the study area. The material is reconnaissance in nature, however, subject to refinement based on additional investigations. The maps, like all maps, represent average conditions as they actually occur on the ground; and on-site examination generally is required for specific evaluations.

The bulletin is organized and cross referenced 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 is divided into sections on specific hazards or topics and is structured around the formats of the map legends. The net result is a logical progression of facts with a potential for a wide variety of uses on various levels of inquiry from general to specific (Figure 1).

Site evaluations

The maps, tables, and text can be used to assess land use potentials and limitations, which can then be matched with specific site requirements of a proposed development and the surrounding area to determine if the development and the site are compatible. An appreciation of the limitations of map detail is a key prerequisite to correct site-specific decisions, and on-site investigations are generally required for site evaluations. Although the text and tables are designed to guide and facilitate site evaluations, consultation of other sources of information is also recommended.

Land use capability analyses

Data provided in this bulletin and on the maps can be used either directly to develop land use capability maps or indirectly to develop such maps 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 three specifications:

- (1) The maps should be prepared for individual types of development 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, informed professional judgment, and type of development contemplated.
- (3) Map scale must be properly appreciated, and provisions should be made for exceptions based on more detailed information.

Extrapolation of data

On the County and city levels, specialists commonly possess a wealth of detailed information on specific sites in their respective fields of expertise but do not readily have at their disposal a mechanism for systematically applying their knowledge in other areas. Thus, an individual may have detailed site-specific information on septic-tank failures, aggregate resources, or landslides but may not have adequate means of anticipating similar problems elsewhere. In this bulletin, geologic units, slopes, and hazards are interrelated in the text and maps in order to provide the specialist with the tools he needs to extrapolate his observations into new areas for which no detailed historic information is available.

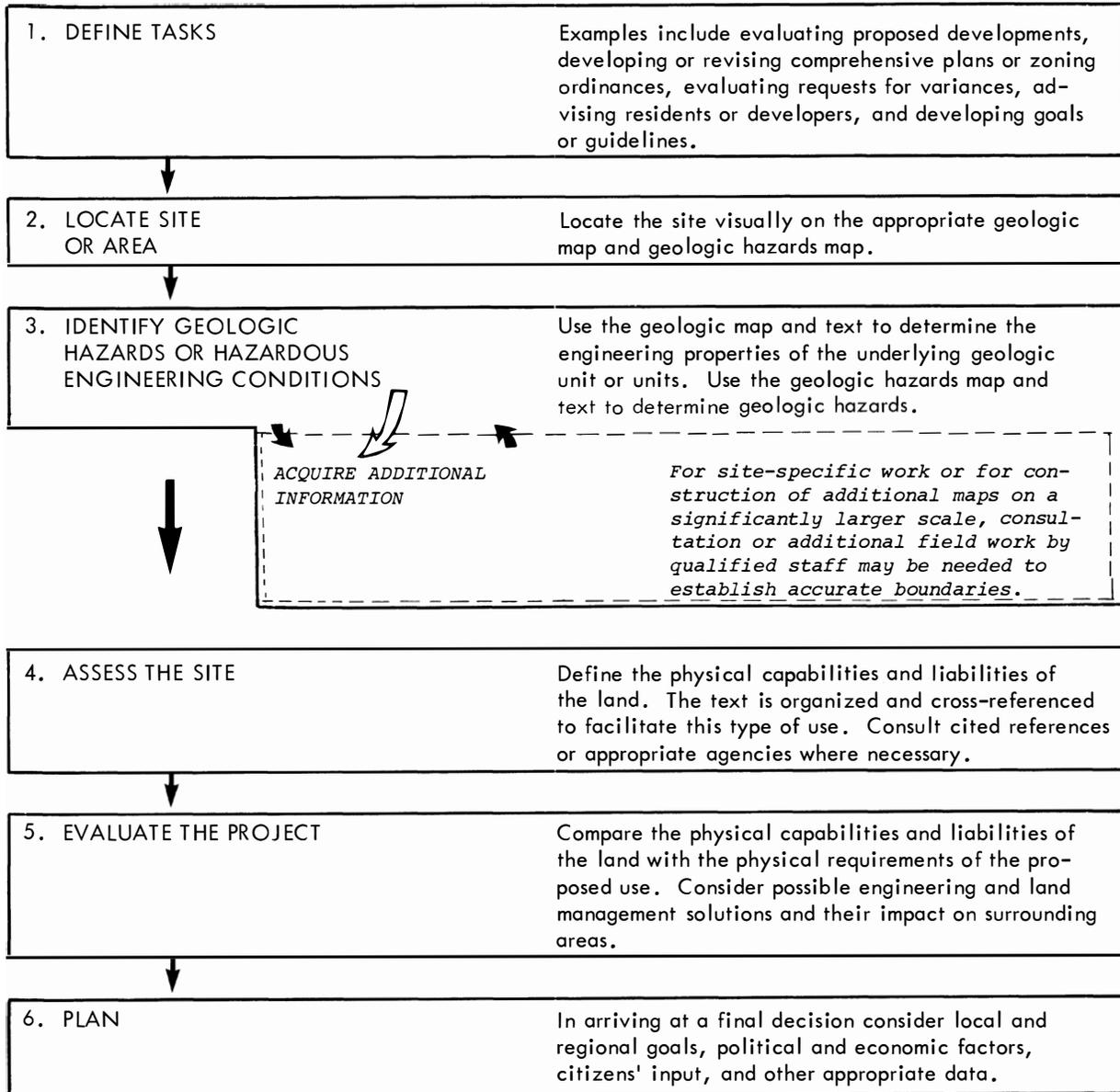


Figure 1. Suggested use of this bulletin in land use decision making.

Policy formulation

When used in conjunction with a realistic set of goals, this bulletin will be invaluable in formulating resource management and land use policies on the local and regional levels. Such policies should represent a coordinated effort on the part of government agencies at various levels, consider all significant hazards, and make provisions for local conditions as revealed by more detailed study or on-site investigation. Policies should be designed to protect the safety and well-being of the public and should be based on adequate and appropriately applied information regarding geologic hazards.

Map Scale and Detail

Obtaining data of an appropriate level of detail for a particular planning task is often the most significant informational concern of the planner. Inventories are generally conducted for a variety of purposes and are available at several levels of detail. Confusion may result if the degree of generalization of a tool generated on a statewide, countywide, or citywide basis is not distinguished from the degree of specificity needed for local implementation. Maps made for a general purpose are usually not adequate for uses requiring more precise levels of inquiry such as site-specific decision making or the construction of large-scale zoning maps.

Where gaps in information exist, arbitrary adjustment of the map scale does not generate the additional map detail required by the new use. Increased detail requires additional data (see INTRODUCTION - Site evaluations and Land use capability analyses) that can be obtained by consultation, additional studies, on-site investigation, or in-house revision based on additional information. The text of this report is intended to supplement the maps and to serve local jurisdictions in generating more detailed maps and information for specified local use.

In summary, completion of regional inventories is a necessary prerequisite of local implementation, but these inventories are not substitutes for site-specific information. As comprehensive plans are elevated to a more distinguished and fundamental role in local planning, more care must be given to their formulation. To preserve the option of making justified zoning variances based on additional future information, the planner must carefully phrase land use restrictions as they are presented in the comprehensive plan.

Table 1. Climatic data, Benton County, Oregon

	Corvallis	Corvallis Water Bureau (4 mi west of Philomath)	Upper levels of Coast Range
Mean annual precipitation (in.)	40	68	126
Average January temperature (°F)	39	40	---
Average July temperature (°F)	67	64	---
Average daily maximum temperature (°F)	63	--	61
Average daily minimum temperature (°F)	42	--	39
Maximum temperature (°F)	100	--	97
Minimum temperature (°F)	17	--	12

GEOGRAPHY

Location and Extent

The study area encompasses the eastern and central parts of Benton County (Figure 2). It is bounded to the west by arbitrary boundaries selected on the basis of topography, population density, County needs for information, and desire for economies in the mapping and publication processes.

Four 7½-minute quadrangle maps and one larger 15-minute composite quadrangle map are included as part of the study. Total areal extent is approximately 425 sq mi. Major access is provided by Interstate Highway I-5, U.S. Highway 20, and Oregon Highways 99W and 34, with State, County, local, and private roads in more remote areas.

Climate

The Willamette Valley is a fairly uniform climatic region, enjoying mild winters and moderate summers because of the modifying effect of the Coast Range on moist maritime air masses moving from over the Pacific Ocean. Rainfall is least in the valley areas, averaging only 40 in. annually, and increases westward toward the margins of the Coast Range. It is greatest toward the higher elevations of the Coast Range, where an average annual precipitation of 120 in. is reported near Marys Peak. Approximately 70 percent of the total rainfall occurs from November through March. Summer rainfall in valley areas is less than 3 in. Heavy winter rainfall occasionally causes major flooding along lowland terraces of the Willamette River and tributary rivers and streams. Climatic data is summarized in Table 1. Additional climatic information is contained in the Soil Survey of Benton County Area, Oregon (Knezevich, 1975).

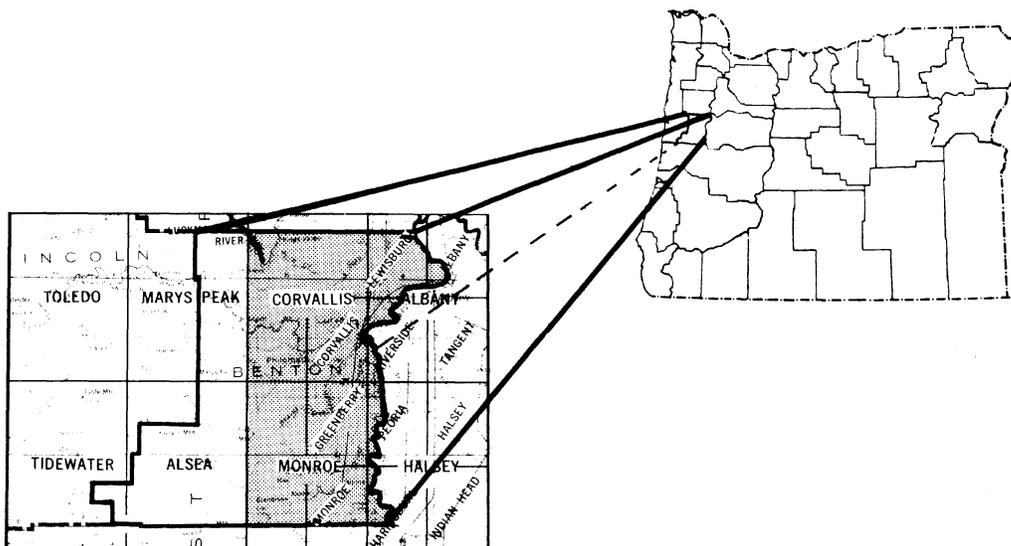


Figure 2. Index map of study area showing 7' and 15' topographic map coverage.

Topography

Broad, flat terraces adjacent to the Willamette River give way to lower foothills and bedrock pediments along the eastern margins of the Coast Range. Elevations in the Coast Range vary from about 800 ft to 2,000 ft. Marys Peak, the highest peak in the Coast Range, has an elevation of 4,097 ft. Marys River joins the Willamette River at Corvallis, and its broad flood plain near population centers significantly affects land use. Muddy Creek, Long Tom River, and the Willamette River all follow northerly courses in the eastern portion of the County.

Lower foothills around the valley margins are underlain by soft to hard sedimentary rocks of low permeability. Slopes are generally low to moderate; and hazards include earthflow and slump topography, soil erosion, and variable cut-slope stability. Northwest of Corvallis, submarine volcanic rock is associated with clay-rich soils with high shrink/swell potential, earthflow and slump topography on low and moderate slopes, and steep-slope failures in steep terrain. Steep terrain in sedimentary rock in the Coast Range is also prone to steep-slope failures. Numerous very hard intrusive dikes and sills in Coast Range volcanic and sedimentary rocks influence slope stability and drainage.

Terraces adjacent to the Willamette River and tributary rivers are underlain by a variety of flat lying, soft to semiconsolidated, surficial geologic units. Hazards include high ground water and ponding, flooding, and stream-bank erosion. Kings Valley and tributary valleys, as well as other valleys in south County areas, are formed in siltstone units.

The engineering properties of geologic units are major factors in the development of landforms and in the distribution of geologic hazards. Accordingly, proper definition and identification of rock units are essential to meaningful land use geology assessments. Engineering properties, regolith, and geologic hazards for each geologic unit are summarized in Table 3.

Population and Land Use

The population of Benton County (Table 2) is expanding at a rapid rate and may nearly double during the next 25 years. The Corvallis-Albany area is the third largest urban complex in the Willamette Valley. Historically, land use has been related in large part to landforms and the location of major transportation lines. Greatest growth in recent years has occurred near Corvallis. Of the population residing outside of incorporated areas, approximately one-third is located in the North Albany area, one-third is located near Corvallis, and one-third is dispersed throughout the remainder of the County.

The eastern portion of Benton County is comprised of forest, woodland, and prairie zones. Oregon white oak is often common on drier sites, and many south-facing ridges with shallow soil support grassland. To the west and in the Coast Range is the Western Hemlock Zone, which, because of fire and logging, is characterized predominantly by Douglas fir, with stands of red alder and big leaf maple on disturbed sites.

Willamette Valley vegetation has always been modified by land use. Earliest written records describe an open landscape of prairies and savanna vegetation, which Indians maintained by annual burning. Woodlands were restricted to the active flood plain of the Willamette River and its major tributaries and to higher elevations of the Cascades, foothills, and Coast Range. This pattern changed with cessation of large-scale burning following pioneer settlement and introduction of agriculture. Flood plain woodland was cleared for agricultural use, former prairie lands were used for grass seed and small grains, and woodland and forest areas increased in bordering hills. During the 19th century, most of northwestern Benton County was burned three or four times by forest fires, probably significantly affecting slope stability in steep terrain at that time.

Dominant land uses in the mountainous areas are forestry, recreation, and scattered residential development. Agriculture predominates in the flat valley areas. In Corvallis, Oregon State University is a center for research in agriculture, forestry, and engineering.

Future urbanization and associated economic expansion into trade, electronics and other technology-based industries, education, and services will lead to increased development pressures on land surrounding present communities. The desire to preserve prime agricultural land has increased development of hillside areas for residential use. Proper management of the land resource will assure most beneficial use of the land and mitigation of existing and future potential hazards.

Table 2. Populations of major communities of eastern Benton County, Oregon *

	1940	1950	1960	1970	1976	1980**	1985**	1990**	2000***
Oregon	1,089,684	1,521,341	1,768,687	2,091,385	2,341,750				3,019,900
Willamette Valley	712,175	1,015,354	1,191,278	1,475,384	1,642,600				2,118,800
Benton County	18,629	31,570	39,165	53,776	65,600	72,470	82,150	93,190	93,600
Corvallis	8,392	16,207	20,669	35,056	40,180	46,700 ^Υ 44,000 ^Ψ		62,700 ^Υ 53,600 ^Ψ	
North Albany (unincorporated)	-----	-----	-----	-----	4,056	9,000			
Philomath	856	1,289	1,359	1,688	2,160				
Adair	-----	-----	-----	-----	599				
Monroe	311	362	374	443	485				
Other unincorporated areas	-----	-----	-----	-----	22,176				

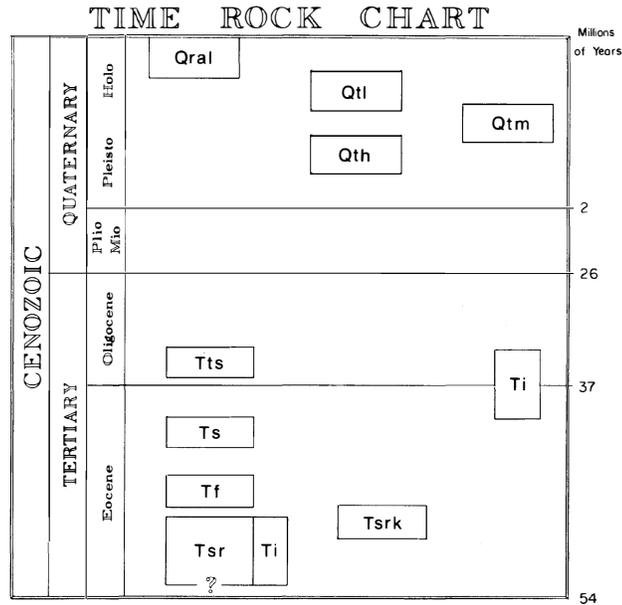
* Oregon Blue Book (1977-1978).

** Figures furnished by Benton County Planning Department.

*** Center for Population Research and Census (1976).

^Υ Based on 3 percent growth rate.

^Ψ Based on 2 percent growth rate.



Description of Units

- | | |
|---|--|
| <p>Qral - Recent river alluvium:
Unconsolidated cobbles, gravel, sand, and some silt within active channels of Willamette River</p> | <p>Ts - Late Eocene sandstone (Spencer Formation):
Massive to thin-bedded, cemented, fine- to medium-grained, micaceous, arkosic, and tuffaceous sandstone</p> |
| <p>Qtl - Quaternary lower terrace deposits:
Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter on low-land terraces</p> | <p>Tf - Middle Eocene sandstone (Flournoy Formation):
Bluish-gray, hard, graded sandstone and dark-gray siltstone</p> |
| <p>Qtm - Quaternary middle terrace deposits:
Semiconsolidated gravel, sand, silt, and clay forming terraces of major extent along Willamette River</p> | <p>Tsrk - Kings Valley siltstone:
Well-bedded, dark-brownish-gray, shaly, tuffaceous siltstone and water-laid tuff</p> |
| <p>Qth - Quaternary higher terrace deposits:
Semiconsolidated gravel, sand, silt, and clay of variable thickness on higher terraces near foothills</p> | <p>Tsr - Eocene volcanic rocks (Siletz River Volcanics):
Marine-deposited, dark-greenish-gray to black pillow lavas and basalt flows with minor interbeds of siltstone and basaltic sandstone</p> |
| <p>Tts - Early Oligocene sandstone:
Greenish-gray, medium- to coarse-grained tuffaceous sandstone</p> | <p>Ti - Intrusive rocks:
Fine- to medium-grained basalt and gabbro dikes, sills, and irregular intrusive bodies</p> |

Figure 3. Time distribution of geologic units.

GEOLOGIC UNITS

Surficial Geologic Units

Benton County's proximity to the Willamette River and numerous Coast Range rivers and streams, coupled with the complex history of inundation and sedimentation during the Quaternary period, has resulted in an abundance of surficial geologic units consisting of unconsolidated and semiconsolidated deposits of gravel, sand, silt, and clay of varying extent and thickness. Origins of some of these units are complex and probably the result of several different episodes and processes. Four surficial units, distinguishable by landform, association with flood plains, and depth and type of material, have been mapped in the study area (Figure 3).

Recent river alluvium (Qral)

Recent river alluvium consists of unconsolidated cobbles, coarse gravel, sand, and some silt within the active channels of the Willamette River. It is equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), and part of Qal of Beaulieu (1974).

The active river channel is characterized by low relief, point-bar deposits, and, in places, secondary active channels, as the Booneville Channel southeast of Corvallis (Figures 49 and 54). Major deposits include well-rounded pebbles of generally basaltic and andesitic composition, often overlying older alluvium. Recent river alluvium overlies a variable bedrock surface of Spencer sandstone (Ts) and ranges from 20 to 45 ft in thickness. Many areas are not vegetated, while others support dense stands of phreatophytes such as willows and cottonwoods.

The dominant hazard is, of course, major flooding, which can occur between October and April. The majority of floods occur in December and January as a result of widespread rainfall of several days' duration and increased runoff due to snowmelt at a time when soils are already saturated. During flooding, stream channel velocities may reach 13 fps (9 mph), and portions of the channel are subject to critical stream-bank erosion and lateral channel migration. Undercutting and caving of banks occur in meanders, primarily at outer bends, which are characterized by steep slopes and deep water near shore, and also at actively growing bars on inner bends, as at Irish Bend and the Corvallis water treatment plant (Figure 54).

Areas adjacent to the Willamette River provide some of the most important sources of sand and gravel for building and construction. These areas are often abandoned major meanders, as at Fischer Island east of Corvallis. Highest ground water yields of several hundred gpm occur where good river infiltration occurs to sustain the yield. For additional information on Qral see GEOLOGIC HAZARDS – Stream Erosion and Deposition.

Quaternary lower terrace deposits (Qtl)

Quaternary lower terrace deposits consist of (1) low terraces above recent river alluvium of the Willamette River, and (2) lowlands of tributary rivers and streams, as Marys River, Frazier Creek, and Muddy Creek. This unit is equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), the Ingram surface of Balster and Parsons (1968), and part of Qyal and Qoal of Frank (1974).

The lower terrace deposits are characterized by a low, undulating, fluvial surface resulting from overbank channeling (Figure 4). Meander scrolls, oxbow lakes, and widespread areas subject to ponding are common (Figure 49). The first terraces above the Willamette River are only a few feet up to 8 ft or more above river level. Deposits here generally consist of 35 ft of river- and stream-deposited cobbles, gravel, and coarse sand derived from volcanic rocks, with relatively large amounts of flood deposits of silt and clay.



Figure 4. Quaternary lower terrace deposits (Qt1) adjacent to Marys River. Low, undulating topography (swell and swale relief) is result of overbank channeling during flooding.

Where lower terraces are found away from the Willamette River, interbedded deposits of sand and gravel interspersed with fine sand and silt below the water table occur locally beneath the surface, forming good aquifers. Composition varies with source area and stream size. In places, this unit contains material equivalent to the Willamette Silt as mapped by Allison (1953) and Beaulieu (1974) but not so mapped for purposes of this study.

Surficial deposits (30–40 ft deep) of semiconsolidated fine sand, silt, and clay generally mantle this terrace and other terrace units (Figure 23). Lenses of cobbles, sand, and gravel are often encountered between depths of 30 to 50 ft, while sediments below 50 ft are predominantly fine grained, with permeable sand and gravel deposits locally. Rivers and streams are usually entrenched – some 20 to 30 ft for Marys River locally and approximately half that for smaller Muddy Creek. Because deposition of lower terrace material away from the Willamette River occurred over an older, irregularly eroded Spencer (Ts) sandstone surface, thickness of this surficial unit is extremely variable. It averages 35 ft along the Willamette River but varies from several feet to 25 ft (Frank, 1974) in the Corvallis–Philomath area, with upper zones generally composed of clays and silts. It is reportedly thin along Marys River (10–30 ft) but exceeds 100 ft at Muddy Creek (well location 12S/5W–32 ccb), where clay beds separate permeable sands and gravels.

The major hazard is flooding (Figure 5). Portions along the Willamette River are subject to frequent flooding and ponding, and some catastrophic lateral channel migration of major scale is possible (Figure 53). Lower terrace boundaries correspond closely with the 100-year flood and standard project flood zones as determined by the U. S. Army Corps of Engineers for the Willamette and Marys Rivers (1971). However, potential flooding at specific sites should be assessed by using the Corps of Engineers' most current data and comparing the elevation of each site with the projected river stage at the nearest location. Tributary and Coast Range streams, many of which flow on impermeable bed rock, may be subject to frequent flooding and ponding during winter months. Overbank water velocities are lower in areas mapped Qt1 (approximately 5 fps) and favorable to siltation.

To varying degrees, these same hazards affect lowland areas adjacent to perennial and intermittent streams. Such areas also generally have fine-grained, organic-rich sand, silt, and clay deposits adjacent



Figure 5a. Intermittent stream drainageway on Quaternary lower terrace deposits (Qt1) north of Corvallis airport, near Marys River (river mile 5.5). Country Club Hill is in background behind barn. Swale of drainageway crossing road has no drainage.



Figure 5b. Flooding and ponding at same location during December 1977, resulting from flooding of nearby Marys River and Muddy Creek and overland flow due to saturated soil conditions.

to streams or drainages, many of which are incised, although deposits may be of limited lateral extent locally. The reconnaissance nature of this study and scale limitations preclude mapping all lower terrace deposits adjacent to these areas, and on-site evaluations should be made whenever developments are contemplated (see GEOLOGIC HAZARDS - High Ground Water and Ponding, and Stream Erosion and Deposition).

Drainage is often severely restricted, as along Beaver Creek Road just south of Applegate Road in Philomath, where more than 8 ft of black, silty clay containing some rock fragments impounded water beneath a foundation from mid-winter until July without drainage.

Ground-water potential is variable. Lenses of sand and gravel occur within fine sand, silt, and clay below the water table within drainages of tributary rivers and streams away from the Willamette River. However, deposits along rivers and tributary streams tend to be thin and fine grained, with corresponding lower yields. High yields are possible in this unit in the lower terraces immediately adjacent to the Willamette River where river infiltration can occur.

Soils tend to be deep and generally range from poorly drained silty clay loams to fine sandy loams adjacent to the Willamette River (Table 10).

Quaternary middle terrace deposits (Qtm)

Quaternary middle terrace deposits generally consist of semiconsolidated gravel, sand, silt, and clay forming the main terraces along the Willamette River (Figure 6). They are equivalent to part of the Willamette Silt of Allison (1953) north of Corvallis; part of Qal of Vokes and others (1954); the Winkle, Calapooia and Senecal surfaces of Balster and Parsons (1968); and part of Qoal of Frank (1974).

These terraces have very flat surfaces well above the level of lower terrace deposits along the Willamette River and form the main broad terraces of Benton County. Near the Willamette River they are generally 15 to 30 ft higher than the river, as east of the Corvallis airport, and consist of river and stream deposits of gravel, sand, silt, and clay, and probably lacustrine silt and clay related to major inundations of the Willamette Valley during the late Quaternary period (Figure 23). A layer of volcanic ash may underlie the upper surface just south of Winkle Butte. The Qtm terraces appear to merge gradually with lower terraces in many places, particularly where streams transect them; in these places a gradual dip toward the streams, which are often incised from 6 to 15 ft, is noted, as near the Adams School and Department of Motor Vehicles Building in Corvallis. Along Frazier Creek through Granger, north of Corvallis, a lower level terrace has been cut into the main middle terrace.

North of Corvallis, where associated glacial erratics occur, this unit represents part of Allison's Willamette Silt. South of Corvallis and west of the Willamette River, the Willamette Silt, as recognized and mapped by Allison (1953) in the Albany Quadrangle and Beaulieu (1974) in Linn County, may thin considerably or be modified by subsequent erosional and depositional episodes. Allison proposed the name "Willamette Silt" (Qws) in 1953 for all "the parallel-bedded sheets of silt and associated materials that cover the greater part of the Willamette Valley lowland," noting their association with iceberg-rafted glacial erratics extending to an elevation of 400 ft. Subsequent workers, including Allison and Felts (1956), Baldwin (1964), Glenn (1965), Balster and Parsons (1969), and Beaulieu (1974), have used or modified the concept of the Willamette Silt. Perhaps most notable, Glenn (1965) cited evidence, based on mineralogical and stratigraphic studies in the Northern Willamette Valley and eastern Washington, that at least 40 large Columbia River floods occurred. For a further discussion of the Willamette Silt, see Environmental Geology of Western Linn County, Oregon (Beaulieu, 1974).

The thickness of the middle terrace deposits probably ranges from 50 to 100 ft or more. Up to 100 ft or more are reported to the north near Granger, and Frank (1974) reports a general thinning to 50 ft or less approaching the Willamette River. Since the middle terrace deposits are generally much thicker than the Willamette Silt, which is approximately 15 ft at the type section at Irish Bend (Figure 52), this entire unit is more practically designated Quaternary middle terrace deposits (Qtm), although the Willamette Silt may constitute a portion of it.

Ground-water potentials of good to high yields from coarser alluvial deposits below 50 ft are reported locally; but yields vary because of lenses of sand and gravel interspersed with fine sand, silt, and clay below the water table.



Figure 6. Distribution of surficial and bedrock geologic units at Corvallis (1978 oblique aerial photo). Corvallis is located on Quaternary middle terrace deposits (Qtm) and Quaternary higher terrace deposits (Qth). Continued residential growth is occurring in surrounding sedimentary and volcanic rock units: Spencer sandstone (Ts), far right; Flournoy sandstone (Tf), Witham Hill; Siletz River Volcanics (Tsr), north and west of Witham Hill, where basalts, breccias, tuffaceous sediments, and intrusive rocks occur west of Corvallis fault zone. Fischer Island, foreground, is former point bar deposit now mined for sand and gravel. Its outline was once Willamette River main channel. Note channel bar deposit at mouth of Marys River.



Figure 7. Dissected, gently rolling topography of Quaternary higher terrace deposits (Qth) 2 mi south of Philomath. Marys Peak, remnant of large sill, is in background.



Figure 8. Yellowish-orange decomposed gravel and sandy lenses within Quaternary higher terrace deposits (Qth) exposed along Bellfountain Road just north of Airport Road. Gravelly material contains textural indications of basaltic and volcanic rock, as well as sedimentary rock. White area (arrow) represents a 2-in. rock fragment which is completely altered to clay.

Soils are generally poorly to somewhat poorly drained silt loams and well-drained and moderately well-drained silty clay loams (see GEOLOGIC HAZARDS - High Ground Water and Ponding).

Quaternary higher terrace deposits (Qth)

Quaternary higher terrace deposits are still higher terraces consisting of semiconsolidated gravel, sand, silt, and clay, often poorly sorted, located toward the western foothills in Benton County. They are equivalent to part of the decomposed gravels (Qdg) of Vokes and others (1954), part of the Quad and Dolph surfaces of Balster and Parsons (1968), and part of the terrace deposits (Qt) of Frank (1974).

These higher terrace deposits are generally higher in elevation and more heavily dissected by streams than middle terrace deposits (Table 9). Near Corvallis they form mostly flat surfaces approximately 15 to 20 ft higher than the middle terrace unit (Figure 6). In general, they consist of semiconsolidated river- and stream-deposited gravel, sand, silt, and clay, with finer material, notably up to 30 ft of light-brown silty clay and fine sand, found on the surface in many locations. At 36th and Harrison Streets in Corvallis, the higher terrace deposits consist of 8 ft or more of yellowish-gray micaceous silt containing minor wood fragments, sand, and small pebbles, covered by 2 ft of light-yellowish-brown silty soil with $\frac{1}{4}$ -in. shrink/swell cracks. Here they overlie buff- and gray-colored siltstones of the Spencer Formation (Ts). The unit is reportedly deeply weathered in places, and the thickness varies generally between 10 to 150 ft (Frank, 1974). Over bed rock in some areas near bedrock hills and local topographic highs, it may be only several to 10 ft thick. At Philomath and south of Philomath, the thickness is reported to be 170 to 200 ft or more locally.

Approximately 2 mi south of Philomath, where the higher terrace deposits occur as dissected benches (Figure 7) coinciding with the decomposed gravels of Vokes and others (1954), they consist of deeply weathered deposits of poorly sorted gravel, sand, and sandy clay, usually interbedded with fragmental plant material. The gravels, which can readily be cut with a knife, consist of sedimentary rocks and a lesser amount of porphyritic volcanic rocks, many containing magnetite. Many deposits consist of pale- to dark-yellowish-orange sands and small siltstone pebbles, probably derived from the Spencer (Ts) or Flournoy (Tf) Formations (Figure 8). Where this fine-grained material overlies the Spencer at relatively shallow depths, it is generally not water producing; however, water-producing sands and gravels are noted within this unit at depths of 100 ft or more.

Higher terrace deposits mapped over the Spencer and Flournoy Formations may have engineering and ground-water properties almost indistinguishable from those of the underlying bed rock, owing either to their shallowness or to derivation from similar sedimentary formations. They may actually consist of weathered material derived from sedimentary bedrock units rather than younger depositional material (see GEOLOGIC UNITS - Pediments). Areas mapped as higher terrace deposits near foothills, where bed rock and planed bedrock surfaces (pediments) also occur, are transitional with these other units. On-site investigation and stratigraphic information from well logs or test pits are required to establish firm differentiation, unavailable in a reconnaissance study (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Regolith).

The higher terraces are free of flooding, and the relatively flat terrain makes them ideally suited for engineering. Small yields of ground water from weathered upper zones and moderate yields from unweathered deeper zones have been reported. Yields of 6-15 gpm from depths of around 100 to 140 ft occur just north of Inavale School. Where the deposits are shallow and well drained, lack of ground-water storage limits yield.

Soils are predominantly well drained to poorly drained silt loams.

Pediments

Pediments are gently inclined, planar erosion surfaces cut into bed rock and generally veneered with thin deposits of unconsolidated material including gravel, sand, silt, or clay in transport. They occur between mountain fronts and valley bottoms and generally form extensive bedrock surfaces over which the products of denudation and erosion from retreating mountains are transported to the basins. Processes include weathering and transport by soil creep, surface wash, and small streams. The collec-

tive processes of erosion on pediments are areal in extent and produce erosion surfaces rather than discrete valleys.

The depth of unconsolidated surficial material is generally greater where pediments merge with valley basins than it is upslope. Pediments are poorly understood owing to the complexity of the processes involved, the slowness of landscape evolution, and the spatial and temporal diversity of the environmental conditions present on them.

Pediments have been classified as denudation slopes, transportation slopes, and accumulation slopes depending respectively upon whether (1) ground loss is occurring, (2) neither ground loss nor gain occurs, or (3) ground gain is occurring. Slope-model concepts envision control by weathering whereby the (1) potential rate of removal exceeds rate of weathering, and weathered material is removed shortly after it is formed, and (2) potential rate of weathering exceeds that of removal, and ground loss is dependent upon rate of removal.

Future understanding of the pediments of the Willamette Valley will incorporate these concepts and will involve increasing interdisciplinary cooperation and investigation.

Tsr pediments

These are areas of flat-lying to moderately sloping terrain with shallow, intermittent stream drainages. Locally shallow soils range from only 1 ft over weathered bed rock in some flatter areas to 2 to 4 ft on moderate slopes (Figure 9). Weathered bed rock near the surface often shows spheroidally weathered volcanic boulders and cobbles, and knolls may be strewn with boulders and cobbles (see GEOLOGIC UNITS- Eocene volcanic rock). Tsr pediments are equivalent to decomposed gravels (Qdg) of Vokes and others (1954), part of the Dolph surface of Balster and Parsons (1968), and part of the Tsr bed rock of Frank (1974).

Although soil thickness is only 1 ft in many places, it is believed to be variable to tens of feet, particularly in local depressions that channel the surface and shallow subsurface flow and that undergo more rapid weathering. Areas farther downslope are expected to have thicker soil. North of Philomath and southwest of Bald Hill, 2 to 4 ft of brownish-black clayey soil with $\frac{1}{4}$ - to $\frac{1}{2}$ -in. shrink/swell cracks overlies whitish, iron-stained, weathered tuff breccia or pillow lava of the Siletz River Volcanics. Gravels are generally absent, and pediments closely resemble transportation slopes. Streams may be incised 15 ft and flow on bed rock, as along Greasy Creek on the Waldport Highway.

Hazards due to mass movement appear limited, although creep and shallow slumping may occur locally near breaks in slope. Soils are organic-rich silts and montmorillonitic clays and exhibit shrink/swell characteristics. Springs may occur locally due to the shallowness of bed rock, and drainage may be poor where thick clayey soils have accumulated. Engineering properties are basically those of the underlying weathered Tsr material, which may be volcanic tuffs or breccias, basalt flows, pillow basalts, and interbedded siltstones.

Accordingly, ground-water potential is like that of the Siletz River Volcanics; both are dependent upon various zones of perched water accumulated in more permeable fracture and contact zones (Figure 18).

Ts and Tf sandstone pediments

Pediments in the sandstones of the Spencer (Ts) and Flourney (Tf) Formations have properties analogous to the corresponding bedrock units. Due to the reconnaissance nature of this project, it has not been possible to differentiate all pediments and terrace deposits in foothill areas where known bedrock outcrops occur. On-site investigation may show that some areas mapped as pediments actually contain terrace deposits of limited or widespread extent and thickness. In some cases, as has already been noted in the higher terrace deposits (Qth), the close similarity between terrace deposits ostensibly derived from underlying bedrock units and weathered bedrock units precludes definite classification without detailed on-site work.



Figure 9. Profile of pediment in Eocene Siletz River Volcanics rock (Tsr) in rock quarry near Watkins Creek off State Highway 34. Bed rock is dark-gray to grayish-black pillow basalt. Variation in soil thickness is evident in section: 6 in. light-tan soil, far left; 3 to 4 ft dark-reddish-brown soil, center.

Sedimentary Geologic Units

Early Oligocene sandstone (Tts)

Two small isolated outcrops of thick-bedded, greenish-gray to olive-gray, medium- to coarse-grained tuffaceous sandstone occur at Oliver and Winkle Buttes, within the Monroe and Greenberry 7½-minute Quadrangles. They were first described by Vokes and others (1954) and assigned by fossils to an early Oligocene age, correlative with the lower to middle Keasey Formation to the north and possibly to the Fisher and/or Eugene Formation to the south.

Well-indurated massive beds within the unit range in thickness from 3 to 12 ft. The total thickness of the unit appears to be only on the order of several hundred feet, and little is known of this unit.

Late Eocene sandstone: Spencer Formation (Ts)

Late Eocene sandstone consists of fine- to medium-grained arkosic, micaceous, and tuffaceous sandstones and siltstones, but, as mapped, it also contains dark-greenish-gray, basaltic sandstones and breccias. Its composition indicates relatively near-shore deposition with derivation in part from the underlying Flournoy (Tf) and Siletz River Volcanics (Tsr) Formations. The Spencer Formation was named by Turner in 1938 in his *Stratigraphy and Mollusca of the Eocene of Western Oregon*. Fossils indicate a late Eocene age equivalent to the Tehon stage, and the unit correlates with the upper part of the Nestucca Formation to the north.

Spencer sandstones overlie the Flournoy with generally moderate easterly dips. The contact generally appears slightly discordant but exhibits sharp angular unconformity where the underlying Flournoy has been faulted and more steeply folded. The Spencer sandstones occur in the lower Coast Range foothills and in isolated erosional remnants in the western part of the Willamette Valley northeast and southwest of Corvallis and are believed to underlie most of the terrace deposits between the foothills and the Willamette River. Easternmost outcrops occur in Spring Hill and the east-west trending ridge west of North Albany. Outcrops form a roughly arcuate belt up to 3 mi wide. No complete section is present, but at least 4,200 ft are estimated to be exposed between the base and alluvial cover.

The lower section of the Spencer sandstone is reported to be a well-indurated, dark-greenish-gray basaltic and arkosic sandstone. Generally, however, beds are massive to thick bedded, with a few thinner beds of sandstone and frequent partings of thin, shaly siltstone. Weathered exposures in roadcuts and septic-tank pits are generally pale-yellowish-orange to dark-yellowish-orange due to iron staining. Thin lenses of tuff and pyroclastic andesite breccias (palagonite tuffs and breccia) are also found in the section. A prominent andesite breccia occurs in the east-west ridge near North Albany. Carbonaceous material and bony coal are also present. Calcareous and manganese-rich concretions, light-gray and usually fossiliferous, are reported to occur; dark-brown concretions are rich in manganese and have no fossils.

Parts of the Spencer resemble the Flournoy, from which it was probably derived. In general, the flakes of biotite and muscovite are smaller (less than 1/50 in. in diameter) or missing in the Spencer. Massive beds generally weather spheroidally (Figure 10) and rapidly to a light-to-moderate-yellowish-brown soil, while thinner, fine-grained beds weather to a light tan to rusty white, very similar to parts of the Flournoy. Some sections appear to be entirely altered to clay, and pits in the Spencer near Monroe have yielded large quantities of brick and tile clay for local clay product manufacture.

Zones of dark-gray, hard, fine-grained material occur locally (Figure 11) and require jackhammering for sewers and drilling for roadcuts (Figure 22). These zones are probably slightly baked sediments near intrusions. Mapped and unmapped intrusives are associated with this unit (Figure 19). Spencer sandstone, like the Flournoy, is often deeply weathered and generally easily excavated by ripping or with backhoe.

In the Monroe 7½-minute Quadrangle, rounded knobs mapped as terrace deposits are probably resistant remnants of Spencer sandstone with shallow or no surficial terrace material. Elsewhere within the County, where dome-shaped topographic highs occur near Spencer bed rock, more Spencer sandstone may be present than has been mapped. These domes, as southeast of Philomath, are often very hard, possibly as a result of low-grade baking related to intrusive activity.



Figure 10. Spheroidal weathering in pyroclastic section of late Eocene sandstone (Ts - Spencer Formation), northwest of Albany.



Figure 11. Bulldozer uncovered these blocky and angular fragments of buff and medium-light-gray indurated siltstone from Spencer Formation (Ts) near 36th and Harrison Streets, Corvallis. Hard, dense, gray siltstone below regolith often requires jackhammering for sewer installations.

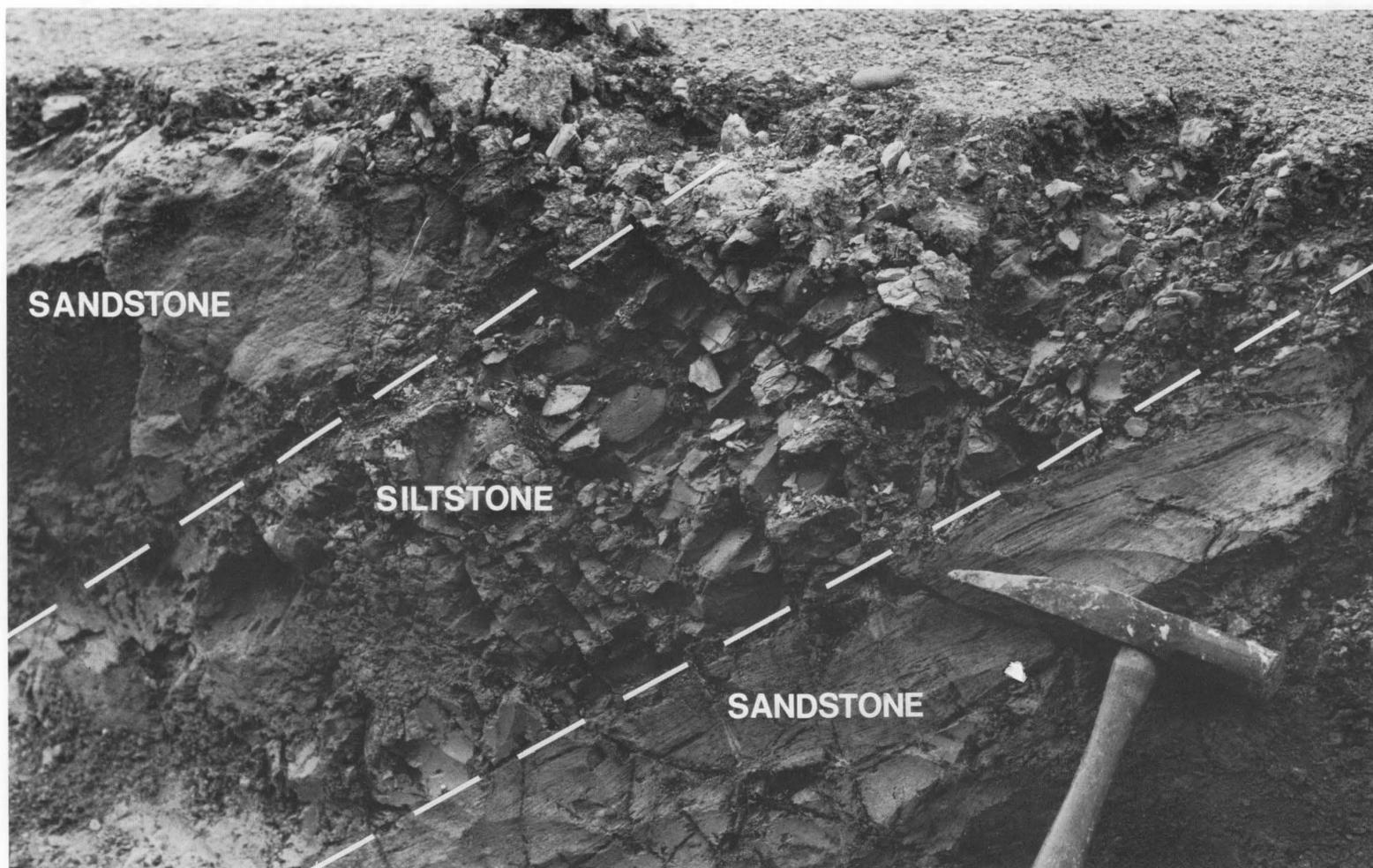


Figure 12. Rhythmically bedded sandstone and siltstone beds in middle Eocene sandstone (Tf - Flournoy Formation) on west side of Witham Hill. Sharp, distinct contacts and graded bedding (gradation in grain size from coarse below to fine above) are common in this unit. Fresh surfaces of Flournoy sandstone and siltstone from the above cut are very pale-orange or ivory in color; weathered bedrock surfaces, however, tend to be dark-yellowish-orange due to iron staining. Conchoidal (shell-like form) fracturing of siltstone beds helps to distinguish it from more massive and coarser sandstone beds above and below. Although apparent dip is only 25° in this cut, actual dip (which is important to cut-slope stability) is closer to 40° .

Ground-water yields appear similar to those of the Flournoy Formation. Some wells drilled into the Spencer unit beneath the valley plain have encountered saline water; therefore, well deepening in this formation in response to water level decline is not always possible. Such a recent project in Country Club Heights in Corvallis encountered saline water. Relatively high permeability of the unit in surrounding areas suggests moderate ground-water potential locally.

Soils generally range from 2 to 4 ft in thickness over sedimentary bed rock and are light- to dark-yellowish-brown silt loams and silty clay loams. Thin soils 1 ft thick occur on some steeper slopes, as near Mt. Union Cemetery southwest of Corvallis; soils up to 6 to 8 ft thick can also occur (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Drainage).

Middle Eocene sandstone: Flournoy Formation (Tf)

The Flournoy Formation consists of graded beds of firmly cemented gray to blue-gray sandstones and mudstones (Figure 12). Sandstones are medium grained, micaceous, arkasic (containing much feldspar) to lithic wackes (containing rock fragments) in lower sections, grading upward into carbonaceous siltstones. Minor conglomeratic sandstone beds also occur (Figure 13).

This formation in Benton County was formerly mapped as the Tye Formation (Tt), which it resembles very closely. Baldwin (1975) has revised the stratigraphy of southwestern Oregon and has now restricted the Tye Formation to southwestern Oregon south of the Siuslaw River. He named the Flournoy Formation in the Flournoy Valley southwest of Roseburg. All beds formerly mapped as Burpee (Schenck, 1927) and later as Tye (Vokes, Norbistrath, and Snavelly, 1949) are now assigned to the Flournoy Formation. Age of the Flournoy is middle Eocene, equivalent to the Ulatisian and Domengine stages.

Flournoy sandstone is probably the second most widespread rock unit in Benton County, occurring as steeply eastward- and westward-dipping beds mainly along the eastern boundary of the Siletz River Volcanics (Tsr) unit, from which it is separated by the Corvallis fault. The Flournoy Formation occurs on both sides of the Siletz River Volcanics, as north and west of Kings Valley, and it reportedly also unconformably overlies the Siletz River Volcanics. Although a complete section of the Flournoy is not exposed in Benton County, total thickness of the unit is estimated to be about 3,700 ft.

Fresh outcrops are firmly compacted and blue gray with conspicuous flakes of muscovite and biotite mica up to $\frac{1}{4}$ in. in diameter. The sandstone and siltstone are composed of angular grains of quartz, feldspar, tuff fragments, and wrinkled flakes of muscovite and biotite. Ripple marks and groove casts are common on tops of beds, which range from less than 3 to 12 ft in thickness. Sediments are generally cemented by calcite, and subrounded siltstone clasts and calcareous concretions are sometimes present.

The Flournoy sandstone weathers deeply to light tan (very pale orange) to grayish orange in color. Light-gray siltstone chips often occur (Figure 14), and minor stringers of iron-stained, banded, weathered bedrock material add color to soils and cuts. This unit is also extensively intruded by fine- to coarse-grained basaltic to gabbroic dikes and sills.

Deep and moderately deep, dark-yellowish-brown, often well-drained, silty clay loam soils develop in upland and foothill slopes underlain by the Flournoy Formation and intrusive rocks. Soils are often only 3 to 4 ft deep on ridges, as on Witham Hill, but may be as much as 6 ft or more locally. However, at West Hills Tennis Club, soil is only 0 to 1 ft thick with $\frac{1}{2}$ -in. shrink/swell cracks. Near the Corvallis fault west of Witham Hill, the soil and weathered bedrock zone (regolith) is more than 15 ft thick in places and reflects a mixture of coarse- and fine-grained sediments and possible fault gouge. Generally, near Corvallis and within the Willamette Valley, the Flournoy sandstone is deeply weathered and easily excavated by backhoe (see GEOLOGIC HAZARDS - Mass Movement).

The Flournoy Formation contains fine-, medium-, and coarse-grained marine sandstones and shales and has poor permeability, yielding only small quantities of ground water to wells. In uplands and foothills, small to moderate yields of good-quality water adequate for domestic use occur in perched zones above the regional water table.



Figure 13. Conglomeratic bed near top of Flournoy (Tf) sandstone section on south-east side of Logsdan Ridge, near contact with overlying Spencer (Ts) sandstone. These coarse gravels and cobbles are not deeply weathered and consist of well-rounded material of basaltic and intrusive rock composition. Other conglomeratic sandstone beds occur within Flournoy on west flank of Logsdan Ridge and locally on west side of Witham Hill.



Figure 14. Mosaic-like siltstone chips in raveling cut slope in Flournoy (Tf) sandstone near Witham Hill Drive.

Kings Valley siltstone (Tsrk)

The Kings Valley siltstone generally consists of well-bedded, dark-brownish-gray, tuffaceous siltstone and waterlaid tuff, which may interfinger with volcanic rocks, particularly along the eastern and southern edges of Kings Valley. The shaly, soft, thin-bedded siltstone is nonresistant and weathers rapidly to small, crumbly, medium-gray siltstone chips (Figure 15).

This unit is equivalent to the Kings Valley siltstone member of the Siletz River Volcanics (Tsrk), as mapped by Vokes and others (1954). It was named after extensive outcrops which occur in Kings Valley, where it is reportedly about 3,000 ft thick.

The unit forms a belt 2 to 3 mi wide and 6 to 8 mi long in the northwest corner of the Corvallis 15-minute Quadrangle, where it separates the Siletz River Volcanics (Tsr) from Flournoy (Tf) sandstone to the west. It occurs in a zone of significant faulting and lineaments (see GEOLOGIC UNITS - Bedrock Structure).

The lower part, near Wren, is a dark-gray, shaly, tuffaceous siltstone, which weathers spheroidally to talus of grayish-orange to light-brown chips. Interbedded pillow lavas, basalt flows, tuff, and minor flow breccia also are more common in this area. The upper part, near Hoskins, consists of thin-bedded, fine-grained, tuffaceous siltstone interbedded with occasional light-yellow to grayish-white tuff, which weathers to light-brown silty clay and silty clay loam soils. Resistant calcareous lenses of medium-grained basaltic sandstones 1 to 4 in. thick, are locally interstratified with clayey siltstones. Clay minerals are predominantly montmorillonite with smaller amounts of mixed-layer montmorillonite-mica, and chlorite (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Regolith). Zeolites and calcite often occur within small fractures and veins within the siltstone.

The Kings Valley siltstone forms the major aquifer of Kings Valley, with yields ranging from 0.5 to 40 gpm (average 12 gpm) that are adequate for domestic and stock uses. Ground water occurs under confined conditions at depths greater than 100 ft in sandier or more highly fractured, thin-bedded siltstone; it is generally semiconfined at shallower depths. Some unconfined ground water occurs locally in stream alluvium above the siltstone. Because minimum well casing requirements prevent development of wells in alluvium in most places in Kings Valley, yields are limited to the southwest part of Kings Valley, where deposits are thicker. At depths greater than 150 to 200 ft, yields are not significantly increased, and chemical quality is degraded. Geochemical data suggest that confined ground water is undergoing natural softening in zeolites and clay minerals. Geology and ground-water conditions of the Kings Valley area are described in greater detail in Geology and Ground Water Resources of the Kings Valley Area, Central Oregon Coast Range, Oregon (Penoyer, 1975).

Volcanic Geologic Units**Eocene volcanic rock: Siletz River Volcanics (Tsr)**

The Siletz River Volcanics is the oldest rock unit in the central Coast Range and consists of vesicular to amygdaloidal and zeolitic pillow lava, basalt flows, flow breccias, coarse pyroclastics, and interbeds of thin tuffaceous siltstone. These rocks are of lower and possibly middle Eocene age, equivalent to the Capay Stage of California, and correlate locally with the Tillamook Volcanic Series (north Coast Range) and the volcanic member of the Umpqua Formation (south Coast Range). They constitute part of a eugeo-synclinal sequence which erupted into a north-trending trough that occupied most of western Oregon and western Washington during early and middle Eocene time (Snively and others, 1968) (Figure 16).

The Siletz River Volcanics is the predominant geologic unit in north and western Benton County and occurs at the higher elevations west and north of Corvallis, extending southwest in a broad belt about 6 mi wide. Estimates of the minimum thickness in Benton County range from 3,000 to 5,000 ft while elsewhere, near former centers of volcanism, the Siletz pile may be as much as 20,000 ft thick.

Fresh surfaces are dark, greenish-gray to black with a general black-and-white mottled appearance, caused by a high percentage of secondary calcite and zeolite minerals (Figure 17). In general, weathered zones are deeper in soft sediments and breccia (often 20 to 50 ft), but 4- to 10-ft zones are more common in pillow lavas and basalt flows. Infiltration also influences the weathering zone, which is generally a



Figure 15a. Exposure of shaly, soft, thin-bedded Kings Valley siltstone (Tsrk) in roadcut along Highway 223 north of Wren. Loose talus of siltstone and mudstone chips often forms at base of cut slope.



Figure 15b. Close-up, showing bedding distinctness, mudstone parting, and siltstone and mudstone chips.

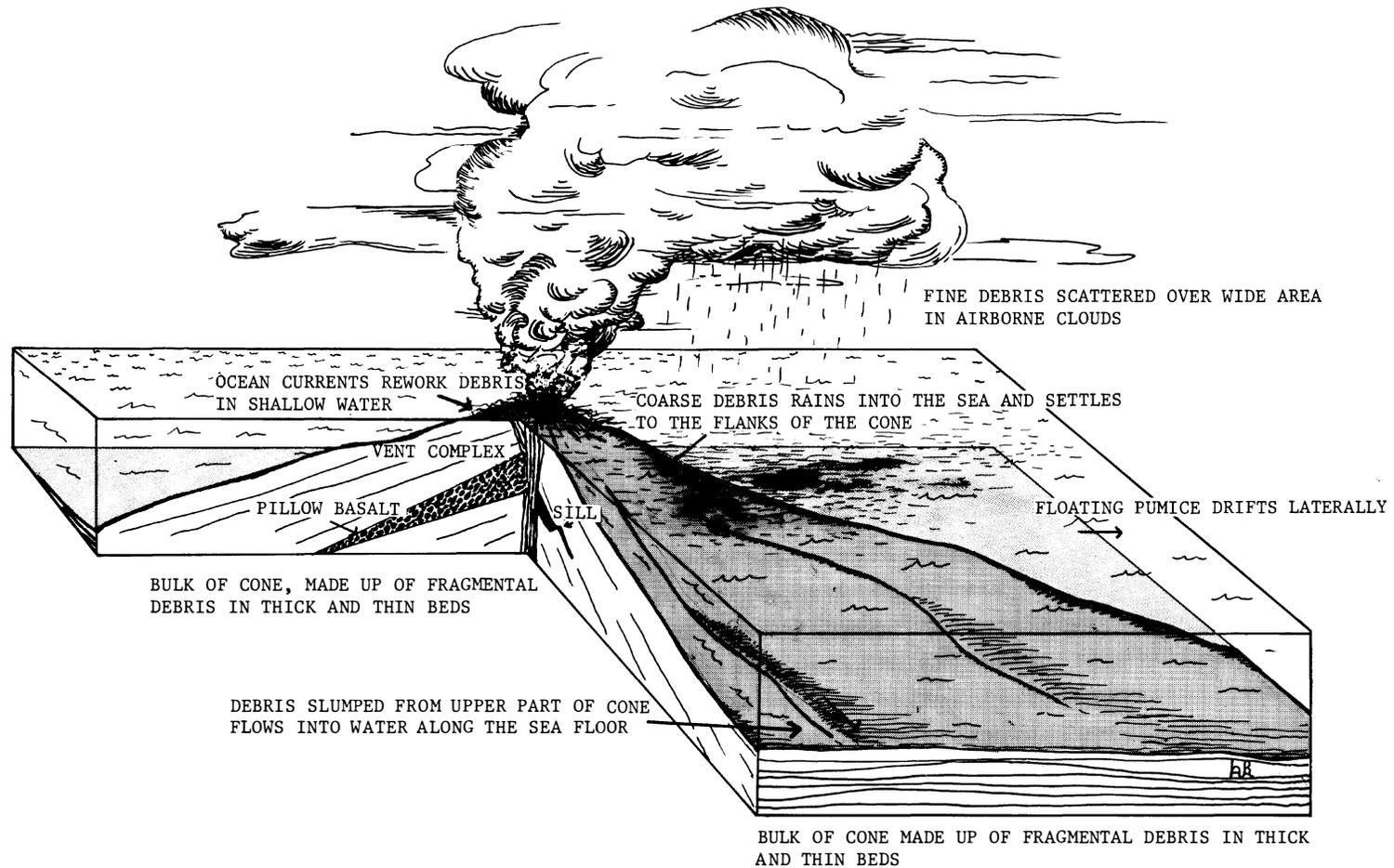


Figure 16. Schematic representation of geologic processes attendant to deposition of Eocene volcanic rock (Tsr - Siletz River Volcanics), illustrating spatial relationships of pillow basalts, fragmental sedimentary debris and breccia, and intrusive dikes and sills. Vast differences in engineering properties of these materials make development in sloping terrain much more difficult. Larger scale mapping of such individual rock units as pillow basalts, basalt flows, breccias, sediments, and sills may be required for some engineering or land use purposes. (After U.S. Geological Survey, 1977)



Figure 17. Calcite and zeolite minerals (white mottles) in black pillow basalt and breccia of Eocene volcanic rock (Tsr - Siletz River Volcanics). This rounded pillow has glassy outer surface indicative of rapid quenching in seawater. Small cavities formed by expansion of gas or steam in cooling basalts are called vesicles and when filled with secondary minerals such as zeolites are called amygdules.

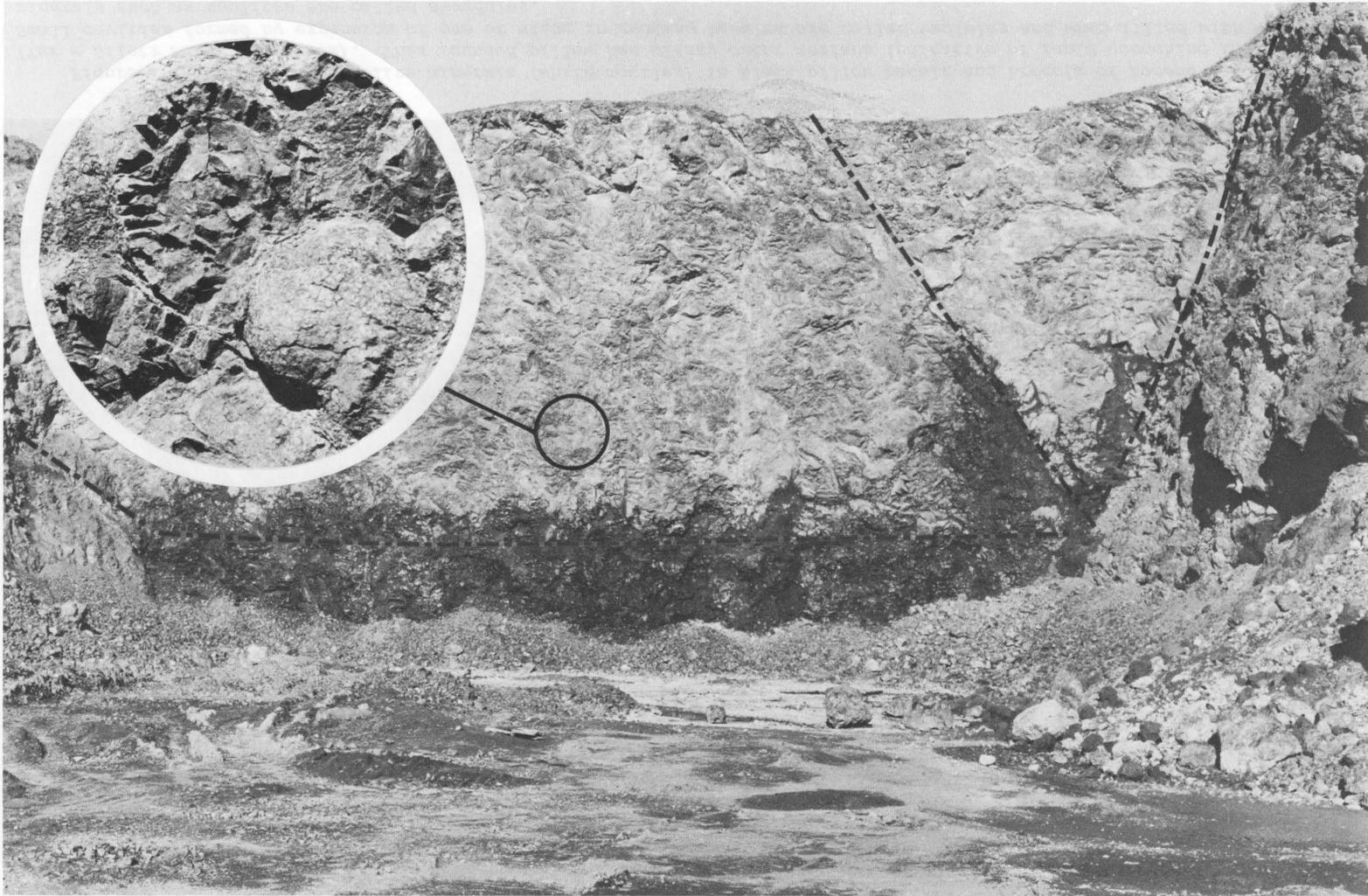


Figure 18. Section in quarry site 84 (Schlicker and others, 1978) in pillow basalts of Siletz River Volcanics (Tsr) near Watkins Creek and Greasy Creek. Darker color near base is due to ground-water infiltration and seepage along fractures or joints which extend through rock to ground surface. Pillows in this quarry are generally 2 to 3 ft in diameter with glassy (clayey) outer margins and radial columnar jointing (inset) but occasionally range up to 12 ft or more. Dashed lines indicate joints.

light-rusty-brown color and dramatically exposed in quarries and roadcuts (Figure 9). Tuffaceous siltstones and pyroclastics are dark, greenish-gray and thin-bedded, somewhat like shale. Pillows and breccia fragments are commonly fine grained, vesicular to amygdaloidal; alteration contemporaneous with marine deposition is prominent, with chlorite, clays, calcite, and zeolites being the main secondary minerals formed. Conspicuous crystals (phenocrysts) of feldspar and augite often occur, with magnetite usually present in the groundmass. Radiating columnar jointing is prominent in individual pillows (Figure 18), and the thinner, lenslike, fine crystalline flows and intrusive dikes and sills quite often have well-developed columnar jointing. Individual pillows average about 3 ft in diameter, and the chilled margins, originally basaltic glass, are usually altered to greenish-black clay minerals. In breccias and tuffs, original basaltic glass has been altered to greenish-brown, fibrous clay minerals, including montmorillonite.

Massive pillow lavas and breccias are relatively resistant to erosion and form topographic highs, with shallow or no soil cover, whereas interbedded siltstones and tuffs are easily eroded and weather spheroidally, leaving shells coated with iron and manganese oxides. The volcanics and associated sediments of this unit have been folded into broad anticlines and are cut by northeast- and northwest-trending faults and fracture zones (see GEOLOGIC UNITS - Bedrock Structure). This unit also contains unmapped intrusive rocks.

Soils are generally dark-brown to very dark-brown, silty clay loams to silty clays of generally 1 to 4 ft in thickness, often containing igneous rock fragments. North of Philomath on Marilyn Drive, 1 to 2 ft of reddish-brown, clayey soil overlies deeply weathered, light-brown, iron-stained basalt. Natural drainage is often good but variable; it is more restricted locally on pediments where springs occur or thick clayey soil accumulates. Shrink/swell characteristics are common, forming $\frac{1}{4}$ - to $\frac{3}{4}$ -in. surface cracks, and may cause problems in shallow foundations if not removed before construction. Steeper slopes, such as those that occur at Vineyard Mountain, show signs of past and recent landslide activity; to minimize potential hazards site-specific investigation by qualified engineering geologists and soils engineers is required prior to development. This problem is discussed by Schroeder and Swanston (1975) (see GEOLOGIC HAZARDS - Mass Movement).

The Siletz River Volcanics unit is extensively quarried for crushed rock used for building and road construction. Locally, firm bed rock near the surface hinders construction of roads and underground utilities.

Ground water normally occurs in perched zones above nearby stream channels and is generally adequate for domestic use owing to moderately good infiltration through weathered bed rock and fractures (Figure 18). During droughts, perched zones may drop drastically in water level or become depleted. Well deepening may not always solve these low water problems, as a number of wells may be tapping the same limited perched zone. Where concentrated developments are contemplated in foothills well above the regional water table, the possibility of using fewer wells to tap the area system should be considered in addition to the usual practice of supply by individual wells. Such an area system would decrease the possibility of pollution from septic-tank effluents as infiltration patterns are altered by home, road, and septic-tank construction.

Intrusive Geologic Units

Post-Eocene intrusive rocks (Ti)

Intrusive rocks are bodies of once-fluid igneous rocks that penetrated other rocks but solidified before reaching the surface. Many intrusive rocks, consisting of fine- to medium-grained basalt to gabbro dikes, sills, and irregular intrusive bodies, occur in Benton County. Dikes are tabular bodies that cut across the structure of adjacent rocks or cut massive rocks (Figure 19); sills are bodies of approximately uniform thickness, relatively thin compared to lateral extent, emplaced parallel to bedding of the intruded rock. Age of these intrusives is not established, but because they intrude both the Flournoy and Spencer Formations, most are believed to have been emplaced during late Eocene to early Oligocene.

In the western part of the Monroe 15-minute Quadrangle, intrusives usually are sheetlike masses covering large areas. Larger sills cover up to a square mile and are locally more than 800 ft thick. They are present in the headwaters of Bull Run Creek, Flat Mountain, the area near Dawson, and west of Glenbrook.

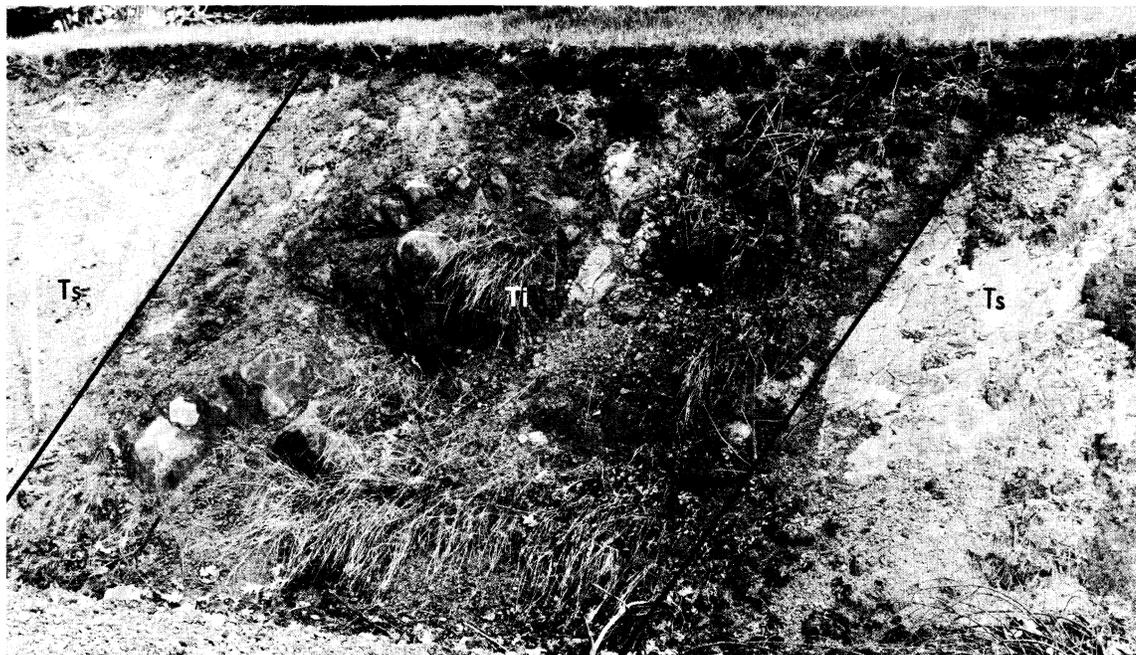


Figure 19. Intrusive dike, 12 ft thick, cutting Spencer (Ts) siltstone and mudstone along Peterson Road south of Llewellyn Road. Darker color of bouldery looking intrusive rock is due to manganese staining. Abrupt change from bed rock to shallow soil is result of grading which has completely removed regolith.

Marys Peak is an erosional remnant of a larger sill. Intrusives generally fracture, deform, or alter (metamorphose) the surrounding host rock. Contacts of intrusives with other rock units are often locations of mass movement in steeper terrain.

Intrusive rocks are dark-gray, fine- to medium-grained basalt to gabbro, with porphyritic and diabasic textures common. The term "gabbro" generally refers to coarse-grained, dark igneous rocks. Edges of intrusive bodies have a chilled, fine-grained texture, while interiors have from medium- to coarse-grained granophyric texture ranging from gabbro to diorite in composition. Feldspars reportedly average andesine in composition. Crosscutting veins of quartz-feldspar (aplite) micropegmatite occur rarely. Thicker sills are essentially horizontal, while others appear to occupy contact zones between Flournoy and Spencer sandstones. Unmapped intrusives may occur in all rock units and are generally associated with high topographic relief and elongate ridges.

Quarries for road rock are often developed in these intrusive rocks, which are among the hardest and most resistant of rock types within the County. Some zeolites are present in the fractures and interstices of coarser gabbros.

Intrusive rocks present problems in excavation for underground utilities and sewers. They usually will require blasting. They generally provide little or no water for wells, although locally they may be adequate for domestic use. In addition, ground water may be perched above some of the near-horizontal sills.

Bedrock Structure

General

Bedrock structure refers to the general disposition and spatial relationships of the bedrock units.

A knowledge of structure is valuable in extrapolating geologic information. Within Benton County, a preliminary review of the structure indicates that

- (1) Structural data in volcanic rocks is often scarce, and uplift is believed to have been complicated by numerous superimposed folds and faults.
- (2) More structure is present in the Coast Range than has been mapped, and faulting appears more abundant than large-scale folding; strike-slip faults may be more common than previously recognized.
- (3) Lineaments may help locate additional faults and significant structures.
- (4) Major structural trends are generally northeastward across the Monroe and Corvallis 15-minute Quadrangles.
- (5) No active faulting is known to occur at the surface because, according to presently available information, no Quaternary units are cut by faults.

Each of these conclusions is based on reconnaissance information, subject to refinement with more detailed study.

Benton County is primarily an association of Eocene rocks, which are believed to have once formed the continental margin of western Oregon and Washington. Bouguer gravity and aeromagnetic surveys show a steep, east-sloping gravity gradient and a north-trending elongate belt of low-amplitude magnetic anomalies, suggesting possible major faulting along the west edge of the Willamette Valley graben and greater depth of burial of volcanic rock (Tsr) off the east flank of the Coast Range uplift. Furthermore, lack of major gravity expression for Tsr west of Corvallis, similar to other large outcrops of volcanic rocks in the Coast Range, may indicate an eastward thinning of flows and an increase in thickness of sedimentary interbeds (Bromery and Snavely, 1964).

Local structure

The geologic maps accompanying this text show major faults and linears. Major features include the Corvallis and Kings Valley faults. Linear features observed on low- and high-altitude photographs and satellite imagery are called linears or lineaments. They may be related to faults or significant geologic structure as discussed below. The principal uplift is a broad anticlinal fold trending northeast across the Corvallis 15-minute Quadrangle (Vokes, 1954). Eocene sedimentary rocks that crop out in the Monroe 15-minute Quadrangle have an eastward homoclinal dip from part of the east limb of the Coast Range geanticline.

Corvallis fault zone

The Corvallis fault is the major structural feature in Benton County, separating older and upthrown Siletz River Volcanics (Tsr) from younger and downthrown middle and later Eocene sandstone (Tf and Ts). Vokes and others (1954) described it as a fault zone consisting of numerous subparallel high-angle shear planes of reverse (?) movement. The fault zone is distinguished by (1) juxtaposed Siletz River Volcanics (Tsr) and Flournoy sandstone (Tf) beds, (2) steeply dipping beds (65° to 85° southwest of Logsdan Ridge) of Flournoy sandstone (Tf) toward Siletz River Volcanics (Tsr), and (3) opposing dips within volcanic rocks. Steeply dipping beds in the Flournoy sandstone (65° to 85° northwest) are taken as an indication of numerous steep-limbed drag folds present along the downthrown side of the fault.

Sandstone outcrops at the bottom and top of the new straight road before the Marys Peak turnoff indicate that the Corvallis fault is a fault zone containing sizable blocks of sandstone (Lawrence, personal communication, 1977). New construction northwest of Witham Hill shows similar intermixed assemblages of basaltic-type rock and deeply weathered sediments of Flournoy sandstone (Tf).

The Corvallis fault zone has a mapped length of approximately 34 mi. In 1955, Baldwin traced its extension into the Alsea Quadrangle, using steeply dipping (60° to 70°) Flournoy (Tf) beds toward the fault zone and observed that it apparently died out within the Flournoy sandstone south of the Alsea River. A subsequent study (Faroqui, 1973) confirmed this. Vokes and others (1954) believe that displacement of several thousand feet occurred during early or mid-Eocene time (54 to 47 million years ago). This is indicated by the sharp angular unconformity (difference in strike and dip of beds indicating an abrupt change in deposition) between Flournoy (Tf) and Spencer (Ts) sandstone adjacent to the fault zone.

Some post-Eocene movement along the fault is probable, however, since in places it appears to cut beds of Spencer (Ts) sandstone.

Since no Quaternary units are displaced, no field evidence suggests that surface faults are still active. More definitive studies are needed, and future interpretations may alter our present perspective of active faulting within the Willamette Valley and Coast Range (see GEOLOGIC HAZARDS - Earthquakes).

Kings Valley fault

Kings Valley lies on the southeast limb of a northeast-plunging syncline found in the Dallas and Valsetz Quadrangles (Vokes, 1954; Baldwin, 1964; Penoyer, 1975). The Kings Valley fault, believed to be a normal fault, cuts the Kings Valley siltstone (Tsrk) of the valley floor. To the south, its trace forms the contact between Tsrk and basalt flows of Siletz River Volcanics (Tsr) near Gellatly Creek and northwest of Pioneer Butte. The amount of displacement is unknown but is thought to be considerable. Bromery and Snively (1964), noting rapid gradient changes of magnetic anomalies across the fault, suggested that the volcanic rocks to its west were downdropped 1,000 to 2,000 ft. South of Kings Valley, the Kings Valley fault is offset by a smaller cross fault near Plunkett Creek; to the north, a northeast branch of the Kings Valley fault downdrops Flournoy (Tf) sandstone against Siletz River Volcanics (Tsr).

Glenbrook fault

The Glenbrook fault is a northeastward continuation of a normal (?) fault mapped in the northwest part of the Elmira Quadrangle. It is considered another major fault. The amount of displacement is unknown, but it is believed to be less than that on the Corvallis fault.

Linears

High-altitude photography recently made available by the Earth Resources Technology Satellite (ERTS 1972) and Land Satellite (LANDSAT 1975) has given geologists an additional tool to use in geologic interpretation. The synoptic views provide an excellent opportunity for identifying significant lineations (linears) of possible fault origin or of structural significance on the earth's surface. On-site field checking is required to determine whether the linears are actual faults, fractures, or dips, or if they instead represent man-made objects, vegetation patterns, optical illusions, or spurious alignments of diverse ground features.

As part of the Benton County geologic study, Robert Lawrence, Oregon State University, conducted interpretive structural studies based on LANDSAT, SLAR (Side-Looking Airborne Radar), and U-2 high-flight photography. He noted major linears that were long, associated with aeromagnetic anomalies, or visible on photographs and on satellite and SLAR imagery, which he believed to be faults or other significant structures. In addition, he delineated minor linears, which are short features not always visible on all imagery.

Major linears on the Corvallis 15-minute Quadrangle include (1) northwest linear through Hoskins and Alexander School, (2) north-south linear through Kings Valley, (3) linear from La Bare Creek through Wren, and (4) linear from Harris through Noon, paralleling Marys River to Evergreen Creek. Major linears on the Monroe 15-minute Quadrangle are (1) linear paralleling South Fork Alsea River, (2) linear trending southwest from the fault west of Monroe, (3) northwest linear paralleling Reese Creek northwest of Bell-fountain, and (4) easterly trending linear crossing Corvallis fault and Alsea Highway in northwest part of map (see the geologic maps).

Linears, as mapped by Lawrence, have been placed on the geologic maps as an aid to planning and hazard evaluation of specific sites. Mapped faults and dikes for which linears can be seen are noted on the geologic maps. Conversely, linears may indicate the presence of previously unmapped faults, fractures, or dikes. Aeromagnetic anomalies noted by Bromery and Snively (1964) are associated with the major north-south linear through Wren and Kings Valley and the major northwest linear through the town of Hoskins and through Alexander School. Faults, fractures, and dikes, which can have significance in controlling ground-water regimes, can be anticipated and guide future ground-water exploration. Road locations or deep excavations in areas where linears represent unmapped faults may encounter heavy clay zones and unstable material.

The geologic map shows that the Corvallis fault deflects from observed linears near Greasy Creek and Philomath. Similarly, the Kings Valley fault is marked by a visible linear everywhere except in the section from Marys River to Woods Creek. Lawrence notes displacement along the Corvallis fault zone of about 5,000 ft \pm 2,000 ft near Marys Peak and Lewisburg, but only several hundreds of feet south of Philomath, as well as an anomalous outcrop pattern that separates Siletz River Volcanics (Tsr) and Flournoy sandstone (Tf) to the north and south but not at Greasy Creek. He believes these variations suggest additional structural complications. These anomalous areas on both the Corvallis and Kings Valley faults are associated with major linears trending up Rock Creek and also paralleling Marys River southwest of Philomath. Additional detailed geologic investigations beyond the scope of this study are needed to resolve the significance of these anomalies.

Linears associated with Price and Woods Creek and the eastern escarpment of Kings Valley correspond to faults recognized in the field by Balster and Parsons (1965, 1966) and Penoyer and Niem (1975). Similarly, during realignment of the Corvallis–Newport Highway west of Wren through Gellatly Creek, heavy very deep weathered zones indicating a probable fault trace were encountered.

Some dike segments within Benton County are associated with linears extending from them. These linears may mark unmapped portions of dikes or fractures along which dikes were intruded. Similarly, minor linears may locate faults, master joints, or joint sets. Since linears are subjective in interpretation and no two people will see all the same linears, their significance must always be verified by on-site evidence.

Lawrence also noted textural differences in SLAR imagery related to rock types. The Siletz River Volcanics (Tsr) unit is marked by a rectilinear pattern of short northwest and slightly longer northeast features. Most of these are not extensive enough to show on the map but are probably related to the joint pattern of the rock unit (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS – Joint development).

Joints measured in the Marys Peak sill have the same pattern, and the angular pattern of entrenched meanders of the Marys River is possibly controlled by such joints. Eocene sandstone areas (Tf, Ts) are marked mostly by more widely spaced longer features which seem more likely to be faults. Two northeast-trending linears southeast of the Corvallis fault in the northwest corner of the Monroe 15-minute Quadrangle probably reflect steeply dipping sandstone near the fault.

Table 3. Engineering properties of geologic units, eastern Benton County, Oregon

General rating	Physical properties								Regolith				Drainage			Local hazards															
	Hardness	Joint development	Bedding distinctness	Foundation capacity	Excavation difficulty	Cut slope stability	Slope intensity	Infiltration rates	Landfill potential	Septic tank capacity of soils	Thickness on steep slopes (ft)	Thickness on gentle slopes **	Clay content	Silt content	Expansion-contraction	Thickness of saprolite (ft)	Overland flow	Shallow subsurface flow	Deep subsurface flow	Deep bedrock slides	Earthflow and slump topography	Steep slope mass movement	Potential future mass movement	Flood prone	Slope erosion potential	Historic channel change	Streambank erosion	Torrential flood terrain	High ground-water hazard		
SURFICIAL UNITS *																															
	Qral	○	-	●	○	-	○	○	○		-	●	○	○			●	-	●		-	-	-	○	●	○	●	○	●	-	●
	Qtl	○	-	●	○	○	○	○	○		-	●	●	●			●	●	●		-	-	-	○	●	○	●	○	●	-	●
	Qtm	○	-	●	○	○	○	○	○		-	●	●	●	○		○	●	●		-	-	-	○	○	○	○	○	○	-	●
	Qth	○	-	●	○	○	○	○	○		-	○	●	●	○		○	●	●		-	-	-	○	○	○	○	○	○	-	○
SEDIMENTARY ROCK																															
	Tts	○	○	○	○	○	○	○	○		1-2	4	○	○	○		○	○	○		○	○	○	○	○	○	-	-	-	○	
	Ts (Spencer)	○	○	○	○	○	○	○	○		1-2	4	○	○	○	4-6	●	○	○		○	○	○	○	○	○	-	-	-	○	
	Ts - p	○	○	○	○	○	○	○	○		-	4	○	○	○	4-6	●	○	○		-	-	-	○	○	-	-	-	○	●	
	Tf (Flournoy)	○	○	○	○	○	○	○	○		2	4	○	○	○	4-20	●	○	○		○	○	○	○	-	○	-	-	-	○	
	Tf - p	○	○	○	○	○	○	○	○		-	4	○	○	○	4-6	●	○	○		-	-	-	○	-	-	-	-	-	○	●
	Tsrk	○	○	○	○	○	○	○	○		-	4	○	○	○	4-6	●	○	○		○	○	○	○	-	○	-	-	-	○	
VOLCANIC ROCK (Tsr)																															
	Pillow lavas	●	○	○	○	○	○	○	○		1	5	○	○	○	1-4	○	○	○		○	○	○	○	-	○	-	○	-	○	
	Basalt flows	●	○	○	○	○	○	○	○		1	5	○	○	○	1-4	○	○	○		○	○	○	○	-	○	-	○	-	○	
	Breccias	○	○	○	○	○	○	○	○		4-10	○	○	○	○	4-10	○	○	○		○	○	○	○	-	○	-	○	-	○	
	Tuffs and sediments	○	○	○	○	○	○	○	○		4-10	○	○	○	○	4-10	○	○	○		○	○	○	○	-	○	-	○	-	○	
	Tsr - p	○	○	○	○	○	-	○	○		-	2	○	○	○	2-4	●	○	○		-	○	○	○	○	-	○	-	○	○	●
INTRUSIVE ROCK																															
	Ti	●	○	-	○	○	○	○	○		1	4	○	○	○	4-10	●	○	○		○	○	○	○	-	○	-	-	-	-	-

* Surficial units may exhibit variable properties. Chart values indicate general case.

** Numbers indicate feet

ENGINEERING PROPERTIES OF GEOLOGIC UNITS

General

Table 3 relates six rock units and four surficial units in the study area to ten physical properties, five regolith properties, three drainage properties, and ten hazards. Categories of rock units are defined primarily on the basis of rock type. Consequently, each category is characterized by a fairly distinct association of engineering properties. Since the surficial units exhibit similar stratigraphies, their engineering properties are treated together (Table 9). Table 3 relates units shown on the geologic maps to specific parts of the text and therefore is a guide in the efficient use of this bulletin.

Physical Properties

Hardness

Hardness refers to a rock's resistance to crushing, abrasion, or deformation under stress. It is a basic factor in quarry rock potential, foundation strength for very heavy structures, and excavation difficulty of a rock unit. Hardness is determined by the composition, cementation, and weathering of a rock and the manner in which constituent grains are geometrically arranged or interlocked.

Intrusive and volcanic rocks of the study area are the hardest rocks, although there is a wide variation on the basis of specific rock type. Because of their higher percentage of glass, pillow basalts (Figure 18) abrade more easily than basalt flow rock. Intrusive rocks are the hardest. Most quarries are located within these units. Sedimentary rocks vary from moderately hard to soft (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Excavation difficulty).

Physical and chemical weathering reduce a rock's hardness and are concentrated along zones of weakness including joints, faults, fractures, and bedding planes (Figures 12 and 15). On flat terrain, weathered material and soil may be removed readily by slope erosion from rocks with low infiltration rates. Consequently, areas of low slope may not be areas of deep weathering and reduced bedrock hardness. Thus, hard unweathered basalts occur at or near the surface of Tsr pediments (Figure 9), but 20- to 50-ft-deep weathered zones may be found in quarry pits and road cuts in steep terrain, where faults, joints, or easily weathered rock (generally volcanic sediments) are present.

Joint development

Joints are surfaces of active or potential fracture or parting in rocks. Joints differ from faults in that they are not surfaces of actual displacement; they differ from bedding planes in that they are not primarily the result of deposition and are not made up of contrasting rock types. From an engineering standpoint, joints are surfaces of weakness within a rock which influence strength, cut-slope stability, excavation difficulty, infiltration rates, weathering, and landslide potential (Figure 20).

Joints are formed by cooling stresses in volcanic and intrusive rocks; pressure stresses in sedimentary rocks due to deformation, folding, or intrusion by igneous rocks (Figure 19); and the effects of rock decay in weathering.

Igneous intrusive rocks are characterized by blocky jointing on all scales. Their potential as quarry rock is generally good. Siletz River Volcanics (Tsr) pillow basalts exhibit pronounced radial, columnar jointing. Jointing patterns of other Tsr volcanic rocks vary from moderately spaced blocky joints in fresh basalt to irregularly spaced joints in breccias and agglomerates. Close jointing on a scale of inches often gives some basalts a gravelly and cobbly appearance in cut slopes. Crushing characteristics of breccias and agglomerates are considerably lower in quality than those of basalt flows. Bedded sedimentary rocks such as Flournoy (Tf) and Spencer (Ts) sandstones generally have jointing perpendicular to the bedding planes.

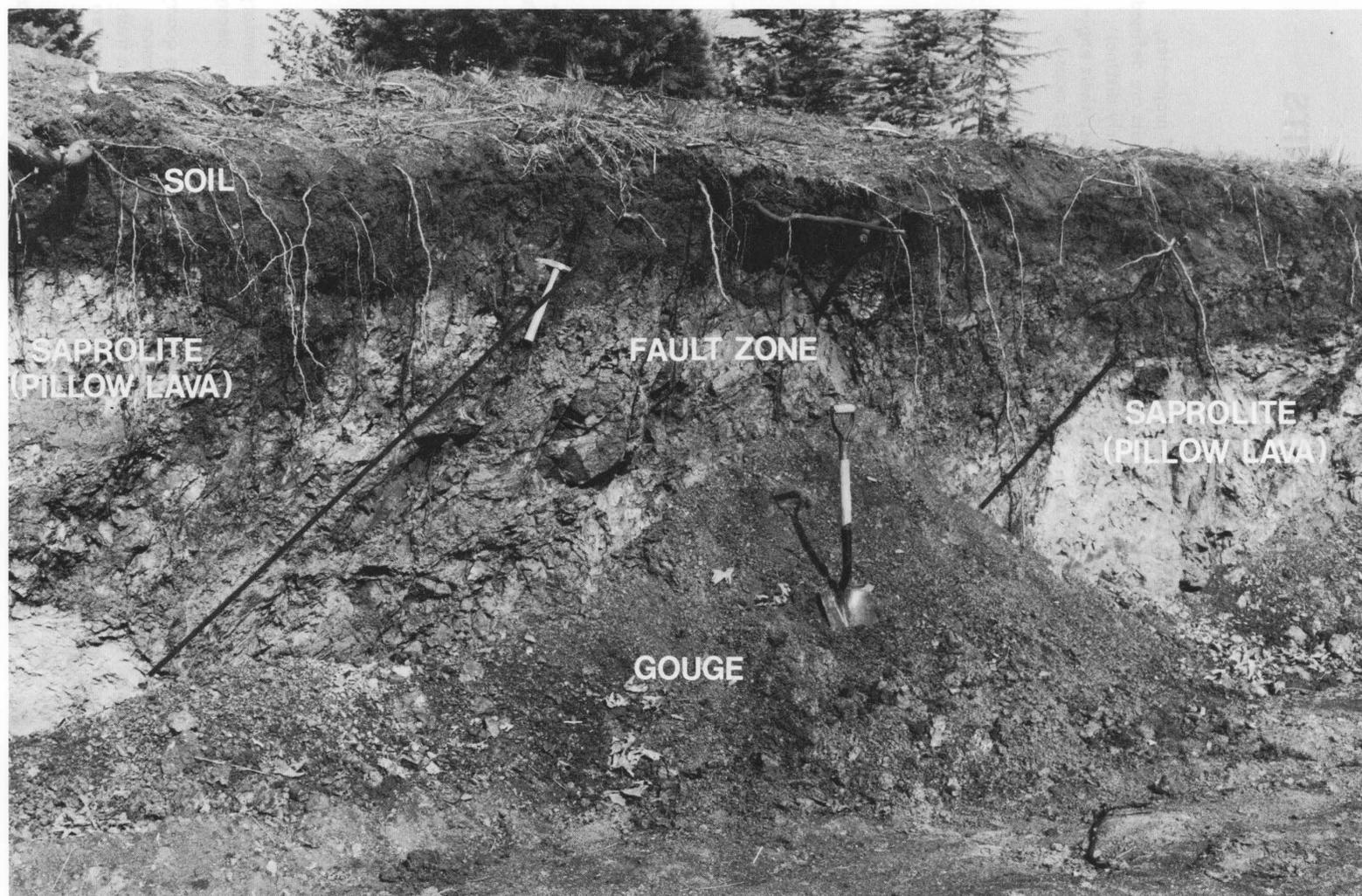


Figure 20. Six-ft-wide fault within regolith of Eocene volcanic rock (Tsr) in Corvallis fault zone, exposed during construction northwest of Hoover School, Corvallis. Dark-reddish-yellow to rusty-brown color of fault gouge that has fallen from cut slope and sheared, chloritized boundaries distinguish fault from weathered pale-yellow and gray pillow basalts on either side. Much material below soil is saprolite.

Limited bedrock exposures and the generally deep, soft, weathered surfaces do not permit a detailed description of jointing. Jointing is inferred to be widely spaced, based on low infiltration rates and generally low ground-water yields. Quarry exposures of resistant Flournoy sandstone in Kings Valley exhibit two sets of nearly vertical joints occurring at intervals ranging from inches up to 5 ft (Penoyer, 1975). Surficial geologic units are not consolidated (cemented enough to form solid rock) and are therefore not jointed.

Jointing is a critical property of rock in terms of several hazards and engineering practices. For example, joints perpendicular to bedding planes are another weak link in potential bedding-plane slide geometry. Although general observations are made here, specific determinations must be made on a site-by-site basis. For example, jointing properties of a specific quarry rock may be determined by blasting tests and core sampling, as well as by routine field examination.

Bedding distinctness

Bedding refers to the arrangement of sedimentary rocks in beds or layers. Distinctness refers to the degree of difference in rock type and resistance to erosion between adjacent bedded layers. Where bedding distinctness is great, various layers of rock generally have significantly different engineering properties.

The Flournoy sandstone (Tf) is described as rhythmically bedded because it consists of a repeated pattern of coarse and fine sandstone and siltstone, each bed grading from coarser sandstone at the base to finer siltstone at the top (Figure 12). The finer siltstone beds are softer than the sandstone layers, although both are often quite soft in weathered zones near the surfaces.

In the more massive Spencer sandstone (Ts), bedding is less distinct because of subtle variations in the environment of deposition. Consequently, Spencer sandstone bedding planes are more difficult to identify from small weathered exposures in cuts.

Within the Siletz River Volcanics (Tsr), bedding distinctness is distinguished locally by layers of tuffaceous siltstone or basaltic sandstone, generally several to tens of feet in thickness. The Kings Valley siltstone is generally a thinly bedded siltstone (Figure 15) but does contain thicker basaltic sandstone layers, along with some thin, white, tuff laminae. Here bedding distinctness is primarily a function of parting or jointing between adjacent siltstone interbeds rather than major differences in grain size.

Where distinct interbeds are tilted steeply toward a cut or steep slope, the surface between any two beds is often a plane of weakness. The contact between beds with vastly different permeabilities may also be a locus of ground-water accumulation and flow. Thus, steeply dipping distinct interbeds often define surfaces of slope failure and are a major factor in low cut-slope stability.

Excavation difficulty

The difficulty with which rock material is excavated is determined by rock hardness, jointing, bedding, and weathering. Rock of considerable hardness can be excavated with relative ease if planes of weakness effectively separate it into small manageable pieces. Excavation difficulty is significant in planning for all underground facilities, including basements, utility lines, sewer lines, and road construction.

Volcanic and intrusive rocks of the study area generally require blasting for large excavations and quarry operations, except in areas of deep weathering. These are determined by on-site investigation. Generally, overburden over volcanic and intrusive rocks on ridge crests is thin, but deeply weathered zones in steep mountainous terrain have been observed. Siletz River Volcanics (Tsr) pillow basalts exhibit pronounced radial columnar jointing, which aids excavation; they are generally easily crushed into 2- to 4-in. blocks. A small percentage of very hard pillows in near-surface excavations are not easily crushed in common equipment and are often piled together at the edge of a site (Figure 17); in some cases they are stockpiled for use as riprap. Heavy equipment may be adequate for minor excavations and for excavations in the weathered zone.

Since sedimentary rocks of the Spencer (Ts) and Flournoy (Tf) Formations vary from moderately hard to soft, excavation is most often accomplished using a backhoe or light-duty ripping bar and is facilitated by fairly deep zones of weathering. Self-loading scrapers can often be used for road construction (Figure 21).



Figure 21. Self-loading scraper easily handles road construction in clayey, weathered sandstone and siltstone (regolith) of Flournoy Formation (Tf) at Witham Hill, Corvallis. Note thin soil on cut slope to left.

However, since these sedimentary rocks have also been intruded, baked, and hardened by molten igneous rocks (Figure 19), excavation may become extremely difficult near the baked rock adjacent to the intrusive body.

The Spencer sandstone around Corvallis contains intrusives which were discovered only after excavation commenced, as near 36th and Harrison Avenues and on top of Country Club Hill (Figure 22). A clue to the existence of very hard, underlying intrusives is the presence of hard, dark-gray sedimentary rock that requires jackhammering, drilling, or blasting. The sedimentary rocks have been hardened by contact with the intrusives (Figure 11). The possibility of encountering unmapped intrusive bodies within these sedimentary units must be considered where extensive excavation must be done, as for sewage systems. Dome-shaped topographic features within the Spencer Formation, as just south of Philomath, also are generally very hard and difficult to excavate. Concretions within Spencer (Ts) sandstone also can contribute to excavation difficulty. Laminations in the Spencer (Ts) and distinct bedding in the Flournoy (Tf) aid excavation. Unweathered Flournoy sandstone (Tf) is also difficult to excavate and has been quarried in some locations.

Siltstone is generally more easily excavated than cemented sandstone, particularly where blocky parting along bedding planes is prominent, as occurs within the Kings Valley siltstone (Tsrk) (Figure 15).

Surficial deposits are easily excavated, as described elsewhere in this section (Figure 23).

Tsr pediments exhibit variable degrees of excavation difficulty because of variable soil depths (Figure 9), weathered zones, and types of volcanic rock encountered. Generally, although pediments have terracelike forms, they will usually require excavation as bed rock.

Foundation capacity

Foundation capacity is the ability of a rock or deposit to support structures without failure by shear or penetration. It is determined largely by rock hardness, weathering, jointing, and bedding. Because variation of rock type beneath the surface is of additional concern for major construction, foundation



Figure 22. Approximately 12 to 16 ft beneath ground surface, this sewer line route near Corvallis Country Club was thwarted by presence of very hard, coarse-grained, gray intrusive rock (Ti) (arrow) within Spencer (Ts) sandstone. Jointing in overlying firm sedimentary rock aided excavation. Blasting near residential areas is often not feasible because of safety and other considerations.

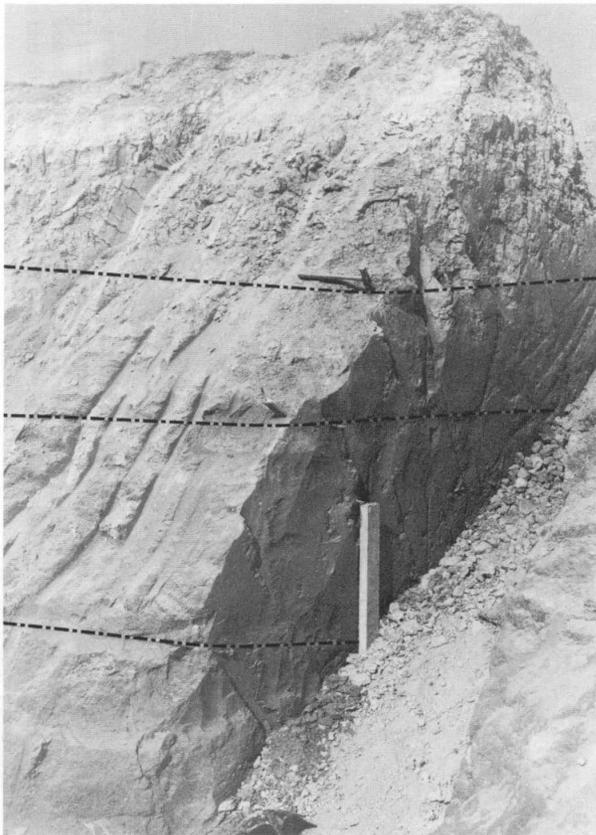


Figure 23. Excavation in Quaternary middle terrace deposit (Qtm) for swimming pool at Highland Junior High School in Corvallis. One- to four-in.-thick wavy bands of silt (dashed lines) are interspersed with light-tan silty-clay material at 2- to 3-ft intervals. Below permanent water table (approximately 16 ft), color changes to bluish-gray.

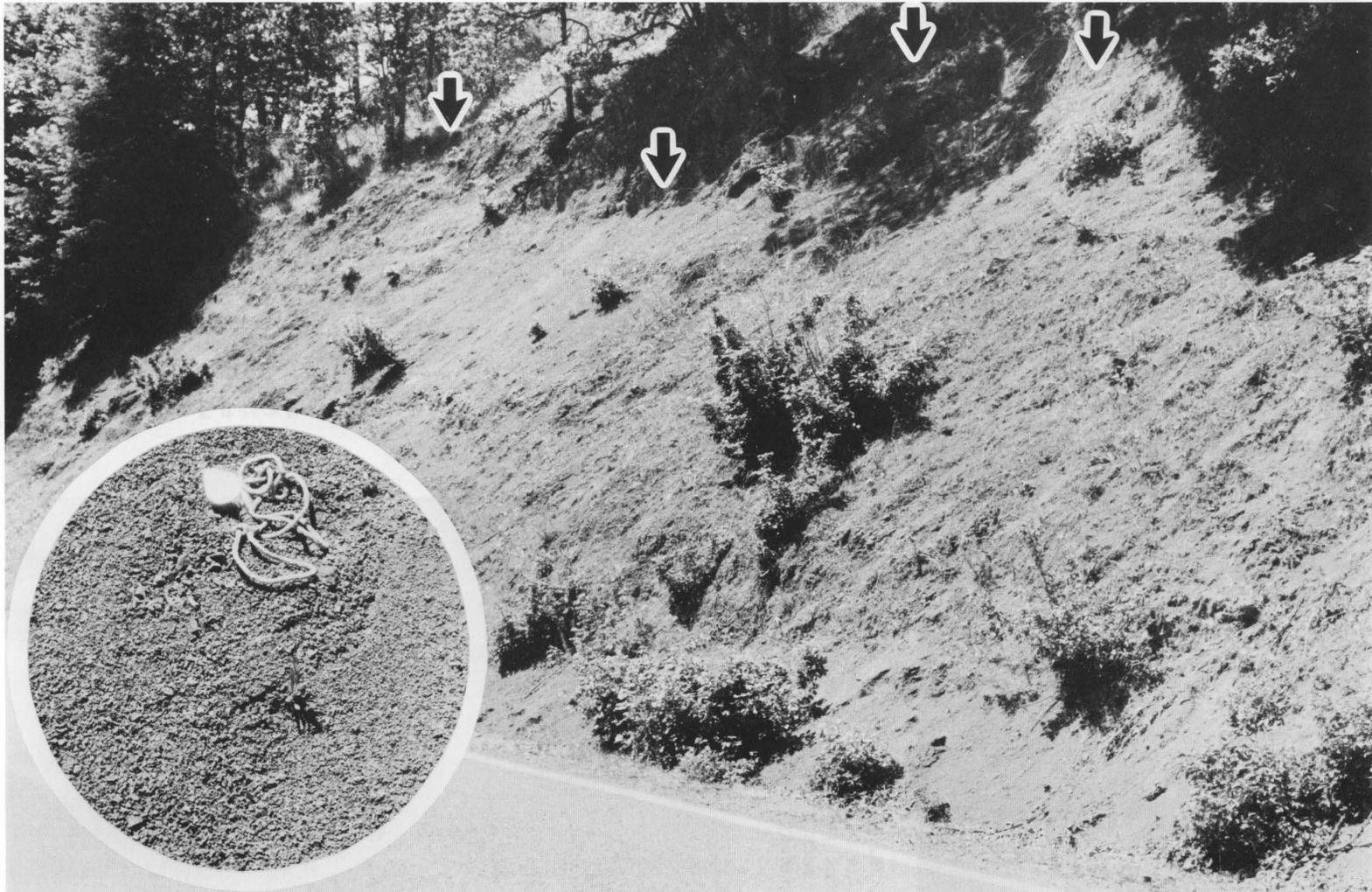


Figure 24. Cut slope of weathered later Eocene sandstone (Ts) west of North Albany (NW $\frac{1}{4}$ sec. 2, T. 11 S., R. 4 W.). Siltstone weathers to angular fragments, chips, and fine clay (inset - note hand lens for scale). Mid-slope profile becomes convex due to creep and shallow slumping from steepened upper part of cut slope (arrows). Material from steep cut slopes in raveling clayey siltstones of all sedimentary units often fills roadside ditches, which then need additional maintenance.

strength is also studied by subsurface boring and sampling and a variety of tests.

Settlement, particularly differential settlements between different parts of a structure, is quite often a greater factor in design considerations or innovations than strength. Settlements are primarily a consideration where silty clay soils are encountered in the surficial terrace units (Qt1, Qtm, Qth) and where thick soils occur on pediments of the Siletz River Volcanics (Tsr). In urban environments, areas of fill may be encountered which could, if not recognized, cause differential settlement problems.

Means for dealing with site-specific conditions of soil or rock strength and settlement include innovative foundation design, basements, mat foundations, drainage control, preloading, use of piling, and actual avoidance of critical areas. Construction cost is usually a prime consideration in selecting foundation alternatives.

Foundation strength of volcanic, intrusive, and sedimentary rocks is moderate to high in unweathered areas of Benton County. Therefore, it is generally more than adequate for most types of construction. On steep slopes, mass-movement potential is a closely related hazard that warrants attention.

Foundation strength of terrace surficial deposits (Qra1, Qt1, Qtm, Qth) is generally good, but variable. Settlement considerations, ground-water level, and drainage are equally important; therefore, the precise nature of subsurface material and conditions should be determined for many applications. The general foundation characteristics of the surficial deposits are discussed in Table 9.

Cut-slope stability

Cut-slope stability is resistance to shear failure or sliding in artificial cuts. Removal of material from a cut provides a site for possible sliding if shear stresses of the newly formed slope exceed shear resistance. Cut-slope stability in bed rock is determined largely by surfaces of least strength, including joints, faults, distinct bedding planes, glassy surfaces of pillow basalts, clay horizons, and avenues of ground-water flow.

Cut-slope stability in intrusive geologic units (Ti) of this study is generally high. Potential instability is governed by joints and contacts between overburden and bed rock in shallow cuts. Moderate to steep slopes along flanks of contacts between intrusive rocks and sedimentary rocks are also often areas of deep and shallow slumping and landsliding which must be assessed in determining overall stability (Figure 40).

Basalt flows are most stable. Pillow basalts are generally stable, although large pillows may drop out of cut slopes and vertical quarry walls. Sediments within Eocene volcanic rock (Tsr) are generally weak and prone to instability in unfavorable conditions of thickness, bedding orientation, or drainage. Shallow cuts through siltstone ravel and exhibit a characteristic accumulation of mosaic-like chips along the base (Figures 14 and 15). In distinctly bedded sedimentary rocks (Tf, Tsrk, Ts), beds dipping steeply into cuts reduce cut-slope stability (Figures 12 and 15).

In more mountainous terrain, as on Vineyard Mountain, cut slopes may intersect older landslide deposits or unconsolidated colluvium (Figure 41). Coupled with alterations in runoff and drainage caused by road and home building, such cut-slope stability can be extremely variable. Site-specific investigations are therefore essential to mitigate potential cut-slope stability problems. Where contrasting rock types are interlayered, as siltstones and basalts, cut-slope stability can be adversely affected by undercutting or by ground-water flow.

Factors influencing cut-slope stability in unconsolidated and semiconsolidated surficial terrace deposits include ground water, cohesion, density of material, shear strength, height of cut, and angle of cut (Figure 23). Specific stability assessments are the task of the civil or soils engineer. Thick unconsolidated material in the study area includes deeply weathered bed rock, where encountered, and base-slope colluvium (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Regolith).

Cut slopes in the Spencer (Ts) sandstone are generally stable, usually assuming a convex profile midslope (Figure 24) as material sloughs from the top of the cut in episodes involving material of one to several yards in volume (Figure 25). This sloughing occurs equally on sandstone and siltstone interbeds. Where cut slopes intersect areas of shallow subsurface seepage, saturated earthflow material often accompanies slumping (Figure 27). For further discussion of factors affecting cut-slope stability see GEOLOGIC HAZARDS - Mass Movement.



Figure 25. Shallow earthflow slump in steep cut slope in Spencer (Ts) sandstone along Pettibone Road. Areas with shallow subsurface seepage are particularly prone to such slumps. This one, typical of individual events, contains approximately 2 cu yd of material. Filling of ditches and culverts commonly results, affecting surface drainage.



Figure 26. Large blocks of gabbro (Ti) placed at toes of shallow slumps in Spencer Formation (Ts) siltstone along Pettibone Road near Lewisburg.



Figure 27. Cut-slope failure in Quaternary higher terrace deposits (Qth) overlying Spencer (Ts) sandstone along Airport Road just east of Bellfountain Road. Shallow subsurface flow (arrow) led to complete loss of strength of soft clayey siltstone and mudstone regolith. Slip surface contains dark-gray sticky clay and visible ground-water seepage. Shovel handle left of slump provides scale.



Figure 28. Shallow earthflow slump in Kings Valley siltstone (Tsrk) along Maxfield Creek Road east of Kings Valley. Shovel handle (center) provides scale. Presence of large shrink/swell cracks during the dry season indicates that expansive montmorillonitic clays are present.

Slope intensity

Slope intensity or steepness is generally measured in percentage of slope or degree of rise. The percentage of slope is determined by dividing the vertical change in elevation by horizontal distance and multiplying by 100. If, for example, elevation increases by 10 ft over a horizontal distance of 10 ft, slope intensity is 100 percent. In this study, slope intensity derived from maps is an average of variable local slopes because of large contour intervals and small map scale compared to the size of typical sites under investigation.

Steep slopes generally occur over hard bed rock in areas of youthful topography. Rock types include all units except surficial deposits. Deep weathering along joints, faults, and other zones of weakness produces gentler slopes locally. The evolution of large-scale erosive landforms, such as river valleys, produces flat slopes and pediments by other processes in addition to local rock weathering.

Surficial deposits are characterized by gently sloping to very flat terrain. Landscape evolution is another consideration in slope interpretation. For example, although the various formations have dramatic differences in hardness and other physical properties, their forms and slopes are quite similar.

Slope intensity is the most critical factor in determining soil erosion potential and soil creep; it is a controlling factor in the distribution and nature of mass movement, runoff, and large overland flow (see GEOLOGIC HAZARDS - Soil Erosion).

Infiltration rate

Infiltration rate is defined here as the general rate at which surface water percolates into geologic units. The concept is qualitative, and statements are based on professional judgment rather than actual measurements. Infiltration rates of the associated soils and regolith are further discussed in the Soil Conservation Service soil survey of Benton County and in recent research by Hammermeister (1978) and others (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Shallow subsurface flow and Septic-tank capacity of soils). Infiltration rates, which are determined by rock permeability, joints, fractures, faults, and orientation of bedding, are significant in terms of landfill potential, drainage, ground-water potential, and steep-slope mass movement.

Because infiltration rates in intrusive, volcanic, and sedimentary rocks are generally low, ground-water potential is also low in these rock units. Rocks from the Siletz River Volcanics (Tsr) are fractured, faulted, and jointed (Figure 18) and are characterized by variable and moderate infiltration rates and ground-water potential generally adequate for small domestic supply (5 to 60 gpm) from fractures beneath the surface. In areas of steeply sloping terrain over fresh basalts or intrusives within this unit, bedrock infiltration rates are lower than in the overlying silty clay colluvium; ground-water flow predominates at the interface between bed rock and colluvium.

Spencer (Ts) and Flournoy (Tf) sandstone units have low to moderate infiltration rates. The salinity encountered at depth within the Spencer Formation probably attests to this, indicating either that sufficient percolation of fresh water has not occurred to flush the salinity or that flow is so slow that salts have been leached from bed rock. Infiltration rates of surficial deposits are limited where mantled by silty clay soils and high where permeable sands and gravels occur (see GEOLOGIC HAZARDS - High Ground Water and Ponding). Most ground-water flow occurs within sands and gravels occurring locally at depths of 15 to 50 ft. "Overconsolidated" stiff blue clay is essentially impermeable (Table 9).

Landfill potential

Landfill potential is the capacity of a rock unit to be used successfully as a site for the sanitary disposal of solid waste. Leachate develops when ground water or surface water filters through the solid waste and is almost always produced in humid climates like that of Benton County (Table 1). It is the most important source of potential ground-water pollution. Ideal landfill sites provide a great deal of natural protection against pollution and are characterized by (1) favorable topography, including flat up-land areas and gentle slopes; (2) low infiltration rates resulting either from thick deposits of relatively impermeable silt and clay material or from shallow, relatively sound unjointed or unfractured bed rock which also limits ground-water leachate movement; (3) low ground-water table; (4) ease of excavation; (5) iso-

lation from overland flow and surface waters; and (6) adequate quantity and quality of cover material.

The distance pollutants can travel depends on the concentration at the source, interaction with regolith or bed rock, rate of ground-water flow, and extent of mixing by diffusion and dispersion. Chemicals have been known to travel two to thirty times farther than bacteria in some cases.

The volcanic and sedimentary units (Tsr, Ts, Tf) come closest to meeting these specifications in places, but excavation difficulty is variable. Major problems associated with volcanic and intrusive geologic units include high excavation difficulty, steep slopes, and infiltration along joints. The use of quarry sites for landfill sites eliminates excavation difficulty as a consideration but still requires careful analysis in terms of overland flow, leachate production, and adequate covering.

Surficial geologic deposits (Qral, Qtl, Qtm, Qth) are generally the least favorable because of flood or high ground-water potential. Qth is relatively better than Qtm. In some parts of the world, solid waste disposal in landfill mounds has been successfully accomplished. Impermeable liners are also being used to more nearly adequately insure against landfill leachate (which may be carried to a treatment plant) entering the ground-water system.

Proper selection and development of sanitary landfill sites require highly technical input from the fields of engineering geology, ground-water and surface hydrology, and ecology. Climate is also a very important consideration, since rainfall controls the amount of infiltration, rate of fill decomposition, and rate of leachate production. Within Benton County, intermountain areas like Kings Valley may have rainfall amounts twice that recorded nearer the Willamette Valley. On-site investigations incorporating borings are necessary to confirm assumed geologic and hydrologic conditions. Adverse site factors can sometimes be mitigated with success by proper design, ground-water monitoring, and appropriate engineering practices.

Septic-tank capacity of soils

The potential of soils to be used for septic-tank disposal waste is determined by soil texture, soil thickness, and drainage. Because soil formation is determined by parent material (bed rock), time, slope, climate, and organic activity, there are no clear-cut relationships between bed rock and septic-tank capacity of soils (Table 10). Therefore, there is no substitute for on-site evaluation to determine septic-tank capacity. The Soil Conservation Service soil survey contains information on septic-tank capacities of specific soils. However, an understanding of geology assists in the identification of potential problems that might otherwise be overlooked (see GEOLOGIC HAZARDS - High Ground Water and Ponding).

Unfavorable permeabilities are common in black clayey soils on Tsr pediments, where soil is also often too thin (Figure 30), and in clay-rich soils over weathered tuffaceous sandstone, as found in the Spencer (Ts) sandstone in North Albany. Soil is commonly too thin in steep terrain over hard bed rock. Slope is not an automatic indicator of adequate regolith thickness, but steep slopes are generally inappropriate for septic tanks because of installation difficulties and the high potential for downslope surfacing of effluent and for slope failure.

Where concentrated developments are contemplated in foothills well above the regional water table within the Siletz River Volcanics (Tsr) unit, septic-tank contamination of domestic water wells is a potential problem that increases with the number of wells and septic systems, due to the nature of fractures within the unit (Figure 18) and alterations in infiltration patterns that occur through home, road, and septic-tank construction.

Recent research on movement of wastes from septic-tank systems on hillside soils in Benton County revealed rather large differences in the capacity of soil and rock to transmit water or waste without becoming saturated, depending mainly on clay layers, slope position, and permeability of underlying rock (Hammermeister, 1978). Even the B and C horizons of the best drained soils tested were found likely to become saturated from storms of high intensity and long duration. High flow rates of 20 ft per hour or more during saturated conditions on some sites suggest that potentially dangerous solutes and particulates may move downslope several hundred feet if saturated conditions persist for 24 hours. Therefore, conventional setbacks of septic tanks from wells, roadcuts, and surface waters may be too small for drainfield trenches over sloping impermeable bed rock (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Infiltration rate and Shallow subsurface flow).

Regolith

Regolith is unconsolidated rock and soil material overlying solid bed rock and includes surficial geologic units (Qral, Qtl, Qtm, Qth), landslide debris, colluvium, and soil (Figure 29). The term is applied to material which is weathered from underlying bed rock or material which is transported by wind, water, or creep. Specific kinds of regolith (surficial geologic units, landslide deposits, and soils) are discussed in detail elsewhere in the text.

The nature and thickness of residual weathered bed rock, called saprolite or saprolite, are important engineering considerations in assessing excavations and drainage characteristics. Saprolite closely resembles in structure the firmer bed rock from which it has weathered (Figures 20 and 30), even though deep weathering may have reduced its texture to silt and clay, particularly in sedimentary units. Generally, saprolite thickness follows regolith thickness: for example, on steep slopes where regolith is thin, saprolite is also thin; on flat slopes where regolith is thick, saprolite is also thick.

Thickness on steep slopes

On steep slopes thickness of regolith influences the depth of subsurface ground-water flow, stability of the slope, and cut-slope stability. Thickness is determined by rock type, weathering rates, erosion rates, and amounts of colluvial or stream deposition.

Regolith is generally thinner on steep side slopes, where bedrock exposures, particularly of more resistant volcanic and intrusive rocks, are more common. In steeply sloping Siletz River Volcanics (Tsr) terrain, colluvial thickness can be quite variable. It is thicker where shearing, interbedded pillow basalt flows, basalt, intrusive rock, and tuffaceous sandstone occur, as on Vineyard Mountain (Figure 31). Zones 10- to 20-ft-thick are also associated with drainages and old landslide deposits, while zones only 1- to 3-ft-thick occur over firm basalt or intrusive rock.

Accumulation of slope wash material, colluvium, and creep material at the base of a slope contributes to the relatively thick regolith found at the bases of many steep slopes. In addition, accumulation of ground water at bases of slopes results in more effective chemical weathering of bed rock, which, in turn, produces more regolith.

In general, accelerated chemical weathering and creep contribute to relatively thicker regolith in drainageways on all rock units. From a geologic time perspective, debris avalanches and debris flows in small linear channels on steep slopes eventually scour loose material from the slope, producing ephemeral stream channels (Figure 43). It is this process, rather than classical headward erosion, that produces first-order streams in much of the Coast Range of Oregon (see GEOLOGIC HAZARDS - Mass Movement).

Thickness on gentle slopes

Regolith thickness on gentle slopes influences excavation difficulty, foundation design, cut-slope stability, and landfill potential. Thickness is determined by rock type, weathering rates, erosion rates, and age of the land surface.

Where surficial terrace deposits cover bed rock, regolith thickness is equivalent to the thickness of the alluvial unit (Figure 29), readily determined by well-log data and field observations. This thickness varies from a few feet to tens of feet (where surficial units merge with pediments) to greater than 100 ft in some locations within the main portion of the Willamette Valley.

Regolith thickness overlying pediments is generally thin (Figure 9) and results from control by weathering and fluvial erosion. Generally, regolith is thin on ridge crests and thick on side slopes, indicating active creep and erosion.

Clay content

Clay refers to extremely fine particles (0.002 mm or less) as well as to a group of minerals with a specific crystallographic structure and range of composition, generally hydrous aluminum silicates with continuous sheet structures, like mica, with cohesive properties.

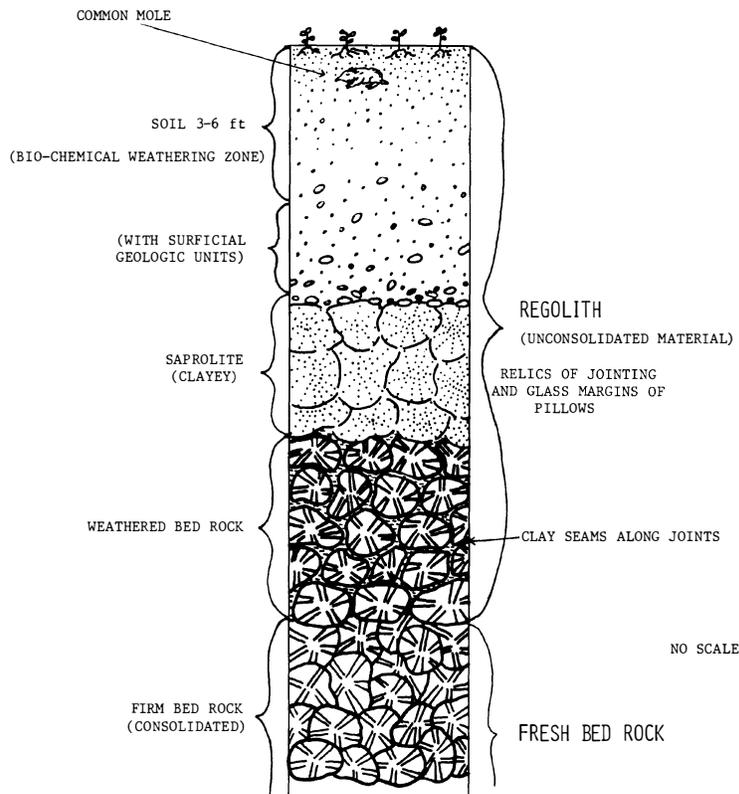


Figure 29. Relative positions of regolith, its soil, and underlying country rock. Bed rock is typical Eocene volcanic pillow basalt (Tsr). Saprolite may not always be present. Surficial geologic units (Qral, Qtl, Qtm, Qth) are equivalent to regolith. In some places, regolith may be so thin that it is merely soil resting on bed rock. Saprolite and weathered bed rock are part of true regolith but have engineering properties intimately related to underlying country rock. (After Brady, 1974)

Clay size and clay mineral content of regolith is determined by the texture and composition of the parent material, soil-forming processes, and stage of mineral weathering. Clays are believed to form by alteration, an extremely slow low-temperature process, and by recrystallization of the decomposed products of original minerals. Complex events and processes in the Willamette Valley apparently produced wind-blown, fine-grained materials which are now part of some area soils and regolith. In flood-prone areas, as Qtl units, overbank deposition is also a major source of clay content in soil.

Water is a prime weathering agent. In the soil/water regime, hydration, acid attack, and oxidation occur simultaneously, although weathering of silicates is primarily a process of hydrolysis. Rates of weathering are functions of grain size, amount of fracturing, and chemical susceptibility. Silicate clay formation is most abundant from feldspars, micas, amphiboles, and pyroxenes. These minerals are present in all rocks in Benton County. The permanent water table roughly coincides with the top of the unoxidized zone, since pore water restricts access of oxygen and carbon dioxide; this zone is often noted in borings by color change to blue or dark gray.

Types of clay: The type of clay formed depends on climate, soil profile conditions, and nature of the parent material. Clays differ in composition and lattice structure. Kaolinite clays are common in humid temperate climates on well-drained slopes.

Montmorillonite and illite clays have a high content of cations such as magnesium (Mg^{++}), iron (Fe^{++}), and potassium (K^+). Montmorillonite forms where parent material is high in bases, particularly magnesium, or soil drainage discourages leaching of these bases. Both montmorillonite and illite dominate in semiarid and arid climates where soil solutions are slightly alkaline. Illite is favored by an abundance of potassium and is the most common clay mineral of marine sediments. Bentonite is a montmorillonite-type clay derived from volcanic ash. Montmorillonite, vermiculite, and illite are more likely to form in cooler climates.

Clay minerals may also be inherited from previous sediments rather than formed in place.



Figure 30. Very shallow, light-tan clayey soil overlying weathered bedrock pediment of Siletz River Volcanics (Tsr-p) in quarry site 84 (Schlicker and others, 1978). Although weathered pillow basalt form is evident below soil contact, this clayey material is almost saprolitic and readily decomposes during excavation. Angular rock fragments within clayey soil above suggest that this is transportation slope. On some pediments, saprolite and weathered bed rock zone are so thin that soil rests directly on firm bed rock.



Figure 31. Colluvium is loose and incoherent mixture of soil, rock, and rubble that accumulates at foot of slope or cliff as result of downslope movement, chiefly by gravity. This cut slope along Cardinal Drive, Vineyard Mountain, consists of colluvium above tuffaceous sediments (not visible). Large disparity in particle size, angular features, and absence of relict jointing are common. Since boulders are unattached, they readily fall from cut slope.



Figure 32. Weathered bed rock of jointed basalt flow rock within Eocene volcanic rock (Tsr) along Cardinal Drive, Vineyard Mountain. Although this cut slope is similar in some respects to that in Figure 31, generally uniform size of material (controlled by jointing) and more rounded rocks (from in-place weathering) indicate that this cut slope is in weathered bed rock rather than colluvium. Further examination would show boulders attached to generally firm bed rock. Because of vastly different cut-slope stabilities, particularly with shallow subsurface flow, accurate distinction between weathered bed rock and colluvium is essential.

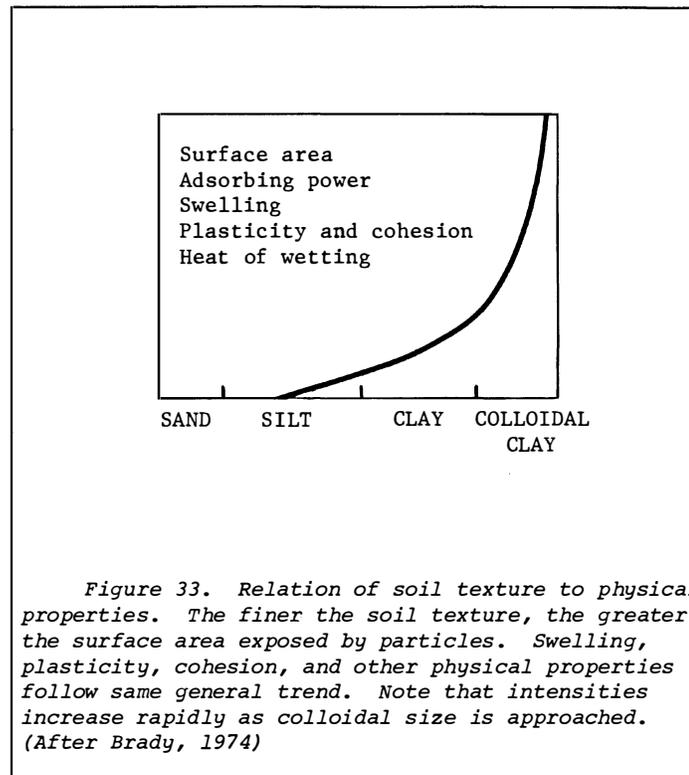


Figure 33. Relation of soil texture to physical properties. The finer the soil texture, the greater the surface area exposed by particles. Swelling, plasticity, cohesion, and other physical properties follow same general trend. Note that intensities increase rapidly as colloidal size is approached. (After Brady, 1974)

Clay type and clay behavior: Clay properties are primarily related to extremely small grain size and consequently large surface areas. For example, one thimble of clay has about the same surface area as five trucks of gravel. Surface area is important because interparticle attraction and adsorption of water and organic material, nutrients, and gas are all surface phenomena (Figure 33). The degree of plasticity, cohesion, swelling, shrinkage, dispersion, and flocculation differs from one clay mineral to another according to structure and composition. The most important engineering properties are shrink/swell, cohesion, and plasticity. All are closely interrelated and depend on the clay mixture, the dominant adsorbed cations, and the nature and amount of humus colloids.

Soils with more than 15 percent clay exhibit plasticity, with properties dependent in large part on the quantity and nature of adsorbed ions. Clays with adsorbed sodium (Na^+) tend to be sticky and impervious, while those with adsorbed calcium (Ca^{++}) tend to be granular, easily worked, and readily permeable. Thus in agriculture, gypsum is often added to convert soda clays to calcic clays. A high concentration of sodium in irrigation water is harmful because it can destroy soil structure and productivity.

Cohesion is believed to be primarily due to attraction of clay particles for water molecules held between them. Although all clays adsorb water, shrink/swell variations, which depend on structure, are quite great.

Kaolinite clays consist of alternating silica and aluminum layers which are generally more tightly bound than in other clays, allowing less ionic substitution. Ion exchange capacity is low, and plasticity is less.

Montmorillonite clays have a three-layer structure, exhibit the greatest volume change of any clays, and are often referred to as expanding lattice type. Their layers are easily separable, have an abundance of adsorbed ions, and easily adsorb much water. Montmorillonite clays undergo notable expansion when wet.

Plasticity is dependent on the kind of adsorbed ions, being greater for sodium (Na^+) and hydrogen (H^+) montmorillonites and less for calcium (Ca^{++}) montmorillonites. Alteration of other silicate clays, chlorite, illite, and vermiculite yield montmorillonite. It may also form by recrystallization from a

variety of minerals under appropriate conditions, generally thought to include mild weathering environment, neutral pH, relatively abundant magnesium (Mg^{++}) ions, and absence of excess leaching.

Illite clays and chlorites have structural layers which are partly bound by nonexchangeable cations and exhibit intermediate plasticity and ion exchange capacity. Illite is often associated with montmorillonite, but potassium (K^+) ions bind adjoining crystal units into relatively nonexpansive structures.

The vermiculite structure is similar to that of montmorillonite. However, the degree of swelling is much less because the water molecules and magnesium (Mg^{++}) ions adsorbed between crystal units act more like bridges than wedges. Chlorites are silicates of magnesium with some iron and aluminum present; like illite, they have structural layers partly bound by nonexchangeable cations. They therefore exhibit intermediate plasticity and ion-exchange capacity, relatively little water adsorption, and are relatively nonexpansive.

Colloidal clay properties: Where subject to erosion, colloidal clay contributes to high and lasting turbidity in streams.

General distribution: Most clays in soils are mixtures of two or more clay minerals with properties intermediate between individual extremes. Mixed crystal layers also occur with layers of different clay minerals joined together in the same crystal unit. Thus the Kings Valley siltstone (Tsrk) is described as having predominantly montmorillonite clay minerals with lesser amounts of mixed-layer montmorillonite-mica and chlorite. While a pure sample of montmorillonite may swell up to 15 times, in most soil mixtures a volume increase of 3 percent or more is considered potentially damaging (Rogers and others, 1974). Small loads, of course, decrease the swell.

All geologic units in Benton County contain fine-grained components and clay-rich regolith and/or saprolite. The high clay content of surficial terrace deposits is probably the product of deep weathering and derivation from flood and wind-blown sources (Figure 23). Clay in sedimentary units is largely from weathering of fine-grained sediments and possibly from concomitant weathering of some wind-blown material.

Areas of potential expansive soil problems include the Siletz River Volcanics (Tsr) and associated pediments (Tsr-p). Pediments, with their often variable depths of clayey soil, overland flow characteristics, and suitability for a variety of land uses, should be given particular attention. Sandstone of the Flournoy Formation (Tf) has clay minerals in its matrix and siltstone interbeds of predominantly montmorillonite, illite, and mixed-layer montmorillonite-mica. Consequently, potential expansive problems are more likely where sediments of this formation are fine grained, generally in the northern parts of the County. On sloping terrain, creep may become significant, and problems may arise where customary flatland methods of site preparation and construction are applied to hillslopes. Flood plains of tributary rivers and perennial and intermittent streams, particularly those draining volcanic terrain, can be expected to be relatively higher in expansive soil properties. Expansive characteristics of fine-grained material mantling many terrace units is described elsewhere in the text (Table 9).

Tests for expansive soil conditions: The presence of potential expansive soil hazard is indicated by sticky surface soil when wet, open cracks when dry, lack of vegetation due to heavy clay soil, and soil that is very plastic and weak when wet but rock-hard when dry.

Understanding of the factors governing swelling plus knowledge of previous local experience with expansive soils are required in evaluating the potential swell hazard (Figure 34). In areas where extensive shrink/swell damage is known or expected, tests are made on soil samples that are as representative as possible of site conditions. Geometric and environmental factors of the site are taken into account; for example, the stream flowing underneath the Crescent Valley High School is utilized to maintain constant moisture conditions and prevent the shrink/swell cycle.

The U.S. Bureau of Reclamation utilizes colloid content (percentage less than 0.001 mm), plasticity index, and shrinkage limit as expansive soil criteria. A table gives relations of soil index properties and probable volume changes for highly plastic soils. This approach is generally preferable to single index methods, except where local experience has shown unique relationships. The 1976 Uniform Building Code utilizes an Expansion Index based on one-dimensional volume expansion of a prepared specimen under a loading of 1 lb per square inch.

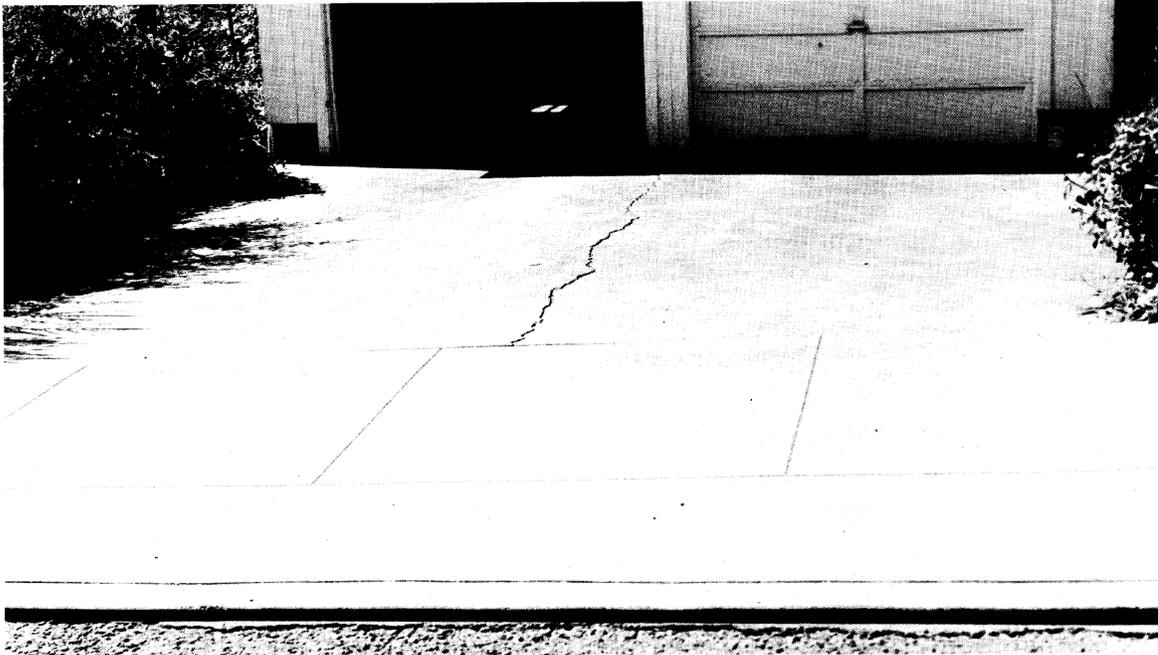


Figure 34. Cracking of unreinforced concrete slabs is symptomatic of presence of expansive clay soils and regolith, common to surficial geologic units (Qt1, Qtm, Qth). Effects can be minimized by proper care during and after construction.

Tests requiring more equipment are the Proctor method, determining moisture density relationships; the Standard and Modified AASHO; the Dietert T-190 expansion pressure test with or without modification; and the PVC (potential volume change) test.

Recommendations: Foundation problems causing economic loss from expansive soils do not appear widespread in Benton County. The general lack of major problems is probably the result of relatively constant soil moisture conditions, use of reinforcing steel in foundations (typically two #4 bars in a one-story house), and inherent flexibility in wood-frame structures. However, the need to continue to appraise significance of expansive soils in future development is indicated by the following: (1) the known expansive characteristics of the light-brown silty clay material mantling terrace units (up to 1-in. swell for footings or slabs founded on dry soil), (2) Atterberg limits suggesting a medium swell potential of 1-5 percent, (3) cracking of unreinforced slabs, and (4) montmorillonite clay content in Siletz River Volcanics units (Tsr, Tsr-p), Kings Valley siltstone (Tsrk), Flournoy sandstone (Tf), and presumably Spencer sandstone (Ts). It is suggested that a record of ongoing significant problems related to expansive soil (regolith) be maintained to guide further planning efforts. Coordination with Oregon State University research projects, such as the recent study by Hammermeister (1978) detailing failure of septic tanks in saturated hillside soils, will significantly aid in detection of specific problem areas.

While expansive clays generally present only minor problems to single family dwelling construction in Benton County, locally more severe expansive soil conditions are occasionally encountered, requiring detailed on-site assessments. Relatively fewer problems have been noted in the higher elevations in the Oak Creek area near Corvallis. Related geologic hazards include high ground water and ponding.

Engineering properties of clays include low permeability, water retention, consolidation and compressibility, low shear strength when wet (Figure 35), and shrink/swell properties. Regolith and saprolite with high clay content are characterized by lower shear strengths, ease of excavation when wet, low to moderate cut-slope stability, low infiltration rates, and low septic-tank potential. Potential use as embankment, backfill, or road base is also very low. Related hazards include ponding on flat surfaces, creep, and mass movement on gently to moderately sloping terrain.



Figure 35. In southeast Philomath, soft silty clay of Quaternary higher terrace deposits (Qth) loses strength when saturated, thereby restricting construction traffic. Note limited surface drainage.

Problem zones for expansive soils are those experiencing alternate wet and dry cycles. In these areas, surface cracks (3/4-in. on some Tsr slopes) typically form on drying; they allow the first rains to penetrate, then swell shut and become impermeable. The best time to build is in the spring when soil is saturated. Foundations tend to prevent drying of the soil by evaporation; hence soil moisture tends to remain more constantly moist. It is important not to let foundation trenches dry out before a foundation is placed, and a thin layer of gravel is often used for this purpose. Expansive subgrade soils may cause uplift upon wetting, particularly if the surface loadings are light, the initial density is high, and the initial moisture is low.

Mitigating measures for expansive soils include drainage, foundations adequately designed to resist swell pressures, and landscaping to provide constant moist or dry conditions (breaking the alternate wet/dry cycle). Floating slabs, problem soil removal, and pile and grade-beam foundations have also been used extensively in other parts of the country. In large fills, as for highways, deep fills placed in the ordinary manner, at optimum moisture and density, swell very little; nearer grade, however, there is no overburden present to reduce swell. Here placement densities lower than those obtained by standard compaction and placement moisture higher than standard or near optimum are combined to give low expansion (American Society of Civil Engineers, 1956).

Silt content

Particles that are coarser than clay and finer than sand are called "silt." Silt size limits in the United States are 0.002 mm to 0.05 mm. Silt composed of angular particles usually does not possess the sheetlike structure or colloidal properties of clay; however, where it consists of platelike particles or is intermixed with clay, silt has properties similar to those of clay. Surficial units generally have properties of silty clays or clayey silts, but local deposits of more silty material may also occur. Regolith associated with sedimentary units generally contains silty clay material; locally, where silty beds occur within these units, the regolith may have properties dominantly of silt, characterized by higher permeability and better

drainage, higher cut-slope stability, and greater septic-tank potential than clay-rich regolith. Since the associated cohesive strength is lower, severe erosion potential in unlined ditches and canals may occur.

Silt content of regolith is also determined by the texture and composition of the parent material, soil-forming processes, and the youthfulness of the weathering surface.

Drainage

Drainage is the process of discharge of water from an area by flow and includes overland flow, shallow subsurface flow through regolith, and deep subsurface flow through bed rock. It is here distinguished from soil drainage, which is the rate at which water percolates downward through a soil. This distinction is helpful in understanding the ground-water and ponding problems of the study area (see GEOLOGIC HAZARDS - High Ground Water and Ponding).

Overland flow

Whenever rainfall exceeds the infiltration capacity, a film of water develops on the ground surface and finally results in overland flow to drainage channels. Infiltration capacity of soil is the maximum rate at which water can enter the soil under a given set of storm conditions, including antecedent precipitation (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Soils). Awareness of overland flow, which affects surface drainage and erosion, is important. Sheet erosion, wherein soil is removed more or less uniformly from all parts of the slope, is the major erosion process of overland flow. Rill erosion, causing tiny, irregularly dispersed gullies, often accompanies sheet erosion. Gullying is the result of concentrated volumes of water forming large and small ravines by undermining and downward cutting (see GEOLOGIC HAZARDS - Soil Erosion).

Infiltration capacity of soil is influenced by texture, antecedent moisture, organic content, kind and amount of swelling clays, soil depth, and presence of impervious soil layers. Along with structural stability, it is one of the most significant factors influencing erosion. Table 4 gives relative minimum infiltration capacities for sand, loam, and clay, the three broad soil groups, as well as minimum infiltration rates for the more commonly encountered soil groupings in the Unified Soil Classification System. These values are for uncompacted soils and may be decreased 25 to 75 percent for compacted soils, depending on degree of compaction and type of soil (Jens, 1977).

Vegetation also greatly affects infiltration capacity, and a good permanent forest or grass cover may increase the capacity three to seven and one-half times that of bare soil. Hard rain on unprotected soils tends to degranulate and pack the surface, reducing infiltration. Vegetation protects the surface from impact, and plant roots and organic material improve soil structure, which increases permeability. Moreover, vegetation intercepts part of the rainfall and evaporates it directly into the air without its ever reaching the soil. Permanently forested areas are most effective in intercepting precipitation; in coniferous forests, one-third to one-half of the annual precipitation may never reach the soil (Brady, 1974) (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Infiltration rate).

Table 4a. Relative minimum infiltration capacities of three broad soil groups *

Soil group	Infiltration capacity (in./hr.)
Sandy, open-structured	0.50 - 1.00
Loam	0.10 - 0.50
Clay, dense-structured	0.01 - 0.10

*Jens, 1977

Table 4b. Expanded grouping of minimum infiltration rates of commonly encountered soil groups of the Unified Soil Classification System *

Description	Unified Soil Group symbol **	Infiltration capacity (in./hr.)
Sand and gravel mixture	GW, GP SW, SP	0.8 - 1.0
Silty gravels and silty sands to inorganic silt and well-developed loams	GM, SM ML, MH OL	0.3 - 0.6
Silty clay sand to sandy clay	SC, CL	0.2 - 0.3
Clays, inorganic and organic	CH, OH	0.1 - 0.2
Bare rock, not highly fractured	---	0.0 - 0.1

* Jens, 1977

** See Table 6

Since many factors must be considered in evaluating overland flow at a particular site, remarks in this section are of general nature. The following comments refer to the overland flow characteristics of the bed rock or saprolite (Figure 29). For surficial units, the comments are applicable to both the soil and the weathered material directly beneath it. General understanding of overland flow characteristics of the various geologic units is useful because large areas of saprolite or bed rock are often exposed during road construction and urban development. More specific information regarding behavior of the soils (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Soils) may be found in the Soil Survey of Benton County (Knezevich, 1975).

Generally, overland flow is pronounced on surficial units and pediments, particularly Qtl, Qtm, Tsr-p, Tf-p, Ts-p (Figure 36). Gullyng and creep are also attendant processes on pediments, particularly on Tsr-p. The often fine-grained nature of sedimentary rock units and the low bedrock infiltration rates generally mean a high potential for overland flow. In Corvallis, heavy winter rains have caused local flooding on Highland Drive near Walnut Boulevard, as overland flow accumulated in a slight depression at the base of a slope underlain by Spencer (Ts) sandstone and middle terrace material (Qtm) (Lawrence and others, 1977).

Overland flow is potentially greatest over exposed or near-surface volcanic and intrusive bed rock. However, in the steeper and heavily forested terrain throughout the County, most of the runoff probably occurs as shallow subsurface flow through colluvium to drainage channels.

On surficial units, slopes are very gentle, and infiltration capacities of soil and regolith are often very low because of the silty clay texture of the material. Although some of these soils are described as moderately well-drained, winter ponding of rain water is common because of local impermeable soil, low-slope gradients and topographic depressions, and high ground water.

Road embankments through areas of overland flow in surficial units and pediments are common. They provide barriers to overland flow, which is then concentrated and must be handled adequately to eliminate ponding and to prevent erosion and sedimentation problems. Overland flow in sloping terrain is also a concern in erosion control, road design, and fill placement and stability. Ponding and high ground water also influence land potential for septic-tank and landfill uses (see GEOLOGIC HAZARDS - High Ground Water and Ponding).

Shallow subsurface flow

Shallow subsurface flow predominates where thin, permeable regolith overlies impermeable bed rock or saprolite on sloping ground. Infiltration of water is increased by animal runs within the soil, decaying roots, and shrinkage cracks within clay-rich soils. Because regolith thickness and bedrock infiltration



Figure 36. Intermittent stream overland flow during intense rainstorm of December 1977 on Quaternary higher terrace deposits (Qth) and pediments (Tf-p, Tsr-p) west of Witham Hill, Corvallis. Where land use changes occur, overland flow of small natural intermittent stream drainageways is often significantly increased. It is most pronounced over pediments and clay-rich surficial geologic units.

rates often cannot be linked directly to type of bedrock slope, recognition of critical areas requires field reconnaissance. Springs and persistent green vegetation in drainageways in late summer indicate areas of shallow subsurface flow. Evidence of rapid subsurface flow from naturally forested slopes is noted in the literature (Hammermeister, 1978).

Hammermeister (1978) and others contribute to the understanding of shallow subsurface flow on sloping ground. In studying the movement of water, halide anions (I^- , Br^-), and bacteria in perched water tables or saturated zones in soil and regolith at eight sites on low hills near the western border of the Willamette Valley, injections of test solutions were made at different depths; and samples were periodically collected from saturated and unsaturated depths upslope and downslope. Water-pressure potentials were determined by using appropriate equipment, and hydraulic gradients in vertical and downslope directions were calculated. Saturated hydraulic conductivity measurements were made on intact cores of soil and weathered rock from different depths and from *in situ* measurements.

Impermeable regions of rock near or below $3\frac{1}{2}$ ft were found to be mainly responsible for perched water at most sites. Shallow subsurface flow and direct rainfall also contributed water to sites in lower hillslope positions. Under saturated flow conditions, evidence showed that halide ions moved mainly through large pores and perhaps channels or macropores in both soil and bed rock at rates up to at least 20 ft per hour on several sites. Refined monitoring techniques for bacteria movement studies indicated rates two to three times as great were possible. At almost all sites, some rapid movement was noted in unsaturated horizons above the saturated zone. In upper horizons, vertical permeability was often greater than horizontal permeability, indicating that the combined effect of roots, worms, macrofauna, and flora is possibly greater in the vertical direction. Table 5 shows site-specific locations and characteristics for these study plots.

In steeply sloping terrain over hard bed rock, the development of stream channels is often preceded by development of small linear drainageways characterized by relatively thick colluvium and both shallow subsurface flow and surface or overland flow (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Thickness on steep slopes). Rainfall percolates through the colluvium and moves downslope along the

Table 5. Geologic units, soil, and specific site descriptions of water and anion movement study plots, eastern Benton County, Oregon *

Geologic unit	Soil series	Site *	Location	Soil texture	Depth to bed rock (ft)	Vegetation	Local slope (percent)	Hillslope position	Relative site relationships
Ts: Finely laminated siltstone with micaceous and clay minerals	Bellpine	1	NW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$ sec. 35, T. 12 S., R. 8 W., Willamette Meridian.	Reddish-brown and yellowish-red silty clay loam and silty clay	2-3	Not cultivated recently; now in various grasses	21	Upper backslope	
Ts: Clayey saprolite	Jory	2	do.	Dark-reddish-brown silty clay loam and yellow-red silty clay and clay	3-4	Cultivated Christmas trees cut previous year	14	Upper footslope	
Tf: Poorly-sorted fine-grained sandstone; primarily micaceous quartz and feldspar minerals	Steiwer	3	NW $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$ sec. 33, T. 11 S., R. 5 W., Willamette Meridian.	Dark-brown and yellowish-brown, well-drained silt and clay loam	1 $\frac{1}{2}$	Native grasses	12	Upper footslope	
Tf: Laminated siltstone with micaceous and clay minerals and areas of saprolite	Steiwer	4	do.	Dark-brown and yellowish-brown, well-drained silt and clay loam	1 $\frac{1}{2}$ -2	Native grasses and Oregon white oak	19	Upper footslope	
Qth: Massive clay layer from below $\frac{1}{2}$ to at least 6 ft	Hazelair	5	do.	Dark-brown silt loam and silty clay loam	-	Native grasses	9	Lower footslope	
Tsr: Basalt	Philomath	6	SW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$ sec. 28, T. 11 S., R. 5 W., Willamette Meridian.	Dark-brown silty clay loam; clayey; montmorillonitic	1 (R=5) **	Native grasses	13	Summit	
Tsr: Clayey saprolite and deeply weathered basalt or related Tsr sediments	Dixonville	7	do.	Dark-brown silty clay loam and dark-reddish-brown silty clay and dark-brown heavy clay	2 $\frac{1}{2}$ (R=2-4) **	Native grasses, poison oak, and wild rose	14	Upper backslope	
Tsr: Clayey saprolite and deeply weathered basalt or related Tsr sediments	???	8	do.	Dark-brown silty clay loam and dark-brown silty clay	2 (R=1-4) **	Native grasses, poison oak	14	Lower backslope	

* Data for sites 1 through 8 after Hammermeister (1978). Measurements indicated that saturation to the base of the regolith and above impermeable soil layers occurred within sedimentary and volcanic units (Ts, Tf, Tsr). Moreover, for upper slope positions, impermeable bed rock at or near 4 ft below surface was more effective in creating and maintaining zones of saturation than were changes in permeability within soil horizons. Sites in lower slope positions receive water from shallow subsurface flow as well as from direct rainfall.

** Regolith thickness where recorded.

contact between the colluvium and the impermeable rock. Such channels are particularly common in the steeper volcanic and sedimentary terrain of the Coast Range within Benton County.

Shallow subsurface flow through colluvium over Flourney sandstone (Tf) is the source of springs and well water south of Hoskins in Kings Valley. Similarly, springs at the downslope margins of many Tsr pediments indicate shallow subsurface flow. Those north of Philomath were responsible for locations of many of the log ponds nearby.

Shallow subsurface flow through colluvium is probably most significant in drainages in steeper terrain of the Siletz River Volcanics (Tsr) and Flourney sandstone (Tf). Cuts in this colluvium are more apt to fail by slumping when shallow subsurface flow is occurring. Study sites of Hammermeister (1978) and others over Tsr bed rock indicate that the permeability of the upper bedrock mantle is highly variable, with no apparent relationship between the maximum rates of movement and depth of measurement below bedrock contact. Highest rates of water movement occurred in the weathered rock zone and in some soil horizons, while some depths and locations below 5 ft were virtually dry.

Surficial units also exhibit shallow subsurface flow locally where flow is perched above less permeable clay-rich horizons or flat surfaces. This flow presents problems when encountered in excavations and requires dewatering for larger sites. Perched water is relatively common on Qtl surfaces. It occurs on all units locally in areas of topographic depressions and probably plays a large part in maintaining intermittent stream flow.

Clear definition and treatment of shallow subsurface flow problems at specific sites requires a monitoring program, site investigations, and feasibility studies.

Deep subsurface flow

Deep subsurface flow is the movement of water by gravity and potential forces through bed rock or through deeper zones of surficial geologic units. Flow is generally vertical through the overlying geologic units or horizontal from water sources to the sides. Slopes or structural confinement by impermeable beds also may cause gradient flow. Deep subsurface flow is equivalent to ground-water flow and is discussed in greater detail in the section entitled GEOLOGIC UNITS.

Where vertical infiltration of surface water to depth is significant, the importance of overland flow and shallow subsurface flow is diminished. Such areas are zones of aquifer recharge and are generally not suitable for large-scale waste disposal. Percolation of surface water to depth is favored by permeable geologic units (Qral, part of Qtl), jointing (Tsr; and parts of Ts, Tf, and Tsrk), or significant shearing or faulting (see the geologic maps and GEOLOGIC UNITS - Bedrock Structure).

Soils

Purpose

The study of soils and the application of soils data, which together constitute a separate discipline, are not directly the concern of basic geologic investigations. Soils, however, are often closely related to bedrock geology, surficial geologic processes, and geologic hazards. The purpose of this soils discussion is to relate soils to general geologic information and concepts developed elsewhere in the text to (1) promote refinement of soils concepts, (2) assist future soils mapping, (3) supplement standard soils data in site evaluations, (4) make information on the origin of geologic units more useful to the soils scientist, and (5) present geologic concepts of soils and soils-forming processes.

General

In this study the term "soil" refers to the upper and biochemically weathered part of the regolith (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Regolith). The soil zone is generally 3 to 6 ft deep and is generally distinguished from material below by (1) relatively high organic matter, (2) an abundance of plant roots and organisms, (3) more intense weathering, and (4) characteristic horizontal layers. This definition of soil is more restrictive than the concept of soil used by soils engineers (regolith

of this report), who are primarily concerned with strength and workability. It does not include all of surficial geologic units, as Qtl, Qtm, Qth, which also reflect the deeper and less weathered parts of the regolith. It is consistent with most of the methods of sampling (limited to the upper 5 or 6 ft) employed by the U.S. Soil Conservation Service.

Weathering processes at the earth's surface include chemical breakdown of minerals, chemical reconstitution to form new minerals (clays), physical disintegration, and leaching (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Clay content). During the initial stages of soil development, the composition of the parent material is a dominant factor in determining soil type. Climate determines the kinds and rates of chemical reactions and the nature and distribution of vegetative cover. Slope intensity influences drainage and mass movement, and slope orientation partly determines the balance of soil-forming processes within a given area. As time passes, climate becomes increasingly more significant in determining soil development. The composition of the parent material is a dominant factor in determining soil type.

Horizons of differing composition and texture are developed within a typical soil profile because physical and chemical soil-forming processes vary with depth. Master horizons are designated as O, A, B, C, and R in Soil Survey reports, although all horizons may not be present in a given profile. A, B, and C are genetic designations indicating distinct soil-forming relationships among horizons: A is the mineral horizon at or near the surface where the most intense organic activity, leaching, and downward percolation of fine-grained material occur; B is an accumulation zone for silicate clays and humus beneath the A horizon, usually of redder or stronger color due to clay coatings; C is a mineral horizon, excluding bed rock, relatively unaffected by the major soil-forming processes dominant above, but also modified by weathering, accumulation of and cementation by carbonates, iron, and silica. O designates the layer of organic matter on the surface of a mineral soil; and R is underlying consolidated bed rock, such as sandstone or basalt.

Systems of soils classification

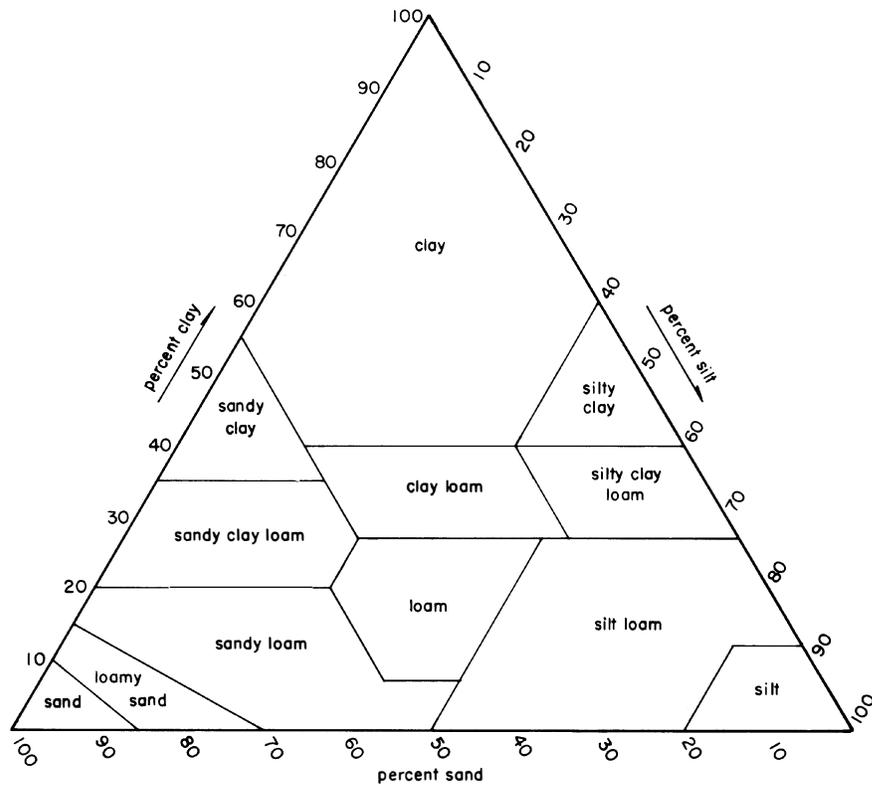
The National Cooperative Soils Survey of the U.S. Department of Agriculture adopted the Seventh Approximation System of Soils Classification in 1965. In it, soils of the nation are grouped hierarchically on the basis of regional climate, physical setting, uniformity and types of horizons, nature of gradation between horizons, and broad textural and compositional features related to plant-growth potential, parent material, genetic horizons, and surface texture. Field recognition of soils textures is summarized in Figure 37. All soils mapping is conducted using the system of classification adopted by the U.S. Department of Agriculture. Because it is based on grain-size distribution, it lends itself well to regional mapping.

Two other major types of soils classification are the Unified Soils Classification System (Table 6) used by the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and soils and foundation engineers; and the AASHO (American Association of State Highway Officials) System (Table 7), used in highway construction.

The Unified Soils Classification System is based on texture and plasticity of ingredients and contains 15 major groupings delineated by their behavior in a remolded or reworked condition. Liquid limit (water content at which soil approaches a liquid state) is used to distinguish clays of high (H) and low (L) compressibility on the Plasticity Chart. Plasticity Index reflects the range of water content in which material exhibits plastic behavior (Figure 38).

Groupings generally do have similar behavior characteristics. The Engineering Soil Classification for Residential Development (Federal Housing Administration, 1959) contains tables showing the general characteristics of the different groups and their relative desirability for various uses with respect to residential building sites for both disturbed and undisturbed soils. Similar tables in the Earth Manual (U.S. Bureau of Reclamation, 1974) describe engineering properties and relative desirability for various uses.

Classification alone is not sufficient information for design planning. Selection of appropriate types and locations of tests requires an understanding of geologic and man-made variations; interpretation of results is based on the particular structure at the site. All of this is best done by engineers or geologists qualified in engineering geology and soil mechanics.



Texture	Dry feel	Moist feel	Moist shine	$\frac{1}{2}$ "-1" wide, $\frac{1}{8}$ " thick moist plasticity (ribbon)	Moist 2"+ long plasticity (wire) $\frac{1}{8}$ "
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	Prominent 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 <u>very</u> sticky - plastic fingerprints	Bright	Long thin ribbon	Wire withstands shaking, rolling, bending, $\frac{1}{16}$ "

Figure 37. Guide to textural classification of soils.

Table 6. Unified Soil Classification System

Major divisions	Group symbols	Typical names	Laboratory classification criteria	
Gravels (More than half of coarse fraction is larger than No. 4 sieve size) Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Clean gravels (little or no fines)	GW Well-graded gravels, gravel-sand mixtures, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3 Not meeting all gradation requirements for GW	
		GP Poorly graded gravels, gravel-sand mixtures, little or no fines		
	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	
	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 Not meeting all gradation requirements for SW	
		SP Poorly graded sands, gravelly sands, little or no fines		
	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	
	Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Sils 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	<p style="text-align: center;">Plasticity Chart</p>
			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				
Sils 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		

*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.

Table 7. 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	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	Greater than 35% passes No. 200	Less than 40	Less than 10	
A-5			Greater than 40		Less than 10		
Clayey soils		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.

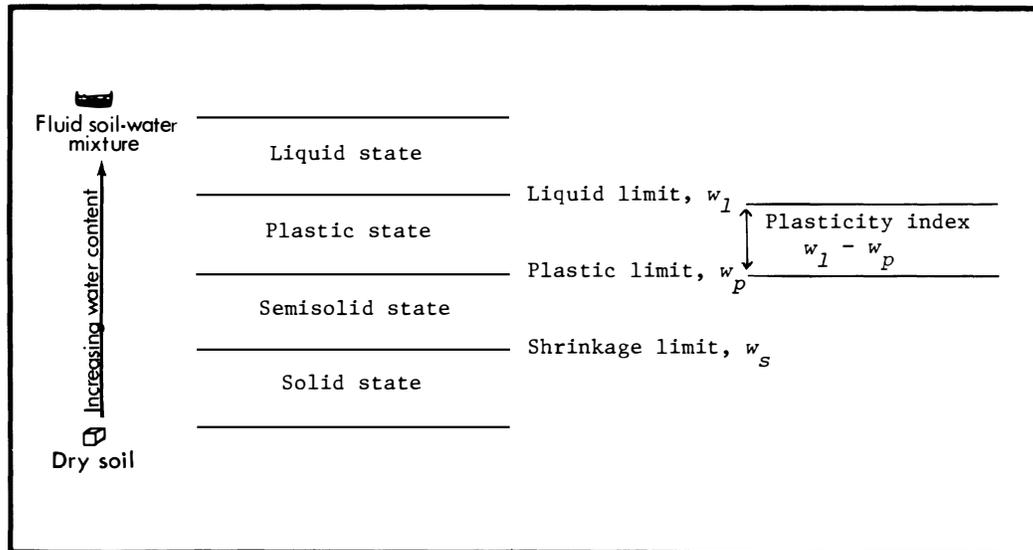


Figure 38. Atterberg limits and related indices. (After Lambe and Whitman, 1969)

Major limitations of the classification systems are that they are based on texture, plasticity, and behavior in a recompacted condition; while the factors influencing strength, consolidation, and expansion depend upon *in situ* consistency and geologic factors. Limitations include variations in soil and regolith formations, hydrologic changes, other site or soil conditions not included in a given description, and complex factors related to mass movement or other large-scale phenomena. Moreover, undisturbed soils in different groups but with similar geologic history and hydrologic conditions may often have more engineering properties in common than will two samples from within the same grouping.

Much additional information regarding application of the Unified Soil Classification System can be found in Engineering Soil Classification for Residential Developments (Federal Housing Administration, 1959) and Soil Sampling and Testing for Residential Developments (U. S. Department of Housing and Urban Development, 1973). Table 8 summarizes the general engineering properties of soil and regolith according to granular, clay, silt, and organic textures. Table 9 and Figure 38 provide a general summary of engineering properties of the surficial geologic units (Q_{ral}, Q_{tl}, Q_{tm}, Q_{th}). Table 3 presents a general overview of differences in physical properties, regolith, drainage, and local hazards of all geologic units.

Distribution

Variations in the five soil-forming factors (parent material, climate, topography, vegetation, and time) produce the many variations of soil type present in Benton County. The influence of parent material is greatest in young soils and is briefly reviewed in the preceding discussions of individual geologic units and their engineering properties.

In Benton County, soils derived from sandstone exhibit a wide range of characteristics from shallow, brown, stony loams to deep, reddish, silty clay loams with some clayey zones. Soils from siltstone are similar but generally finer textured (typically silt loam surface with silty clay or clay subsoil). Basalt bed rock is often overlain by 1- to 3-ft deep, relatively stone-free clay loam or silty clay loam with clay

Table 8. General engineering properties of soils

CATEGORY	DESCRIPTION
<p>GRANULAR SOILS: Sand and gravel</p> <p>Surficial units likely to contain granular soils, in decreasing order of granular properties:</p> <p>Qra1, Qt1 (locally and with silt and clay, most likely near Willamette River)</p> <p>Qtm, Qth (possible locally on surface, but more likely as lenses below surface at depth)</p> <p>Unified Soil Classification symbols: GW, GP, GM, GC, SW, SP, SM, SC</p>	<p>Properties: Sand and gravel have essentially same properties: no cohesion; shear strength dependent on internal friction between grains ($s = f(\phi)$) and generally increasing with grain size; settlement under vibratory loads; properties determined by compactness, grain size, grain-size distribution, and grain shape; cuts cave off at slopes of or greater than 1.5:1 (angle of repose).</p> <p>Construction uses: Excellent for supporting structures and roads; small settlements generally occur shortly after load application; best embankment material due to high shear strength, ease of compaction, and nonsusceptibility to frost action; best backfill for retaining walls, basements, etc., because of small lateral pressures, ease of compaction, easy drainage; not susceptible to frost action; gravels generally more perviously stable and resistant to erosion and piping than sands; well-graded sand and gravel (SW, GW) generally less pervious and more stable than those poorly graded (SP, GP).</p> <p>Drainage: High permeability; excavations below water table require dewatering.</p>
<p>COHESIVE SOILS: Clays, silty clays, clays mixed with sand and gravel</p> <p>Surficial units likely to contain cohesive soils, in decreasing order of cohesive properties:</p> <p>Qt1, Qtm, Qth</p> <p>Bedrock units associated with cohesive soils, in relative decreasing order:</p> <p>Tsr-p, Tsr, Ts, Tf</p> <p>Unified Soil Classification symbols: CL, OL, CH, OH</p>	<p>Properties: Contain high proportion of clay and colloidal-size material, passing #200 sieve; shear strength used with caution and judgment because changes occur during and after construction; shear strength changes from c to $c + \sigma' \tan \phi$ as porewater drains; unit weight, void ratio, water content, shear strength, plasticity, compressibility, sensitivity, swelling pressure are influenced by platelike structure and mineral composition; in general, montmorillonite has greater and illite and kaolinite less adverse effect on properties.</p> <p>Potential problems: Often low shear strength, losing strength when wet; undergo creep at constant load; clay slopes prone to failure.</p> <p>(a) Plasticity: Liquid limit, plastic limit, plasticity index are arbitrary indices describing gradual transition of properties; plasticity index (PI) indicates relative amount of clay particles in soil; highly plastic soils are undesirable for foundations due to excessive settlement, retaining wall movement, and slope failure.</p> <p>(b) Compressibility: Fine voids require long time to extrude air and water; this slow process is called consolidation.</p> <p>(c) Sensitivity: Cohesive soils may lose portion of their strength on disturbance.</p> <p>(d) Expansion and shrinkage: Some clays undergo large volume changes on alternate wetting and drying; high liquid limit and plasticity index often result of more active clay minerals; soils usually hard and cracked ($\frac{1}{2}$ - 1 in. wide) and several feet deep when dry, soft and plastic when wet. Where damage due to shrink/swell is known or suspected, soil samples are tested for shrinkage limit, free swelling, swelling pressure, etc. Foundations on expansive soils often require unusual designs based on knowledgeable interpretations of lab tests, sound judgment, and local experience; for homes the usual remedy is to break the expansion and shrinkage cycle by drainage or keeping foundation constantly wet.</p>

Table 8. General engineering properties of soils (continued)

CATEGORY	DESCRIPTION
COHESIVE SOILS (continued)	<p>Construction uses: Poor backfill due to large lateral pressures; poor embankment material due to low shear strength and compaction difficulty; when compacted, resistant to erosion and piping; not susceptible to frost action; tends to weave and flow under construction equipment.</p> <p>Drainage: Permeability very low, virtually impervious.</p>
<p>SILT*:</p> <p>Surficial units likely to contain silt, in decreasing order:</p> <p>Qtm, Qth</p> <p>Bedrock units likely to contain silt, in decreasing order:</p> <p>Ts, Tf</p> <p>Unified Soil Classification symbols: ML, MH</p>	<p>Properties: Grain size passing #200 sieve; possesses no cohesion and plasticity; properties essentially those of fine sand where composed of angular particles, more similar to clay where composed of platelike particles; bulky grains reduce compressibility; flaky grains, such as mica, increase compressibility and produce elastic silt.</p> <p>Potential problems: Fine particle size results in low shear strength immediately after load application; high capillarity and frost susceptibility.</p> <p>Construction uses: Difficult to compact due to low relative density; difficult to simulate tests corresponding to field conditions; difficult to mix with water; tends to be fluffy when dry and to weave under compaction equipment when too wet; easily erodible and subject to piping and boiling; unconsolidated wet silt easily compressible.</p> <p>Drainage: Relatively impervious; inherently unstable, particularly with increasing moisture; tendency to become quick when saturated.</p>
<p>ORGANIC SOILS:</p> <p>Surficial unit Qtl contains organic soil, occurring locally as peat and swamp deposits in abandoned channels near rivers and streams</p> <p>Unified Soil Classification symbol: PT</p>	<p>Properties: Soils containing sufficient organic matter derived from plant life to influence engineering properties are termed organic; as low as 2 percent organic matter will cause undesirable characteristics; occurs in top soil, leached stratum, swamp and peat deposits near rivers.</p> <p>Potential problems: Low shear strength, high compressibility, spongy structure deteriorates rapidly; subsidence without load when exposed to air in excavation; acidity and properties injurious to construction materials; methane or "swamp gas" product of decomposition; potentially hazardous where accumulates in confined areas, such as manholes.</p> <p>Construction uses: Should not be used to support foundations.</p>

* Pure silt material is seldom encountered in Benton County; clayey silts and silty clays predominate.

Table 9. Engineering properties of surficial geologic units

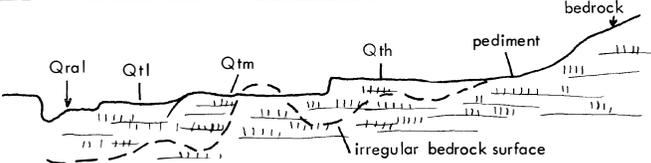
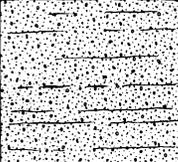
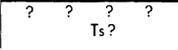
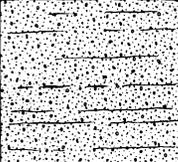
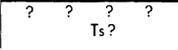
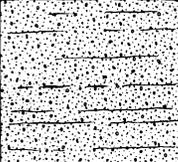
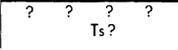
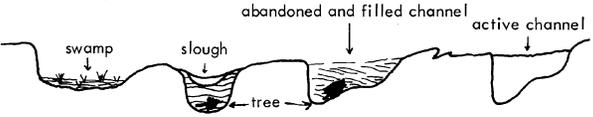
Geologic unit	Description	Generalized section																
<p>Recent river alluvium (Qral):</p> <p>Unconsolidated cobbles, coarse gravel, sand, and some silt within active channels of Willamette River</p>	<p>Restricted map unit of small extent; unsuitable for development due to flooding and major channel change; unit is resource for sand and gravel production (Schlicker and others, 1978), particularly former point-bar deposits; pit-run sand and gravel may be suitable for use as engineered fill and drainage rock.</p>																	
<p>Quaternary lower terrace deposits (Qtl):</p> <p>Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter of variable thickness on lowland terraces above Qral</p>	<p>All units exhibit very similar stratigraphies, although thickness may vary considerably; properties are related to texture of particular stratigraphic section (see Table 8):</p> <p>1. Light-brown silty clay material</p>																	
<p>Quaternary middle terrace deposits (Qtm):</p> <p>Semiconsolidated gravel, sand, silt, and clay forming terraces of major extent along Willamette River</p>	<ul style="list-style-type: none"> ● Widespread in Willamette Valley on all terrace levels except on "decomposed gravels," which resemble Spencer sandstone (Ts). ● Stratigraphic correlation among terrace units near Corvallis suggests a lesser thickness of silt on Qtl terraces. 	<p>Generalized approximate thicknesses of sections within surficial units near Corvallis</p>																
<p>Quaternary higher terrace deposits (Qth):</p> <p>Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 ft) on higher terraces near foothills</p>	<ul style="list-style-type: none"> ● Extensive flood or lacustrine deposits, possibly related to Willamette Silt, of silt and clay. ● High ground-water and ponding potential (severe on Qtl, Qtm, decreasing somewhat locally on Qth); excavations may require dewatering; cut slopes in saturated clayey material prone to failure. ● Somewhat overconsolidated; effective overburden stress greater in past than presently observed; tests indicate preconsolidation at stresses 4,000-8,000 lb/sq ft; means relatively large loads may be applied before settlements occur. ● Bearing capacity range 1,000-2,000 lb/sq ft; general, site-specific investigation and local experience required for design purposes. ● Settlements of concern for larger heavy structures (preloading often employed); minor concern for homes and light structures near surface on spread or continuous footings. ● Expansive properties: slabs or footings near ground surface may swell up to 1 in. if placed on dry soil; swell potential decreases with increasing load; swell is lessened by preventing evaporation in excavations. 	<table border="1"> <tr> <td data-bbox="1102 821 1186 919">TOP (1)</td> <td data-bbox="1207 821 1270 919">15-25 ft</td> <td data-bbox="1281 805 1459 919">  </td> <td data-bbox="1480 821 1690 919">Light brown silty clay; occasional layers fine sand; soft to stiff; somewhat overconsolidated. CH CL</td> </tr> <tr> <td data-bbox="1102 935 1186 1049">MIDDLE (2)</td> <td data-bbox="1207 935 1270 1049">15-35 ft</td> <td data-bbox="1281 919 1459 1049">  </td> <td data-bbox="1480 935 1690 1049">Semiconsolidated fine to medium sands, pebbles, coarse gravels, and cobbles. GP SM</td> </tr> <tr> <td data-bbox="1102 1097 1186 1211">AT DEPTH (3)</td> <td data-bbox="1207 1097 1270 1211">up to 100 ft</td> <td data-bbox="1281 1049 1459 1211">  </td> <td data-bbox="1480 1097 1690 1211">"Overconsolidated" very stiff blue-gray clay and silt with some intervals of fine sand OH MH</td> </tr> <tr> <td colspan="2"></td> <td data-bbox="1281 1341 1459 1391">  </td> <td data-bbox="1480 1341 1690 1391">Ts?</td> </tr> </table>	TOP (1)	15-25 ft		Light brown silty clay; occasional layers fine sand; soft to stiff; somewhat overconsolidated. CH CL	MIDDLE (2)	15-35 ft		Semiconsolidated fine to medium sands, pebbles, coarse gravels, and cobbles. GP SM	AT DEPTH (3)	up to 100 ft		"Overconsolidated" very stiff blue-gray clay and silt with some intervals of fine sand OH MH				Ts?
TOP (1)	15-25 ft		Light brown silty clay; occasional layers fine sand; soft to stiff; somewhat overconsolidated. CH CL															
MIDDLE (2)	15-35 ft		Semiconsolidated fine to medium sands, pebbles, coarse gravels, and cobbles. GP SM															
AT DEPTH (3)	up to 100 ft		"Overconsolidated" very stiff blue-gray clay and silt with some intervals of fine sand OH MH															
			Ts?															

Table 9. Engineering properties of surficial geologic units (continued)

Geologic unit	Description	Generalized section
<p>Qtl, Qtm, and Qth (continued):</p>	<ul style="list-style-type: none"> ● Sensitivity: remolded strength less than undisturbed strength; easily disturbed by construction traffic when wet; sticky; plastic construction material weaves under traffic. ● Backfill: greater lateral pressure when compacted than granular backfill; when not compacted, may soften nonuniformly. ● Landscaping: generally used for landscaping fill. <p>2. Sand and gravel layer(s) below surface</p> <ul style="list-style-type: none"> ● Generally occur 30 – 40 ft below ground on Qtm terrace near Corvallis and Willamette River. ● Locally fine to medium sands occur between overlying silt and sandy gravel. ● Bearing capacity range of 3,000 – 4,000 lb/sq ft; provides firm bearing for bridge pilings along Willamette River. ● Greater permeability; more water problems in construction. <p>3. "Overconsolidated" stiff blue clay</p> <ul style="list-style-type: none"> ● "Overconsolidated" to approximately 10 tons/sq ft. ● Ground water and depth of occurrence generally make foundations other than piles uneconomic. 	
<p>Quaternary lower terrace deposits (Qtl):</p> <p>Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter of variable thickness on lowland terraces above Qral and along tributary rivers and streams</p>	<p>Local peat and swamp deposits, most likely adjacent to Willamette River, in abandoned channels, oxbows, and along river and stream drainages.</p> <ol style="list-style-type: none"> 1. Engineering properties variable: good foundation capacity (bearing capacity and settlement) where well-drained; differential settlement and slab and foundation cracking possible where unconsolidated silt and clay, organic soils, and peat occur locally with high ground water and ponding. 2. Low shear strength; high compressibility; spongy structure deteriorates rapidly; subsidence without load if exposed in excavations; acidity and characteristics injurious to construction materials; should not be used for foundation support (pilings often used). 3. Expansive properties of clay and organic soils. 4. Generally subject to flooding. 	

subsoil, generally with well-developed profiles (Hammermeister, 1978).

Table 10 relates soils to geologic units in Benton County and summarizes engineering classifications and other factors, as determined by the Soil Survey of the Benton County Area, Oregon (Knezevich, 1975). The table shows that for the surficial deposits (1) sand and gravel occur near the surface only along the Willamette River and its flood plain, (2) silty clay and clay occur along lowland areas of tributaries and smaller streams, (3) silt loam and silty clay loam occur on broad flat Q_{tm} and Q_{th} surfaces, and (4) soils indicative of relation to sedimentary bed rock ("decomposed gravels" of Vokes and others, 1954) occur on Q_{th} deposits south of Philomath and in south County areas. For low foothill areas, Jory and Bellpine soils are common to all units. Soils names are listed in relative order of abundance; i.e., those at the top of the list are most abundant.

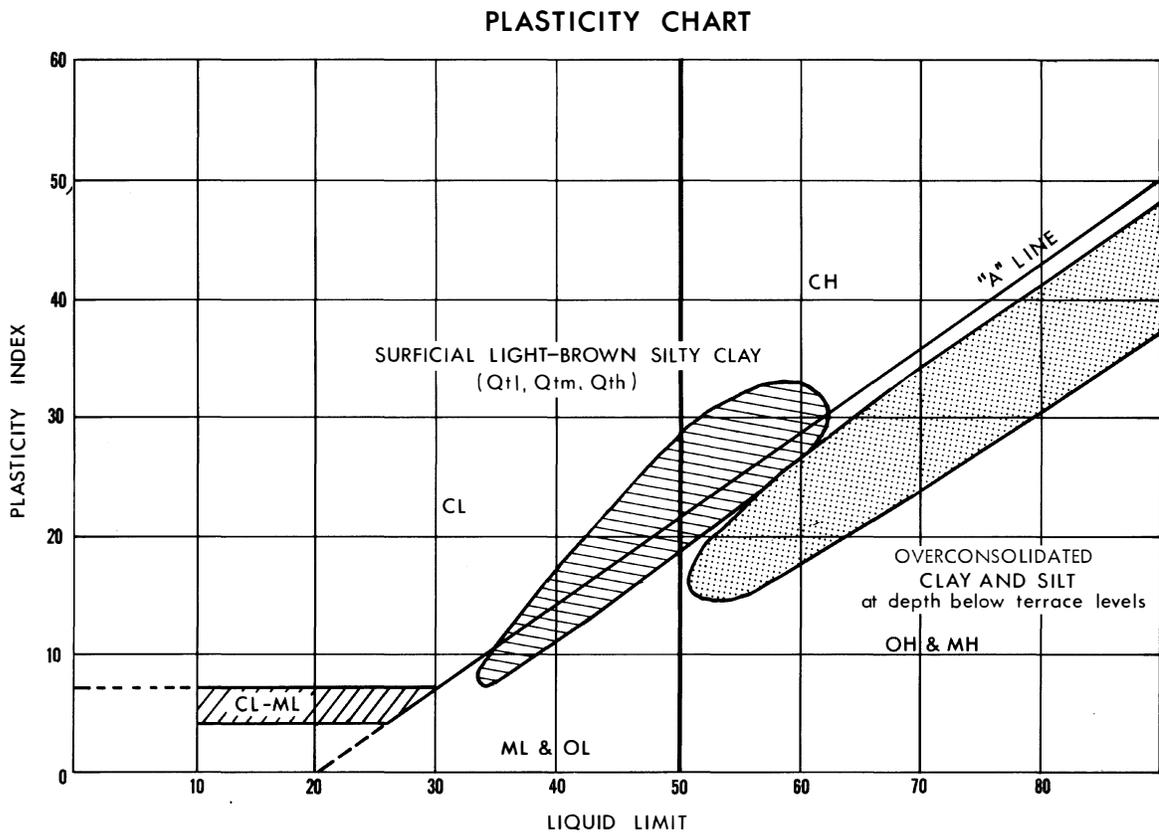


Figure 39. Plasticity chart showing general indices of surficial geologic units. (After Deacon and Fujitani, 1968)

Table 10a. Relationship of soils to surficial geologic units, eastern Benton County, Oregon*

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
Qral		Newberg: Ng, Nm Riverwash: Rw Too variable to estimate; onsite investigation needed Mixed alluvial land: MX Too variable to estimate; onsite investigation needed	B	>72	60	0-60	Fine sandy loam and loam	SM or ML	A-4	
Qtl	Flood plain of Willamette River	Newberg: Ng, Nm	B	>72	60	0-60	Fine sandy loam and loam	SM or ML	A-4	
		Chehalis: Ch Cloquato: Cm Camas: Ca Malabon: Ma	B B A C	>72 >72 >72 >72	>60 >60 >60 >60	0-60 0-60 0-7 7-60 0-65	Silty clay loam Silt loam Gravelly sandy loam Very gravelly sand Silty clay loam and silty clay	CL or ML ML GM or SM GW ML	A-6 A-4 or A-6 A-1 A-1 A-7	
Qtl	Flood plains of tributary rivers and streams	Bashaw: Ba	D	>60	0-6	0-15 15-60	Silty clay loam Clay	CL or ML CH	A-6 A-7	
		Bc	D	>60	0-6	0-60	Clay	CH	A-7	
		Waldo: Wa	D	>60	0-6	0-11	Silty clay loam and silty clay	CL	A-7	
		Coburg: Cn	C	>72	20-36	11-60	0-43	Clay	MH	A-7
						43-60	Clay loam and sandy clay loam	ML or SM	A-6 or A-4	
		Malabon: Ma	C	>72	>60	0-65	Silty clay loam and silty clay	ML	A-7	
		McAlpin: Mn	C	>40	18-36	0-14 14-60	Silty clay loam Silty clay	ML ML or CL	A-6 A-7	
		Abiqua: AbA, AbB	C	>40	>40	0-17 17-60	Silty clay loam Silty clay and clay	CL or ML MH	A-6 A-7	
		Conser: Cs	C/D	>72	0-6	0-17 17-60	Silty clay loam Clay	CL CH	A-6 A-7	

ENGINEERING PROPERTIES OF GEOLOGIC UNITS—SOILS

Table 10a. Relationship of soils to surficial geologic units, eastern Benton County, Oregon* (continued)

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
QtI		Woodburn: WoA, WoC	C	>72	18-36	0-24 24-48	Silt loam Silty clay loam	ML ML or CL	A-4 A-4	
		Nehalem: Ne	B	>72	24-40	48-60 0-60	Silt loam Silty clay loam	ML or CL ML or CL	A-6 A-6	
Qtm		Dayton: Da	D	>72	0- 6	0-15 15-45	Silt loam and silty clay loam Clay	ML CH	A-4 A-7	
		Amity: Am	C	>72	12-24	45-60 0-22	Silty clay loam Silt loam	CL ML	A-6 A-4	
		Woodburn: WoA, WoC	C	>72	18-36	22-60 0-24	Silty clay loam Silt loam	CL or ML ML	A-7 A-4	
		Willamette: WeA, WeC	B	>72	>72	24-48 48-60	Silty clay loam Silt loam	ML or CL ML or CL	A-4 A-6	
		Malabon: Ma	C	>72	>60	0-15 15-57	Silt loam Silty clay loam	ML ML or CL	A-4 A-7	
		Coburg: Cn	C	>72	>60	57-60 0-65	Silt loam Silty clay loam	ML or CL ML	A-6 A-7	
						20-36	0-43	Silty clay loam and silty clay	CL	A-7
						43-60	Clay loam and silty clay	ML or SM	A-6 or A-4	
						0- 6	0-26	Silt loam	CL or ML	A-4
						26-38	Silty clay loam and silty clay	CL or ML	A-7	
Qth	Flat slopes in Corvallis, Philomath, and North County areas	Woodburn: WoA, WoC	C	>72	18-36	0-24 24-48	Silt loam Silty clay loam	ML ML or CL	A-4 A-4	
		Willamette: WeA, WeC	B	>72	>72	48-60 0-15	Silt loam Silt loam	ML or CL ML	A-6 A-4	
		Dayton: Da	D	>72	0- 6	15-57 57-60	Silty clay loam Silt loam	ML or CL ML or CL	A-7 A-6	
						0-15	Silt loam and silty clay loam	ML	A-4	
		Amity: Am	C	>72	12-24	15-45 45-60	Clay Silty clay loam	CH CL	A-7 A-6	
					0-22	Silt loam	ML	A-4		
					22-60	Silty clay loam	CL or ML	A-7		

Table 10a. Relationship of soils to surficial geologic units, eastern Benton County, Oregon* (continued)

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification		
							Dominant USDA texture	Unified	AASHO
Qth	Dissected flat to moderate slopes south of Philomath	Veneta: VeB, VeD	C	40- >60	**	0-27	Silty clay loam	ML	A-4
		Veneta, loamy subsoil variant: VnB, VnD, VnE	C	30-40	**	27-60	Clay and silty clay	CH	A-7
						0-11	Loam	ML	A-4
						11-40	Clay loam	ML	A-6
	Base of foothills and islands in south county areas	Jory: JoC, JoD, JoE, JRE, JRF	C	>40	**	0-15	Silty clay loam	ML	A-6
						15-60	Clay or silty clay	CL or ML	A-7
		Bellpine: BeC, BeD, BeE, BeF	C	20-40	**	0-10	Silty clay loam	CL	A-6
						10-26	Clay and silty clay	MH	A-7
						26	Partially weathered sandstone		
						0- 5	Silty clay loam	CL	A-6
Dixonville: DnC, DnD, DnE, DnF	C	20-40	**	5-37	Clay or silty clay	CH	A-7		
				37	Weathered basalt				

* Knezevich (1975).

** Seasonal high water table at a depth of less than 60 in. does not occur in these soils.

Table 10b. Relationship of soils to sedimentary bedrock geologic units, eastern Benton County, Oregon*

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
Ts - early Oligocene sandstone		Dixonville: DnC, DnD, DnE, DnF	C	20-40	**	0- 5 5-37 37	Silty clay loam Clay or silty clay Weathered basalt	CL CH	A-6 A-7	
	Foothills	Jory: JoC, JoD, JoE, JRE, JRF	C	>40	**	0-15 15-60	Silty clay loam Clay or silty clay	ML CL or ML	A-6 A-7	
Bellpine: BeC, BeD, BeE, BeF		C	20-40	**	0-10 10-26 26	Silty clay loam Clay and silty clay Partially weathered sandstone	CL MH	A-6 A-7		
***Hazelair: HaC, HeC, HeD		D	20-40	12-30	0-23 23-33 33	Silt loam and silty clay loam Clay Fragmented siltstone	CL CH	A-6 A-7		
Hazelair, well-drained variant; mapped only in complex with Hazelair		D	20-40	**	0-19 19-24 24	Silty clay loam and light silty clay Clay Weathered siltstone	CL CH	A-6 A-7		
Veneta: VeB, VeD		C	40- >60	**	0-27 27-60	Silty clay loam Clay and silty clay	ML CH	A-4 A-7		
Veneta, loamy sub-soil variant: VnB, VnD, VnE		C	30-40	**	0-11 11-40 40	Loam Clay loam Weathered sandstone	ML ML	A-4 A-6		
Mountainous broad ridges, long slopes dissected by streams		Honeygrove: HgC, HND, HNF, HOD	C	>60	**	0- 8 8-60	Silty clay loam Clay	ML MH	A-4 A-7	
		Peavine: PEE, PEF	C	30-40	**	0- 6 6-40 40	Silty clay loam Clay Shale	CL or ML MH or CH	A-7 A-7	
Ts-p		Pediments - Soils in pediments of late Eocene sandstone (Ts) include a broad range of silt loam (including Woodburn, Willamette, Dayton, Amity, Veneta, Dupee) and silty clay loam (including Bellpine, Coburg, and Dixonville)								

Table 10b. Relationship of soils to sedimentary bedrock geologic units, eastern Benton County, Oregon* (continued)

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification		
							Dominant USDA texture	Unified	AASHO
Tf - middle Eocene sandstone (Flournoy Formation)	Foothills	Jory: JoC, JoD, JoE, JRE, JRF	C	> 40	**	0-15	Silty clay loam Clay or silty clay	ML CL or ML	A-6 A-7
						15-60			
		Bellpine: BeC, BeD, BeE, BeF	C	20-40	**	0-10	Silty clay loam Clay and silty clay	CL MH	A-6 A-7
						10-26			
		***Hazelair: HaC, HeC, HeD For Hazelair, well-drained variant part of HeC and HeD, see Hazelair, well-drained variant	D	20-40	12-30	0-23	Silt loam and silty clay loam Clay	CL CH	A-6 A-7
						23-33			
		Hazelair, well-drained variant; mapped only in complex with Hazelair	D	20-40	**	0-19	Silty clay loam and light silty clay Clay	CL CH	A-6 A-7
						19-24			
		Veneta: VeB, VeD	C	40- > 60	**	0-27	Silty clay loam Clay and silty clay	ML CH	A-4 A-7
						27-60			
		Veneta, loamy subsoil variant: VnB, VnD, VnE	C	30-40	**	0-11	Loam Clay loam	ML ML	A-4 A-6
						11-40			
		Steiwer	C	20-40	> 72	0-16	Loam or silt loam Clay loam, gravelly clay loam	ML ML	A-4 A-7
						16-29			
Mountainous broad ridges, long slopes, dissected by streams	Apt: ApC, ASD, ASF, ATD Honeygrove: HgC, HND, HNF, HOD	C	> 60	**	0-10	Silty clay loam Clay	CL or ML MH	A-6 A-7	
					10-60				
					0- 8				
						8-60	Silty clay loam Clay	ML MH	A-4 A-7

Table 10b. Relationship of soils to sedimentary bedrock geologic units, eastern Benton County, Oregon* (continued)

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
		***Ritner: RPE, RPG For Price part of RPE and RPG, see Price series	C	30-40	**	0-15	Gravelly silty clay loam	GM or ML	A-6	
						15-40	Very cobbly silty clay	GM or GC, CL, CL-ML	A-7 or A-2	
		Dixonville: DnC, DnD, DnE, DnF	C	20-40	**	40	Fractured basalt			
						0- 5 5-37 37	Silty clay loam Clay or silty clay Weathered basalt	CL CH	A-6 A-7	
Mountainous broad ridges, long slopes, dissected by streams	Apt: ApC, ASD, ASF, ATD Honeygrove: HgC, HND, HNF, HOD	C	>60	**	0-10	Silty clay loam	CL or ML	A-6		
					10-60	Clay	MH	A-7		
						0- 8	Silty clay loam	ML	A-4	
						8-60	Clay	MH	A-7	

* Knezevich (1975).

** Seasonal high water table at a depth of less than 60 in. does not occur in these soils.

*** At least one mapping unit in this series contains more than one kind of soil; these soils may have different properties or limitations, and it is therefore necessary to follow carefully the instructions for referring to other series.

Table 10c. Relationship of soils to igneous bedrock geologic units, eastern Benton County, Oregon*

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
Tsr - Eocene volcanic rock (Siletz River Volcanics)	Lowland drainageways	Bashaw: Ba	D	> 60	0- 6	0-15	Silty clay loam	CL or ML	A-6	
		Bc	D	> 60	0- 6	15-60	Clay	CH	A-7	
		Waldo: Wa	D	> 60	0- 6	0-60	Clay	CH	A-7	
						0-11	Silty clay loam and silty clay	CL	A-7	
		Witham: WkB	D	40	12-30	11-60	Clay	MH	A-7	
		Briedwell: BrB, BrD	B	> 40	> 72	0-60	Silty clay and clay	CH	A-7	
	Foothills	Jory: JoC, JoD, JoE, JRE, JRF Bellpine: BeC, BeD, BeE, BeF ***Price: PrC, PrD, PTE, PTF For Ritner part of PTE and PTF, see Ritner series ***Ritner: RPE, RPG For Price part of RPE and RPG, see Price series Dixonville: DnC, DnD, DnE, DnF Philomath: PhC, PhE	C	> 40	**	0-15	0-15	Silty clay loam	ML	A-6
								Clay or silty clay	CL or ML	A-7
								Silty clay loam	CL	A-6
								Clay and silty clay	MH	A-7
								Partially weathered sandstone		
								Silty clay loam and light silty clay	ML	A-7
	Mountainous broad ridges, long slopes, dissected by streams	Honeygrove: HgC, HND, HNF, HOD Bohannon: BOF, BOG	C	> 60	**	0- 8	0- 8	Silty clay loam	ML	A-4
								Clay	MH	A-7
								Gravelly loam	SM	A-4 or A-2
								Gravelly clay		
								Weathered basalt		
								Partially weathered sandstone		

Table 10c. Relationship of soils to igneous bedrock geologic units, eastern Benton County, Oregon* (continued)

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification			
							Dominant USDA texture	Unified	AASHO	
Tsr-p		Blachly: BLE, BLF	C	>60	**	0- 6	Silty clay loam	MH	A-5	
		Klickitat: KKF, KKG	C	40-50	**	6-60 0-48	Silty clay Gravelly clay loam and very cobbly clay loam	MH GC or GM	A-7 A-2 or A-6	
		Witzel: WLG	D	12-20	**	48 0-15	Fractured basalt Very cobbly clay loam	GC or CL	A-6	
	Pediments		Witham: WkB	D	40	12-30	15 0-60	Fractured basalt Silty clay and clay	CH	A-7
			Bashaw: Ba	D	>60	0- 6	0-15	Silty clay loam	CL or ML	A-6
			Bc	D	>60	0- 6	15-60	Clay	CH	A-7
			Waldo: Wa	D	>60	0- 6	0-60 0-11	Clay Silty clay loam and silty clay	CH CL	A-7 A-7
			Abiqua: AbA, AbB	C	>40	>40	11-60 0-17	Clay Silty clay loam	MH CL or ML	A-7 A-6
			***Price: PrC, PrD, PTE, PTF	C	40-60	**	17-60 0-20	Silty clay and clay Silty clay loam and light silty clay	MH ML	A-7 A-7
			For Ritner part PTE and PTF, see Ritner series				20-50	Gravelly clay Weathered basalt	MH	A-7
			Dixonville: DnC, DnD, DnE, DnF	C	20-40	**	0- 5 5-37 37	Silty clay loam Clay or silty clay Weathered basalt	CL CH	A-6 A-7

* Knezevich (1975).

** Seasonal high water table at a depth of less than 60 in. does not occur in these soils.

*** At least one mapping unit in this series contains more than one kind of soil; these soils may have different properties or limitations, and it is therefore necessary to follow carefully the instructions for referring to other series.

Table 10d. Relationship of soils to intrusive rock geologic units, eastern Benton County, Oregon*

Unit	Location	Soil name and soils map symbols	Hydro-logic group	Depth to bed rock (in.)	Depth to seasonal high water table (in.)	Depth from surface of typical profile (in.)	Classification		
							Dominant USDA texture	Unified	AASHO
Ti - post-Eocene intrusive rocks	Mountainous broad ridges, long slopes, dissected by streams	Marty: MGD, MGF	B	>60	**	0-65	Gravelly loam and clay loam	ML, MH, or SM GC or GM	A-7 and A-5 A-2 or A-6
		Klickitat: KKF, KKG	C	40-50	**	0-48	Gravelly clay loam and very cobbly clay loam		
		Honeygrove: HgC, HND, HNF, HOD	C	>60	**	48 0- 8 8-60	Fractured basalt Silty clay loam Clay	ML MH	A-4 A-7
	Foothills	***Price: PrC, PrD, PTE, PTF For Ritner part of PTE and PTF, see Ritner series Jory: JoC, JoD, JoE, JRE, JRF Bellpine: BeC, BeD, BeE, BeF	C	40-60	**	0-20 20-50 50	Silty clay loam and light silty clay	ML	A-7
							Gravelly clay Weathered basalt	MH	A-7
			C	>40	**	0-15 15-60	Silty clay loam Clay or silty clay	ML CL or ML	A-6 A-7
C	20-40	**	0-10 10-26 26	Silty clay loam Clay and silty clay Partially weathered sandstone	CL MH	A-6 A-7			

* Knezevich (1975).

** Seasonal high water table at a depth of less than 60 in. does not occur in these soils.

*** At least one mapping unit in this series contains more than one kind of soil; these soils may have different properties or limitations, and it is therefore necessary to follow carefully the instructions for referring to other series.

GEOLOGIC HAZARDS

Orderly development which insures public health, safety, and welfare is complex. The complexity is greatly reduced when planners understand the natural characteristics of the land, the processes that shape it, and geologic hazards affecting it, and when they apply that knowledge in the guidance of growth. Geologic hazards of concern to the planner include mass movement, soil erosion, stream flooding (not a part of this study), stream erosion and deposition, and earthquake potential. Each hazard is characterized by unique distribution, causes, and ranges of impacts. In this report, recommendations for treatment or mitigation of geologic hazards allow for variations in physical, social, political, and economic settings. The distribution of geologic hazards based on reconnaissance investigations is indicated on the accompanying geologic maps.

Mass Movement

General

Mass movement is the movement of rock or soil material downslope in response to gravity and seepage forces. Table 3 summarizes several kinds of mass movement in the study area, including earthflow, steep-slope mass movement (debris flow, debris avalanche, rockfall, and rockslide), creep, and potential mass movement. The parts of this study dealing with mass movement are reconnaissance in nature and are valuable tools for regional planning and guides to on-site evaluation. They are not substitutes for on-site investigation, however.

Causes

Mass movement occurs on slopes where the downslope component of gravity exceeds the shear resistance of the slope material. Ground water and seepage also contribute to the loss of strength. In areas of sliding, potential sliding, low cut-slope stability, or hazardous slopes, man's activities should be controlled to assure that slope equilibrium is not altered seriously.

Downslope gravity component: The weight of a potential slide mass, which is usually regolith material, is increased by the placement of fill for road construction or other purposes, saturation during winter rains, and artificial obstruction of surface and shallow subsurface runoff by improperly designed roads, poorly located dwellings, and other developments.

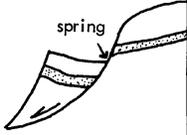
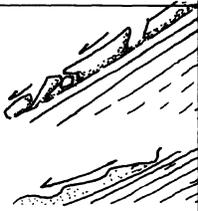
Models of slope failure presuppose that the weight of the regolith column is perpendicular to the earth's surface. Where nearby blasting or seismicity is a factor, a horizontal component of acceleration is introduced along with the vertical gravity component. From an engineering standpoint, the resulting inclined direction of acceleration has the same effect as would steepening of the slope. Also to be considered is the disaggregation and consequent loss of strength caused by the blasting of regolith.

Shear resistance: The buoying up of soil particles under saturated conditions reduces internal friction and shear resistance. When rainfall, drainage interference, or blocking of springs causes soil saturation, shear resistance decreases and possibility of sliding increases. Heavy rain may cause infiltration to exceed the rate of shallow subsurface drainage, so that the liquid limit of the soil is actually exceeded (Campbell, 1975) (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Drainage). Debris flows in colluvial pockets over impermeable bed rock may result.

Cohesion, the mutual attraction of clay particles, varies with soil type and water content. Clay-rich soils can generally accommodate large quantities of water before reaching their liquid limit. Loss of cohesion produces slow-moving earthflows.

Root support by trees is now recognized as a primary agent of stability in colluvial areas on steeply

Table 11. Mass movement in eastern Benton County, Oregon

	Relative occurrence*	Type	Water content	Description	Distribution
Earthflow and slump	○	Deep bedrock slide 	Variable	Slow to rapid downward movement of rock or regolith along a curved or irregular basal shear plane; accompanied by backward rotation of the slide block; characterized by pronounced headscarp overlooking irregular, more gently sloping terrain.	Moderately steep to steep slopes in youthful valleys of moderately large to large streams; more common in faulted or jointed terrain and areas of interbedding of distinctly differing rock types, particularly at contacts with intrusive rocks; favored by deep percolation of ground water.
	●	Shallow earthflow and slump topography 	Variable	Slow to rapid downslope movement of regolith along numerous shear planes in a manner analogous to highly viscous flow; generally accompanied by rotational failure upslope; characterized by irregular topography, sag ponds, and irregularities of soil distribution and drainage; commonly too small to be detected with aerial photography.	Moderately steep to steep slopes in areas of low surface runoff and significant chemical weathering; most common also along faults, joints, and bedrock contacts; also common in heads of gullies or in areas of natural or artificial undercutting of regolith, as along streams and roadcuts; units include Tsr, Tsrk, Tf, Ts, and surficial units along rivers and streams.
Creep	●	Creep 	Variable	Random, very slow, particle-by-particle movement of soil and rock fragments downslope in response to gravity and other random and surficial external forces such as root action, freeze-thaw and wet-dry expansion and contraction, and animal activity; greatest displacement at surface; no slip plane; characterized by bowed trees and tilted fence posts; forms convex slopes.	Moderate to steep slopes where clay-rich, expansive regolith, including colluvium, overlies impermeable bed rock; most widespread in Tsr in gullies and hillside drainages and at break in slope with pediments; also occurs in Tf, Ts, Tsrk, and Ti bedrock units.
Steep slope mass movement	◐	Debris avalanche and debris flow 	Low to moderate High	Rapid flow or sliding of regolith down steep slopes along bedrock surfaces approximately parallel to slope; characterized by linear deposits of unvegetated colluvium in steep drainageways; often forms fan-shaped deposits in streams at base of drainageways.	Steep to very steep slopes (greater than 50% average regional slope) where regolith overlies impermeable bed rock and where shallow subsurface flow is significant, as in steep linear drainageways; favored by silty and silty-clay soils prone to liquefaction when saturated and by removal of vegetation and consequent loss of root support; units include Tsr, Tf, and Ti.
	○	Rockfall and rockslide 	Minor	Falling and rolling rock at the base of cliffs; characterized by unvegetated talus or scattered boulders on slopes beneath cliffs of jointed or faulted hard bed rock.	Very steep slopes with exposures of jointed or faulted bed rock; occurs in parts of Tsr, Tf, and Ti.

* ● Relatively high or great ◐ Variable ○ Relatively low or small

sloping terrain. Root support declines rapidly after logging, and many slides in logged areas are attributed to the loss of root support through root decay (Burroughs and Thomas, 1977). In wooded areas however, it is doubtful that, by itself, increased soil moisture associated with logging has a measurable impact on slope stability.

Distribution

Table 11 lists the prevalent types of mass movement in the study area; provides a general definition and description of each type of mass movement; and summarizes the distribution of each in terms of slope, landform, bed rock, structure, and associated ground-water features.

Interpretation of mass movement on the geologic hazards section on the geologic maps is based upon extensive field reconnaissance, topographic analysis, consideration of slide mechanics, and aerial photographic analysis (scale 1:20,000 with a 3X magnifier). More refined delineation incurs additional expense for more detailed field work, larger scale photographs, and larger map scale. Locally, remote sensing, geophysics, and site monitoring can be appropriately utilized in highly critical areas.

The planner must be concerned with both existing and potential landslides. Cut-slope failures resulting from improperly engineered cuts can generally be avoided by following the provisions of the Uniform Building Code, Chapter 70. Critical features such as jointing, bedding, clay content, and drainage, however, present special problems. These factors and cut-slope stability are discussed in the section entitled ENGINEERING PROPERTIES OF GEOLOGIC UNITS.

Another category of future slides encompasses slides that will be initiated by natural or artificial means other than cuts, including overloading, changes of drainage, and removal of vegetation. Table 12 summarizes engineering properties of geologic units in the study area as they relate to sliding, types of future slides, and man's activities which may contribute to sliding. Interpretation of slide potential is based primarily on slide causes discussed in ENGINEERING PROPERTIES OF GEOLOGIC UNITS.

The distribution of present mass movement features is presented on the geologic maps. Additional areas of present or potential mass movement can be inferred on a regional basis using overlays of slope, critical topographic features, and rock type (Table 11). More detailed maps of local extent can be generated by detailed plotting of engineering features that contribute to sliding in each of the geologic rock units (Table 12).

Impacts

Impacts of mass movement vary with the types of mass movement under consideration. Bedrock slides and deep bedrock failures do not appear widespread in Benton County. They may exist locally, however, and are probably associated with contacts near intrusive rocks (Figure 40). They may be either active or inactive and have associated with them irregular ground water and drainage conditions, highly variable foundation suitabilities and cut-slope stabilities, and secondary slides in eroding areas.

Earthflow and slump topography are widespread in Benton County and are associated with poor drainage, shallow subsurface flow of ground water, springs, thick accumulations of clay-rich colluvium in drainageways (Figure 41), and the possibility of ongoing movement that can destroy such man-made structures as roads and buildings. In addition, active earthflows leading into streams adversely affect water quality. Earthflow and slump topography are also common to broad open slopes of all bedrock units, where depth of regolith to bed rock is shallow (Figure 42). Individual events are relatively small (15 ft by 30 ft to 20 ft by 50 ft), more numerous in gullies and drainages where active soil creep is also occurring, and often self-healing. They are often not evident in aerial photographs.

Debris flows and debris avalanches generally occur in uninhabited areas and therefore pose greatest threats to water quality and the forest resource (Figure 43). Logging roads are particularly subject to damage. Another impact is topsoil loss, which in extreme instances reduces the water-retention capabilities of regolith, thereby contributing to local areas of increased storm runoff.

Although rockfall and rockslide are minor hazards in most of the study area, they pose threats to hikers and motorists in the more steeply sloping terrain. Rolling rocks in areas of high relief occasionally travel considerable distances beyond the bases of slopes from which they were derived.

Table 12. Slide potential of geologic units, eastern Benton County, Oregon

		General rating											Types of slides and activities which promote sliding				
		●	◐	◑	◒	○	—	○	◑	◒	◐	●					
		Relatively high or great	Variable	Moderate	Relatively low or small	Not applicable		Shallow subsurface flow	Deep subsurface flow	Joint development	Bedding distinctness	Slope intensity	Regolith on steep slopes (ft)	Regolith on gentle slopes *	Cut slope stability	Earthflow and slump topography	Steep slope mass movement
Surficial geologic units	Recent river alluvium Qral	●	●	—	◐	○	—	●	○	○	○	—	●	○	○	○	Present and future earthflow and slump failures generally restricted to cutbanks along rivers, streams, and cut slopes in terrace material; areas of unfavorable ground water conditions or incompetent interbeds important in deep cuts; shallow subsurface flow initiates failure in cut slopes in Qth south of Philomath.
	Quaternary lower terrace deposits Qtl	●	●	—	◐	○	—	●	○	○	○	—	●	◐	○	—	
	Quaternary middle terrace deposits Qtm	●	●	—	◐	○	—	●	○	○	○	—	●	◐	○	○	
	Quaternary higher terrace deposits Qth	◐	◐	—	◐	○	—	◐	◐	○	○	—	◐	◐	○	○	
Sedimentary rock	Early Oligocene sandstone Tts	◐	○	◐	◐	◐	1-2	4	◐	○	○	—	4	◐	○	○	Earthflow and slump topography generally; also result from steep undercutting in youthful terrain; debris flow and debris avalanche in steep terrain often initiated by loss of root strength following logging; cut slopes prone to shallow slumps and raveling of swelling clay-rich sediments, forming basal slopes often filling ditches.
	Later Eocene sandstone Ts	◐	○	◐	◐	◐	1-2	4	◐	○	○	—	4	◐	◐	○	
	Middle Eocene sandstone Tf	◐	○	◐	●	◐	2	4	◐	○	○	—	4	◐	◐	●	
	Kings Valley siltstone Tsrk	●	○	◐	◐	◐	—	4	◐	○	○	—	4	◐	○	○	
Volcanic rock	Eocene volcanic rock Tsr	●	●	◐	◐	◐	1	4-10	◐	○	○	—	4	◐	◐	●	Earthflow and slump topography most widespread; shallow on broad open slopes where regolith is thin; cut slopes in clay-rich colluvium in drainageways on moderate to steep slopes likely to initiate slides; cut slope failures in deeply weathered thick colluvium, tuff, sedimentary interbeds, breccia on all slopes; other failures the result of improper cuts or poor drainage control alteration; potential for debris flow and debris avalanche, rockfall and rockslide in steep terrain.
Intrusive rock	Post-Eocene intrusive rock Ti	○	◐	◐	—	◐	1	4	●	○	○	—	4	●	○	●	Major slumps involving bed rock occur locally at contacts with sedimentary rocks adjacent to stream valleys generally of high relief; may be active or inactive; future slides primarily debris flows and debris avalanches on steeply sloping terrain in areas of saturation, thick regolith, and removal of vegetation; cut slopes of sedimentary rocks often prone to shallow slumping and raveling due to fracturing and alteration related to unmapped intrusive rocks.

* Numbers indicate feet



Figure 40. Large slump blocks related to deep bedrock sliding along contact between post-Eocene intrusive rock (Ti) forming ridge at left and later Eocene sandstone (Ts) near Decker and Peterson Roads, west of Greenberry. Vegetation marks springs around margins of slump block. Note flat benchlike surface. Creep (note tree leaning downslope) and shallow earthflow and slump topography are common on downslope portions of slump block. Similar deep bedrock slides and earthflow and slump topography can be anticipated along contacts between (Ti) and sedimentary rocks throughout Benton County.

Recommendations

Reliance on human memory to completely define slide hazards is not enough. Memory is incomplete and often inaccurate and makes no allowance for changing stability with changing land use. Furthermore, it does not provide the sophistication required to address all pertinent factors of potential mass movement.

The grading provisions of the Uniform Building Code, Chapter 70, should be followed in all cuts and fills. Cuts steeper than 30 degrees in siltstone and fine-grained sediments of sedimentary units (Tf, Ts, Tsrk) tend to ravel and fill ditches at the bases of slopes, presenting constant maintenance problems. Where cut heights are shallow to moderate, utilization of flatter slope angle will minimize maintenance. On steep slopes, areas with mass movement potential, or areas with past mass movement, more detailed and rigorous treatment is generally required. Some of these areas are identified in the geologic hazards section of the geologic maps of this report. Others that require more detailed mapping are identified in Tables 11 and 12.

Areas of special concern

With changing land use and multiple land uses of specific parcels of land, areas of critical mass movement such as Vineyard Mountain near Corvallis are occasionally identified. Land management decisions in areas of special concern require systematic analysis of data and ongoing data collection. Consideration of many of the areas northwest of Corvallis illustrates the procedures that can be followed and the types of data that should be collected. This discussion is more technical and is intended in part for use by the resource specialist.

Figure 44 shows the steps that can be followed in land management analysis of critical mass movement potential. Landslide Hazard Study, Vineyard Mountain Subdivision, Corvallis, Oregon (Shroeder and Swanston, 1975) follows a similar approach. Step 1 is to identify geologic units and hazards. In many areas northwest of Corvallis, the unit is Siletz River Volcanics (Tsr) and the hazards are shallow earthflow



Figure 41a. Mudslide in saturated clay-rich colluvium that accumulated in drainage-way on moderately steep to steep slopes within Eocene volcanic rock (Tsr). Slide blocks Cardinal Drive on Vineyard Mountain north of Corvallis during heavy rains in December 1977. Slide surface was base of colluvium overlying tuffaceous sediments. Springs or shallow subsurface flow in colluvium makes cut slopes particularly unstable. (Photo courtesy Corvallis Gazette-Times)



Figure 41b. View of earthflow and slump topography during summer.



Figure 42. Shallow earthflow and slump on 60 percent (30°) slope overlying basalt within Siletz River Volcanics (Tsr) between Newport Highway and Marys River southeast of Wren Hill. Regional slope, calculated from topographic map, is only 20 percent. Thin regolith over hard bed rock favors shallow earthflow and slump. Slide is approximately 50 ft long and 20 ft wide. Note hummocky surface of slide mass.

and slump topography, steep-slope failure, and erosion. For the purpose of this discussion, mass movement is identified as the general hazard which is being analyzed.

In Step 2, specific types of mass movement that are identified are shallow earthflow and slump on broad, open slopes with bed rock near the surface (Figure 42), somewhat deeper earthflow and slumping in clay-rich regolith accumulating in gullies and drainageways (Figure 41), and debris flow and debris avalanche (Figure 43) (Tables 11 and 12).

Step 3 is identification of mappable terrain factors. In the Tsr unit, they may include steep slopes, bedrock jointing, depth of weathering, locations of springs or shallow subsurface flow, drainageways, high silt content of the regolith and soil, areas below saddles in ridges and at breaks in slopes between foothills and pediments, and location of thick colluvium in drainageways or on north-facing slopes. Other considerations may include irregularities of vegetation patterns, concavities in slopes, bedrock contacts between different rock types, especially between intrusive rocks and sediments, and other soil/water features. Monitoring and detailed mapping may be required to adequately delineate some of these features. The professional judgment of qualified specialists in engineering geology and soil mechanics is generally required for proper treatment of many pertinent mappable terrain factors.

Step 4 is preparation of overlays. Care must be taken to assure that information on overlays is accurately related to site conditions on the ground. For example, slopes interpreted from small-scale maps are generally less intense than many slopes observed on the ground because of the averaging effects of map scale and contour spacing (Figure 42). Slope categories must define slopes with fundamental significance to stability and then relate them properly in the field to slopes as they are interpreted from topographic maps. In this report, local slope variations within general categories are noted.

Step 5 is to define categories of mass movement susceptibility and plot them on a composite map. Land use decisions, based on the limitations of present-day engineering practices, are then made either for the entire area of critical concern or for specified areas within the total area of concern.

Treatment of slide-prone areas varies with the nature of the mass movement and the nature of the land use. In general terms, the treatment must effectively address the specific causes of the failure (Table 11).



Figure 43. Debris flow in late Eocene sandstone (Tf) northwest of Kings Valley Cemetery near mile 35 of Luckiamute River. Note rounded, hummocky features of depositional lobe. Steep and unprotected sides of resulting chute above depositional lobe are subject to continued erosion. Slide occurred approximately 10 to 15 years ago.

Soil Erosion

General

Soil erosion is the removal of soil or regolith by sheet wash (soil removed more or less uniformly from all parts of slopes), rill erosion (numerous tiny gullies, irregularly dispersed, often accompanying sheet erosion), or gully erosion (large or small ravines formed by concentrated volumes of water). It does not include erosion by larger channels between slopes, stream-bank erosion, or mass movement, although these are sometimes considered in regional analyses of soil loss. Erosion by water is one of the most common geologic processes, operating in the normal development of plains, valley flats, pediments, and deltas. Accelerated erosion occurs when erosion exceeds the normal (under natural conditions) rate and is of particular importance to agricultural lands. Dominant factors controlling soil erosion are land use, land cover, slope, soil type, and rainfall intensity.

Soil erosion is extremely sensitive to slope gradient and moderately sensitive to slope length. On smooth slopes, raindrop splash causes most of the detachment of soil, and runoff plays the major role in its transportation. Other factors being equal, the greater the degree of slope, the greater the potential for erosion due to the increased velocity of water flow.

Soil erodibility varies greatly with land use and soil cover. Sediment yield rates provide a good general guide to slope erosion, but they should not be confused with actual soil loss (Wischmeier, 1976). Actual soil loss is always greater than measured sediment yield. Sediment yield studies do not measure foot-slope deposition and other local forms of deposition that capture much of the eroded material before it reaches the stream being monitored.

In California, Knott (1973) demonstrated that the conversion of woodland to intensive agriculture and construction increased sediment yields 65 to 85 times. Yorke and Davis (1971) recorded a 90-fold increase in sedimentation during conversion of pastureland to townhouses in a small watershed in Maryland. In the H. J. Andrews Experimental Forest, uncontrolled clear-cut logging increased rates of sedimentation 67 times. Anderson (1971) reported the same results in a similar study in California. Langbein and Schumm (1958) determined that in areas with greater than 40 in. of annual effective precipitation, the sediment yield rate under natural vegetation is approximately 1,500 tons per square mile. In areas with lower rainfall, the sediment yield is greater because of decreased protective cover offered by natural vegetation. These figures apply to land in the natural state; erosion in agricultural or construction areas is much higher.

Soil erosion is also a function of infiltration capacity, structural stability, grain size, and organic content of the soil. In the study area, soils and regolith composed mainly of silt and fine-grained sand with little clay are easily eroded. On some of the steeper slopes, soil erosion is considerable because the very shallow depths to bed rock limit infiltration and cause increased runoff.

Methods of study

Many of the diverse factors controlling soil erosion are brought together in the Universal Soil Loss Equation developed in the Midwest by the U. S. Soil Conservation Service (1972):

$$A = RKLSCP$$

A represents the annual soil loss in tons per acre; R is the rainfall intensity factor; K is a measure of soil erodibility; LS is a slope intensity factor which considers slope gradient and slope length; C is the land cover and land use factor; and P is a factor of conservation practices. Until very recently, empirical data used in deriving the equation were based entirely on studies of flat to gently sloping agricultural land. Land use figures are now extended to consider nonagricultural uses.

Figures for steeper slopes are extrapolated beyond the range of empirical data and are used only for speculative estimates. In practice, mass movement processes are a greater concern on steeply sloping terrain than they are on gentle slopes. The Universal Soil Loss Equation is appropriate for estimating soil losses for particular parcels of land, however, giving good results within broad limits for gently sloping terrain (Williams and Berndt, 1972).

It has been accepted for many years that the particular type of rainfall pattern, low intensity of rainfall, small droplet size, and inherent soil plasticity have combined to prevent virtually all erosion

problems in western Oregon (Huddleston, personal communication, 1978). But no detailed erosion studies of the Willamette Valley have been completed. Studies in progress are the result of recent concerns for water quality and will evaluate this assumption in light of basic research data. Part of the current research effort is to determine what modifications need to be applied to factors in the Universal Soil Loss Equation to bring them into conformance with Willamette Valley soil and climatic conditions.

Additional techniques for estimating soil erosion potential on a regional basis are also available. In a manner similar to the analysis of mass movement terrain outlined in Figure 44, a series of pertinent overlays can be developed for a region, and a series of erosion potential provinces can be defined. These can be related to existing erosion data and monitor information to produce relative measures of erosion or actual semiquantitative estimates of erosion. The identification of erosion potential provinces also allows the projection of erosion data from one locality to other areas of similar nature. The erosion province method of analysis is appropriate for regional assessments of erosion potential and sedimentation potential in gently to moderately sloping terrain.

Impacts

Severe soil erosion removes valuable topsoil and nutrients and may form gullies, damage landscapes, and hinder revegetation. Allowed to continue to extreme conditions, it may cause rapid storm runoff. Soil material carried to streams may adversely impact stream biology and cause excessive flooding by raising the stream bed. Increased turbidity, another adverse impact of soil erosion, is commonly the result of mass movement and stream-bank erosion.

In the spring of 1949, heavy runoff on sloping agricultural lands caused severe soil losses throughout the Willamette Valley (Corvallis Gazette-Times, 1949). Farm losses in the Spring Hill district of north Benton County were estimated to be up to 80 tons per acre. Heaviest losses in Benton County were late-fall seeded crops, unseeded fall-plowed fields, and fields with up-down hill tillage.

Presently, foothill slopes in Christmas tree production are susceptible to moderate to severe sheet and rill erosion, particularly on 25 to 30 percent slopes, because of lack of cover between young trees and up-down hill planting practices favoring harvesting. Many of these areas are located on sedimentary bedrock units comprised of Spencer (Ts) or Flornoy (Tf) sandstone.

Table 3 indicates the general soil erosion potential of the different geologic units, as opposed to soils, as mapped by the Soil Conservation Service. The subjective soil erodibility index K from the Uniform Soil Loss Equation can be used, with judgment, as a guide to relative soil erodibility. During construction for roads and housing, large areas are often bared; shallow surficial soils may be completely removed, exposing the underlying weathered bed rock and regolith to potential erosion during subsequent rainy periods. In general, the clay content and cohesive properties of all bedrock units tend to resist severe sheet and rill erosion. Locally, however, silty and fine sand portions of these units are more susceptible to soil erosion. Near Corvallis, a powdery silt "moondust" often develops from excavation and equipment traffic on Spencer sandstone (Ts), which is then particularly susceptible to erosion. Clay-rich sedimentary material, like the Flornoy sandstone (Tf) on Witham Hill, is subject to rill and gully erosion (Figure 45) due to the low infiltration capacity of bed rock and subsequent high runoff on sloping terrain (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS).

Recommendations

Proper assessment of soil erosion requires systematic and balanced analysis. The Uniform Building Code requires that faces of cut-and-fill slopes be prepared and maintained to control against erosion. Impacts of mass movement and stream-bank erosion are commonly far greater than impacts of soil erosion, especially in steeply sloping terrain. In November and December 1975, regolith on a steep hillside covering a proposed quarry site near Alsea became saturated during heavy rains because all trees and vegetative cover had been cleared, necessitating a massive effort to contain and stabilize the slippage. Dirt from the slide washed into the nearby Alsea River. It cost about \$165,000 to clean up the site, after which the plans for a quarry there were abandoned. A fundamental recommendation for stream-sediment interpretation, therefore, is to consider all means by which sediment may be introduced into streams. It should not be assumed that soil erosion is the only process.

STEPS:

1. DETERMINE GEOLOGIC UNITS AND GENERAL GEOLOGIC HAZARDS:
using geologic maps
using geologic hazards maps
2. DETERMINE SPECIFIC TYPES OF MASS MOVEMENT:
using geologic hazard map legends
using Table 11
using other available literature
3. RELATE SPECIFIC TYPES OF MASS MOVEMENT TO MAPPABLE TERRAIN FACTORS:
including bedrock engineering characteristics (Tables 3 and 12)
including regolith engineering characteristics (Tables 3 and 12)
including topographic factors, groundwater data, and vegetation
4. PREPARE OVERLAYS FOR SELECTED TERRAIN FACTORS:
including factors such as slope, topographic setting, vegetation, groundwater, regolith thickness, and bedrock engineering factors
5. EVALUATE MASS-MOVEMENT POTENTIAL AND RELATE TO AVAILABLE TECHNOLOGY AND DESIRED LAND USE:
using the overlays to identify and define specific categories of susceptibility
determining if available technology can accommodate the hazard within the context of the desired land use

Figure 44. Land management analysis in areas of critical mass-movement terrain.



Figure 45. Soil erosion in saprolite and weathered bed rock (regolith) of late Eocene sandstone (Tf) on road subbase at Witham Hill, Corvallis. Soil, only 2 to 4 ft thick, is often completely removed during road construction. Gullies shown are 6 to 12 in. deep and illustrate low bedrock infiltration rates for Flournoy (Tf) sandstone.

Various governmental agencies are involved in soil erosion investigations and treatment. The U.S. Forest Service conducts hydrologic studies and investigates sedimentation and erosion resulting from forest practices on Federal lands. The Oregon State University Department of Forestry investigates erosion, sedimentation, and streamflow related to various forest practices. The State Department of Forestry regulates forest uses through implementation of the Forest Practices Act of 1971. The Environmental Protection Agency is concerned with soil erosion as it relates to nonpoint source pollution.

Soil erosion can be minimized through proper planning and management. Roads in uplands should be located on benches, ridge tops, and gentle slopes rather than on steep hillsides or in narrow canyon bottoms. Vegetation removal and soil disturbances should be kept at a minimum and perhaps avoided during the rainy season. Where new land uses will measurably affect infiltration rates, adequate provisions for handling runoff should be made. Other techniques to minimize erosion and deposition include the use of buffer strips and settling ponds along drainages and the application of protective ground cover such as mulch, asphalt spray, plastic sheets, sod, or jute matting in critical erosion areas and cuts. Forests and grass are the best natural soil protective features known and are approximately equal in effectiveness; grassed waterways are similarly important features of most successful erosion control systems. Logged or devegetated areas should be replanted where reseeding has been unsuccessful.

High Ground Water and Ponding

General

High ground water is a water table situated high enough to have an adverse effect on human activities. It is recognized on the basis of well-log data and surficial and soil features. These features may include marshy ground, the presence of reeds or marsh grass, extremely flat topography or depressions, high organic content of soil, black to blue-gray mottling of the soil at shallow depths, bleached soil horizons, and higher concentrations of iron and manganese pea- and shot-size concretions. Ponding results from local accumulation of runoff in areas of low slopes, topographic restrictions, and low permeability of the underlying soil or bed rock. It has the same features that characterize high ground water.

High ground water and ponding occur on Willamette Valley terraces, influencing the types of crops raised. The grasses, being particularly suited to survival in wintertime saturated-soil conditions, provide habitat for migratory waterfowl, as well.

Causes

The kinds of water that contribute to high ground water and ponding include (1) winter rain water; (2) ground-water flow and shallow subsurface flow; (3) irrigation, the impact of which is felt only in the summertime and which varies according to management practices used; (4) stream flooding, which produces bank overflow and accumulation in low-lying areas; and (5) surfacing of ground water on flat terrain at the bases of some slopes.

The complex geologic history of the Willamette Valley (stream meandering and braiding, pediment formation, and climatic cycles of erosion and deposition) needs to be considered in the analysis of high ground-water problems. High ground water and ponding in Benton County are closely related to shallow impermeable clay or bedrock layers and low slopes of surficial and bedrock pediment units. Restrictive soil layers include fine-grained flood deposits on the surface, clay and marsh deposits of former abandoned channels and sloughs (Figure 50), tillage pans in agricultural fields, and clay-rich B horizons or cemented horizons in areas of mature soils and deep weathering. Determination of the distribution of each of these factors requires detailed field inspection and soils mapping.

Because of extremely low rainfall intensities, virtually all of the rainfall penetrates the soil surface of vegetated middle terrace soils unless the water table is at the surface (Boersma and Simonson, 1970; Boersma and others, 1970). If vertical drainage is severely restricted by impermeable clay layers, water loss can only occur by evapotranspiration, which is very low in winter, or by lateral movement. Accordingly, flat or nearly flat terrain is the site of most ponding.

Small elevation changes of a few feet or less can often contribute to ponding over large areas where runoff is restricted (Figure 46). Detailed terrain analyses addressing this factor require use of map scales and contour intervals with far greater resolution than those of this study. Subtle terrain changes introduced by development, particularly road embankments, must also be considered.

Distribution

The high ground water and ponding phenomena of the study area result from a combination of the factors mentioned above and generally vary significantly over short distances. Therefore, meaningful mapping on a reconnaissance basis, which is not site-specific, is difficult and beyond the scope of this study.

High ground water and ponding are most common on surficial geologic units and pediments. All lower terrace units (Qt1) adjacent to rivers, streams, and creeks are particularly susceptible to ponding after flood waters subside because of their generally poor drainage and their swell-and-swale relief.

Excavations in Q_{tm} and Q_{th} deposits often encounter ground water near the surface, usually with seepage within the sandy and more permeable layers (Figure 23). Although the greater dissection of Q_{th} deposits generally promotes better surface drainage, ponding and high ground-water problems still need to be considered in planned development. Pediments often have springs, clay-rich soils with poor drainage (Table 10), and deep pockets of clay-rich and poorly drained soil. Bedrock factors contributing to high ground water and shallow subsurface flow are discussed in ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Drainage.

Soil series as mapped by the Soil Conservation Service often have unique relationships to high ground water and ponding. Both the Concord and Dayton soil series, which are common to middle terrace deposits (Q_{tm}), are characterized by very slowly permeable to impermeable B horizons, usually found within 20 in. of the surface (Table 10). They are too wet to suit most crops but can be used for ryegrass seed production and for pasture. Although Concord soils can be improved by closely spaced tile drains, Dayton soils cannot be improved appreciably because of their impermeable subsoils. They are usually found in the lowest areas and receive seepage from surrounding areas. Water tables on these soils remain high for long periods, then rapidly disappear (Figure 47).

Willamette and Woodburn, the two best drained valley soils, occur near stream systems in areas with some relief. Woodburn and Amity (a somewhat poorly drained silt loam) soils generally drain 3 and 4 months later respectively than Willamette soils. Woodburn and Amity soils require drainage for intensive agricultural use and are easily improved by tile drains.

In North Albany, where Veneta and Hazelair soils are associated with later Eocene sandstone (T_s), shallow bed rock and shallow clay layers at intermediate to higher elevations often present severe physical limitations to performance of septic-tank systems (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Septic-tank capacity of soils, Drainage).

Bashaw and Waldo soils are common to lower terrace deposits (Qt1) along rivers, streams, and creeks away from the Willamette River. They are generally in low, poorly drained areas, where runoff is very slow or ponded and are subject to frequent flooding. Witham soils occur on pediments and some terraces and have severe seasonal high water tables. Bashaw and Waldo soils are also common on pediments.

Often detailed on-site study is required for reliable assessments, and highly technical regional research is needed for delineation in larger areas. New techniques used in remote sensing of soil moisture in some instances have yielded semiquantitative results on the basis of soil darkness, soil temperature, and soil microwave emissivity. Success has been limited, however, either to areas of accurate soils mapping or to bare ground devoid of vegetation.

Impacts

High ground water or ponding can cause (1) flooding of basements, underpasses, and other subsurface facilities; (2) flotation or damage to buoyant structures such as pipelines, tanks, swimming pools, and basements; (3) increased lateral earth pressures against basement foundations and differential settling of buildings; (4) loss of foundation strength for utility poles (Figure 48); and (5) complications in installation of underground facilities. Included is the danger of caving during excavation.



Figure 46. High ground water and ponding affecting large acreage on Quaternary middle terrace deposits (Qtm) south of Greenberry Road at Greenberry in December 1977. Impermeable sublayers in Dayton soils severely restrict drainage. Roadway embankment (right) and railroad embankment (background) further restrict drainage.

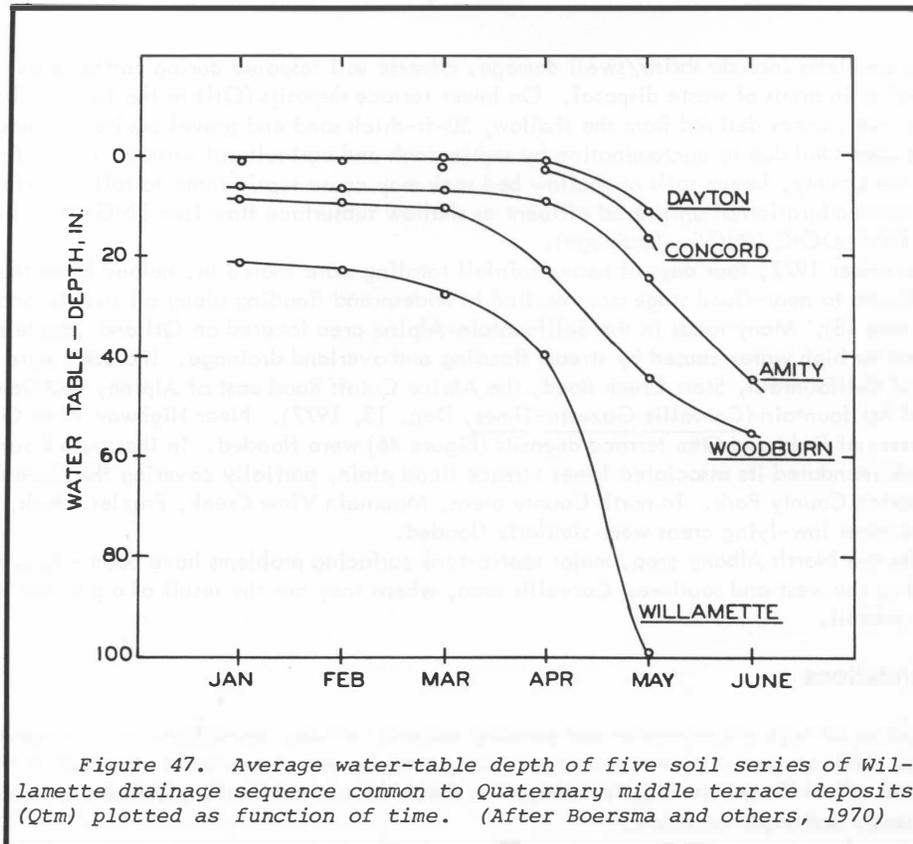


Figure 47. Average water-table depth of five soil series of Willamette drainage sequence common to Quaternary middle terrace deposits (Qtm) plotted as function of time. (After Boersma and others, 1970)



Figure 48. Downed power poles along S.W. 53rd Street, Corvallis, resulted from decreased foundation strength due to high ground water and ponding during heavy rainstorms in December 1977. (Photo courtesy Corvallis Gazette-Times)

Other problems include shrink/swell damage, adverse soil response during earthquakes, and threats to water quality in areas of waste disposal. On lower terrace deposits (Qt1) in the North Albany area, for example, well water derived from the shallow, 30-ft-thick sand and gravel aquifer has become increasingly degraded due to contamination by septic-tank and agricultural wastes. In low foothill areas throughout the County, heavy soils or shallow bed rock may cause septic tanks to fail by surfacing of effluent or rapid migration of unfiltered effluent as shallow subsurface flow (see ENGINEERING PROPERTIES OF GEOLOGIC UNITS - Drainage).

In December 1977, four days of heavy rainfall totaling more than 3 in. helped bring the Willamette and Marys Rivers to near-flood stage and resulted in widespread flooding along all streams and creeks (Figures 46 and 48). Many roads in the Bellfountain-Alpine area located on Qt1 and Qtm terrace units were covered by high water caused by stream flooding and overland drainage. Included were Bellfountain Road south of Bellfountain, Starr Creek Road, the Alpine Cutoff Road east of Alpine, and Dawson Road southwest of Bellfountain (Corvallis Gazette-Times, Dec. 13, 1977). Near Highway 99 at Greenberry, nearly 40 acres of field and Qtm terrace deposits (Figure 46) were flooded. In the south County area, Muddy Creek inundated its associated lower terrace flood plain, partially covering the Greenberry Road at Albert Saxton County Park. In north County areas, Mountain View Creek, Frazier Creek, Bowers Slough, and other low-lying areas were similarly flooded.

Besides the North Albany area, major septic-tank surfacing problems have been encountered in Monroe and in the west and southwest Corvallis area, where they are the result of a perched water table over a clay subsoil.

Recommendations

Mitigation of high ground-water and ponding hazards includes restrictions on development or sanitary systems, limits on general construction practices, and the actual treatment of causes of the hazards. Where hazards affect the entire County, mitigation should be systematically planned and coordinated to assure efficiency and avoid conflicts.

In areas of low slope, engineering investigations for large-scale construction should include an assessment of potential hazards from ponding and high ground water. Emphasis should be placed on the highest level of occurrence during the wet season rather than lower levels typical of the dry season. Underground storage tanks and swimming pools should be kept filled in some areas of high ground water. Adequate safety measures against caving should be followed in all excavations. Plans for reclamation of excavations such as gravel pits should include measures for mitigation against high ground water.

Areas of critical ponding are generally unacceptable for dense development. The reduction of infiltration arising from paving and other aspects of urbanization increases runoff, which may lead to local flooding. Where slopes are very low, there are often few economic solutions to the problem.

Future damage can be reduced through use of realistic zoning ordinances and building codes which allow for workable engineering solutions to specific problems. In regions of particularly severe occurrence, seasonal construction is necessary. Sump pumps and drain tiles are often used to handle severe leaking in basements in regions of high infiltration or high ground water. Major construction sites may require dewatering during and after construction. Where problems are less severe, sealants may be applied to either the interior or the exterior of the foundation walls. High ground water generally prohibits or limits the use of basements in surficial units in Benton County.

Effective treatment of the causes of high ground water or ponding must address the specific causes present at a specific site. Surface water accumulation can be minimized by (1) maintaining drainage ditches, (2) draining flat areas, (3) intercepting runoff above wet areas, (4) properly draining artificial surface areas such as parking lots, (5) eliminating obstructions to surface water flow, and (6) placing structures on elevated fill.

For areas of shallow bed rock, well-log data should be used prior to construction to assess the magnitude of the hazard. Drain tiles may be effective in the collection or redirection of ground water; their success, however, depends ultimately on the ability of the surrounding material to transmit water. In agricultural areas, harvesting practices should be keyed to the capability of the soil to accommodate traffic and to withstand compaction. Trafficability depends largely on soil strength, which is intimately dependent on moisture content and seepage (Figure 35). In areas of ground-water discharge, properly designed drains and culverts are recommended; placing fill in areas of ground-water discharge is not recommended.

Winter ponding caused by bank overflow of minor streams can be minimized by appropriate maintenance and design of channels.

Stream Erosion and Deposition

General

Stream-bank erosion is the loss of land by stream action. It occurs as local bank caving in the upper flood plains of the major streams and along the larger flood plains of the various streams and rivers in the Willamette Valley, where it is most critical. Meandering, the tendency of some streams to assume sinuous courses, is the underlying cause of stream-bank erosion in flood plains.

Meander-generated erosion is characterized by a steep bank on one side of the river associated with a sand or gravel bar on the opposite side (Figure 49). Areas of critical stream-bank erosion are also identified by studying sequential sets of aerial photographs and topographic maps that show changes in stream patterns with time. In recent years the Corps of Engineers has been monitoring significant bank erosion and the conditions of its revetments along the Willamette River by using oblique color photographs taken from helicopters. To assess any particular locality properly, it is necessary to make on-site inspections, interview residents, and coordinate with appropriate State and federal agencies.

Considerable research in recent years has revealed that the ideal shape of a meandering channel is that of a series of smooth, accentuated, S-shaped curves (Leopold and Langbein, 1966). Thus, straight stretches and relatively sharp turns in streams, such as at Irish Bend, that are prone to meandering are signposts of future adjustments through bar deposition and bank erosion. The radius of curvature of an ideal meander bend is generally two to three times the width of the stream (Bagnold, 1960; Leopold and Wolman, 1960).

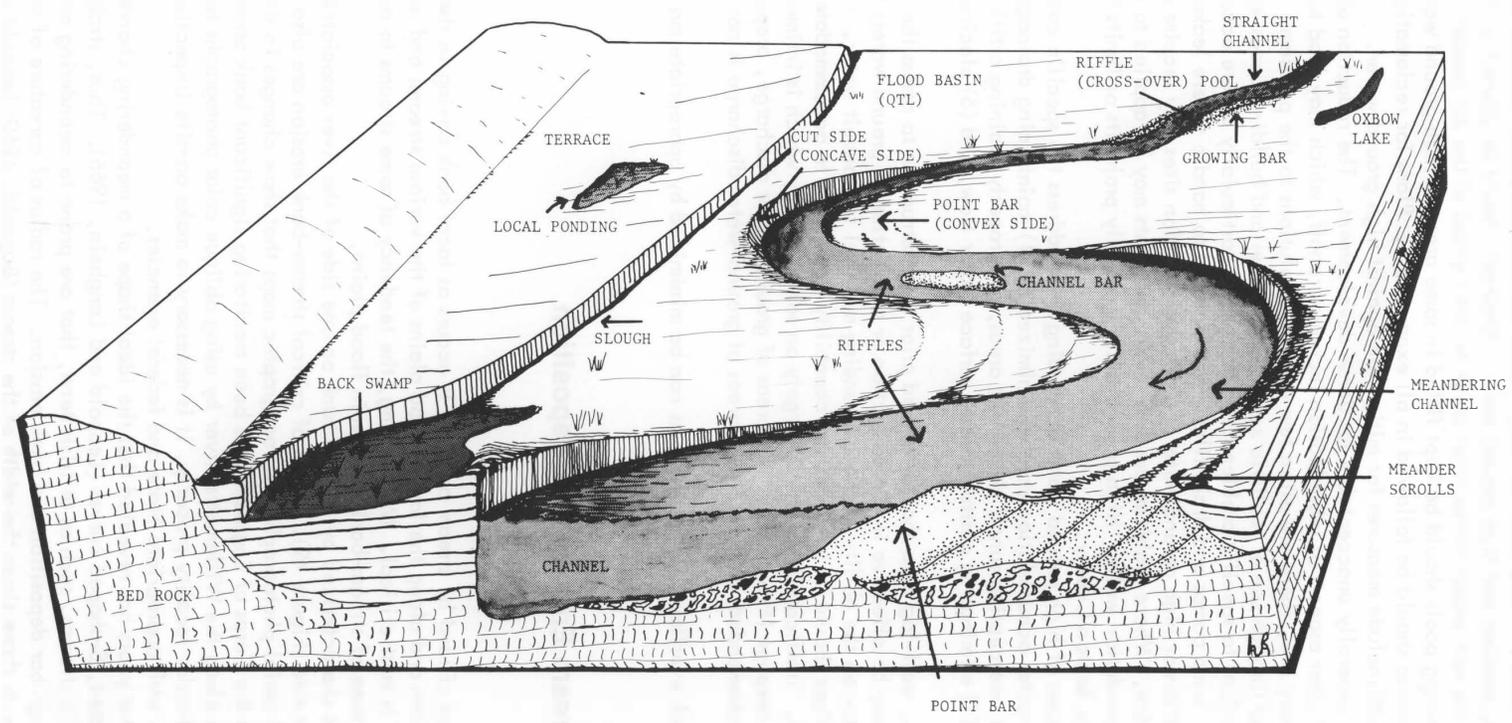


Figure 49. Diagrammatic representation of different types of river deposits and channel patterns. (After Reineck and Singh, 1975)

Schumm (1977) cites three principles of fluvial geomorphology: (1) the landscape is dynamic, (2) landscape changes are usually complex, and (3) thresholds exist and may result in unexpected landform changes. Thus, for a typical river meander, long periods of normal erosion often prepare the way for abrupt cutoff or channel change during floods.

Larger particles in stream beds, including boulders, pebbles, and coarse sand grains, that are moved by rolling, sliding, and bouncing constitute the bed load of the stream. The capacity of a stream to transport bed load is determined by the geometry of the channel, volume of discharge, and velocity. Smaller particles, including fine sand, silt, and clay, are generally transported in suspension. The volume of suspended load is controlled primarily by runoff and soil erosion. This aspect of sediment transport is particularly significant in terms of water-quality management. Medium-grained sand can be carried in suspension under extreme conditions of velocity and turbulence. Most common channel patterns are straight, braided, or meandering, although combinations may occur (Figure 49).

Causes

Erosion in flood plains is restricted primarily to channels, outer bends of meanders, and cutoff channels which develop during times of flooding. Stream deposition includes the deposition of silt and clay from relatively slow-moving overbank flood waters, as well as the formation of bars in channels (Figure 49), on the inner bends of meanders, and behind obstructions such as snags. Stream erosion and deposition operate in harmony to modify the stream channel. Sediment supplied by stream-bank erosion is deposited on bars farther downstream which, in turn, redirect streamflow against riverbanks to cause additional stream-bank erosion. Various types of channel fill deposits which occur in abandoned channels, cutoffs, and sloughs are shown in Figure 50.

The fundamental cause of meandering in streams is not completely understood, although most workers consider helical circulation to be the dominant factor (Reineck and Singh, 1975). Meandering rivers, such as the Willamette, usually exhibit an irregular pattern when free to migrate. Deformed and compressed meander bends tend to reflect the influence of more resistant alluvium or bed rock.

Deterministic projections of future trends of meander development in the study area are not possible. Much remains to be learned about the development of meanders in general, and data on specific river and stream systems are often lacking or incomplete. Instead, assessments of future channel changes must involve a short time frame of only 25 to 30 years and must be based on limited knowledge of past channel changes, which are best observed on aerial photographs.

Continuing research is showing qualitatively how discharge is related to channel width, depth, meander wavelength and gradient. Attempts have also been made to relate the bed load to channel morphology. Refinement of these concepts with regard to a particular river system, such as the Willamette, will improve the usefulness of bank protection measures.

Instability results when channel changes such as width, depth, velocity, sinuosity, and meander wavelength result from hydrologic changes or increased slope due to meander cutoff. As a general rule, areas of previous channel change which have substantially shortened the length of the river downvalley by making it less sinuous tend to indicate areas of unstable readjustment downstream.

Distribution

The relative threat of stream-bank erosion varies with the discharge of the rivers and streams. Large-scale channel changes have occurred and are occurring along the Willamette River (Figures 53 and 54). The Marys River is characterized by numerous smaller scale channel changes. The Long Tom River historically was similar in behavior to the Marys River. However, since the completion of Fern Ridge Reservoir, the river has been straightened and modified by bank protection and several drop structures to accommodate increased periods of discharge from the reservoir.

Major stream-bank erosion, major bar growth, and recent channel changes along the Willamette River were assessed from low-altitude observations by aircraft in May 1978 and from recent aerial photographs. Areas along the Marys River and other smaller rivers and creeks were assessed from examination of stereo aerial photographs (1970), field observations, and more limited, low-altitude aircraft observations during the course of the study. Major stream-bank erosion and deposition are depicted on the geo-

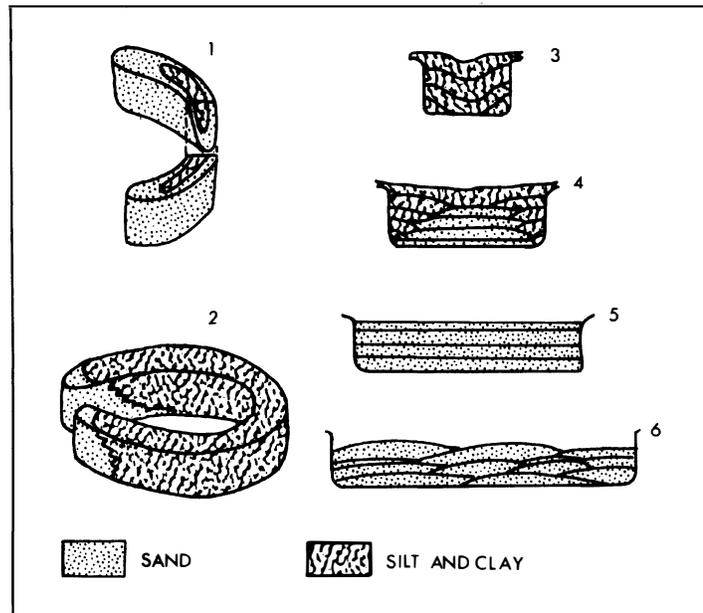


Figure 50. Various types of channel fill deposits: (1) chute cutoff; (2) neck cutoff; (3-6) various ways of filling ephemeral streams and abandoned channels. (After Reineck and Singh, 1975)

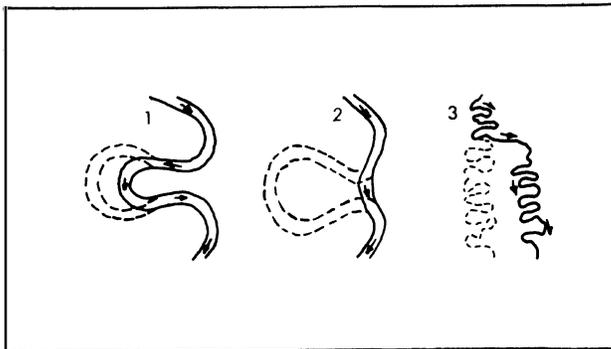


Figure 51. Three processes by which river channels are abandoned: (1) chute cutoff; (2) neck cutoff; (3) avulsion or major channel change. (After Reineck and Singh, 1975)

logic hazards maps for the Willamette and Marys Rivers only, due to the basic reconnaissance nature of this study and limitations of time, funding and map scale. Stream-bank erosion on the other rivers and streams follows the pattern indicated for the Marys River: erosion is concentrated at outer bends of meanders; the tighter (more hairpinlike) the meander bend, the greater the potential for erosion. Many of these other streams and rivers are also being addressed by work in progress by the Soil Conservation Service pursuant to the Resource Conservation Act (RCA).

Willamette River: Relatively recent changes are evident in aerial photographs and topographic maps. Some of the old main channels of the Willamette River abandoned since the 1847 County line was established are shown on the geology and geologic hazards map. Historic County boundary lines on older maps may indicate approximate locations of former main channels. Willamette River: River Lands and River Boundaries (Hoerauf, 1970) shows 1852 and 1961 channel locations. In addition, oxbow lakes and sloughs, which are widespread features of Quaternary lower terrace deposits (Qt1), are also indications of buried channel features (Figures 49 and 50). At present, extensive revetments control much of the course of the river (see the geologic map).

Revetments at Harrisburg protect the city from critical stream-bank erosion. Two mi downstream, near the Benton-Linn County line, a revetment placed in 1947 now lies along an abandoned channel. Immediately to the east, a small oxbow lake formed in 1951 when the Trachsel Channel was excavated and the former meander loop was artificially plugged.

Between the north end of Ingram Island and Irish Bend, the course of the Willamette is presently about 2 mi shorter than in 1847. This reach is unstable and exhibits major erosion along outsides of meander bends, new channel and major bar growth since 1969, and five revetment efforts between 1938 and 1963.

At Irish Bend (river mile 150) the river makes a right angle turn against the east bank. The situation is highly unstable. Continued undercutting at Irish Bend may cause the river to once again undermine the road along the Linn County bank (Figure 52). Alternatively, catastrophic truncation of the meander bend would result in accelerated meandering and stream-bank erosion immediately downstream beyond the north end of the south side revetment. Major overflow channels at Irish Bend carry strong current flow during periods of flood and are depicted on the geologic hazards map. The time scale of these events is unclear.

The most severe major erosion is occurring along the east bank of the Willamette River between Harrisburg and Irish Bend. Within this reach, the river has been shortened approximately $3\frac{1}{4}$ mi since 1947.

At Daws Bend (river mile 145) major erosion with new channel and bar formation has occurred in the short reach between two revetments (Figure 53). Similar large-scale bank loss has occurred 1 mi downstream just south of Hoacum Island. The east bank south of Peoria is also undergoing severe erosion.

Major channel change has occurred near the H.D. Taylor Water Treatment Plant at Corvallis (Figure 54). Previously the plant had obtained its water from the relatively quiet waters of the Booneville Channel, a secondary channel of the Willamette. In 1970 the Corps of Engineers undertook a study which showed that the river was about to change the course of its main channel to include the Booneville Channel. The Corps proposed a revetment to hold the river in its present channel. In the fall of 1971, three years earlier than the Corps had predicted, the Willamette River cut through to the Booneville Channel. In 1976 a revetment was placed just south of the plant on the west bank to stop bank erosion at the outside of the growing meander. Major erosion is continuing on the north end of Kiger Island. At present, deposition of large quantities of sand and gravel around the plant's water intake is seriously affecting its operation. A revetment is planned to control bank erosion at Kiger Island and to aim the Willamette River more directly at the water intake, which it is hoped will reduce the amount of deposition. However, the resulting anticipated increased erosion along the west bank of Stahlbusch Island is cause for concern.

Northeast of Corvallis, between Half Moon Bend and the Adair water treatment plant, the course of the Willamette has been constrained by extensive revetments constructed from 1948 to 1968. A growing bar near river mile 125 is causing increased erosion locally.

Marys River and minor creeks: Marys River and the lesser creeks which drain the Quaternary middle terrace deposits (Qtm) and Quaternary higher terrace deposits (Qth) are generally entrenched 15 to 30 ft into these materials. Erosion is caused by bank sloughing and shallow rotational slumps as streams undercut their banks. Under saturated soil conditions and undercutting, trees may fall from the bank, causing

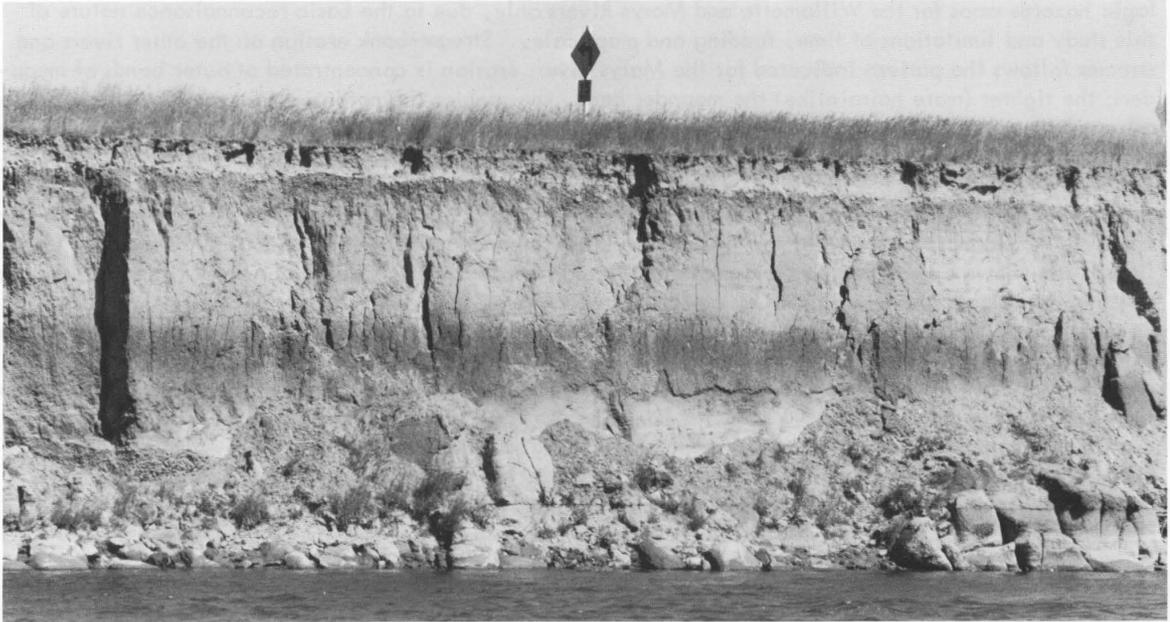


Figure 52a. Major stream-bank erosion along east bank of Willamette River at Irish Bend. Photographed in June 1977, 25-ft-high bank shows section of Willamette Silt believed deposited when glacial meltwaters cascading down Columbia River were temporarily ponded in Willamette Valley. Nearby road may be seriously threatened by continued bank erosion.



Figure 52b. Same scene, one year later, after river had risen to near-flood stage during December. Note new angular blocks from increased bank erosion. Finer size material and rubble at base of cutbank have been scoured away.

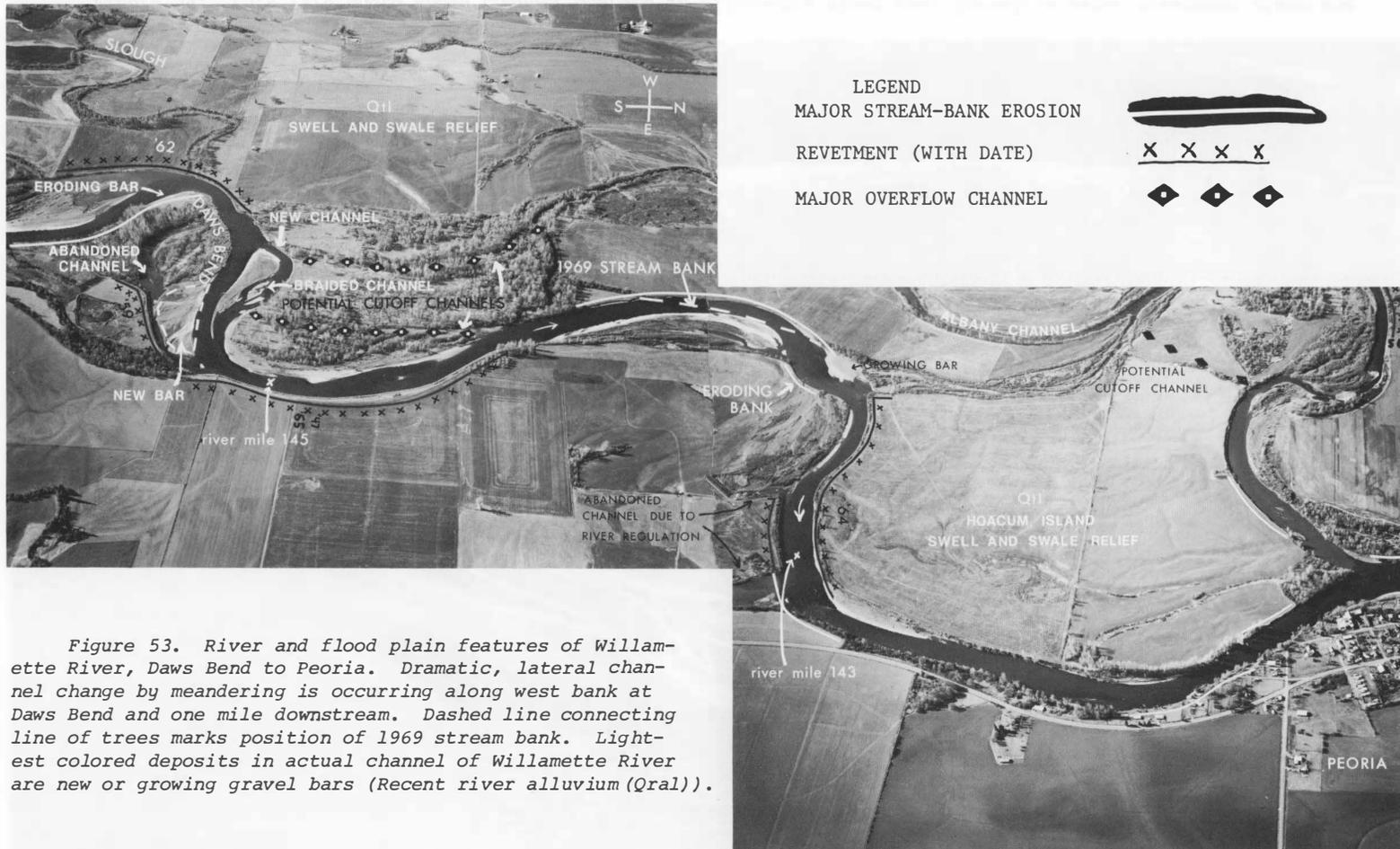


Figure 53. River and flood plain features of Willamette River, Daws Bend to Peoria. Dramatic, lateral channel change by meandering is occurring along west bank at Daws Bend and one mile downstream. Dashed line connecting line of trees marks position of 1969 stream bank. Lightest colored deposits in actual channel of Willamette River are new or growing gravel bars (Recent river alluvium (Q_{ral})).

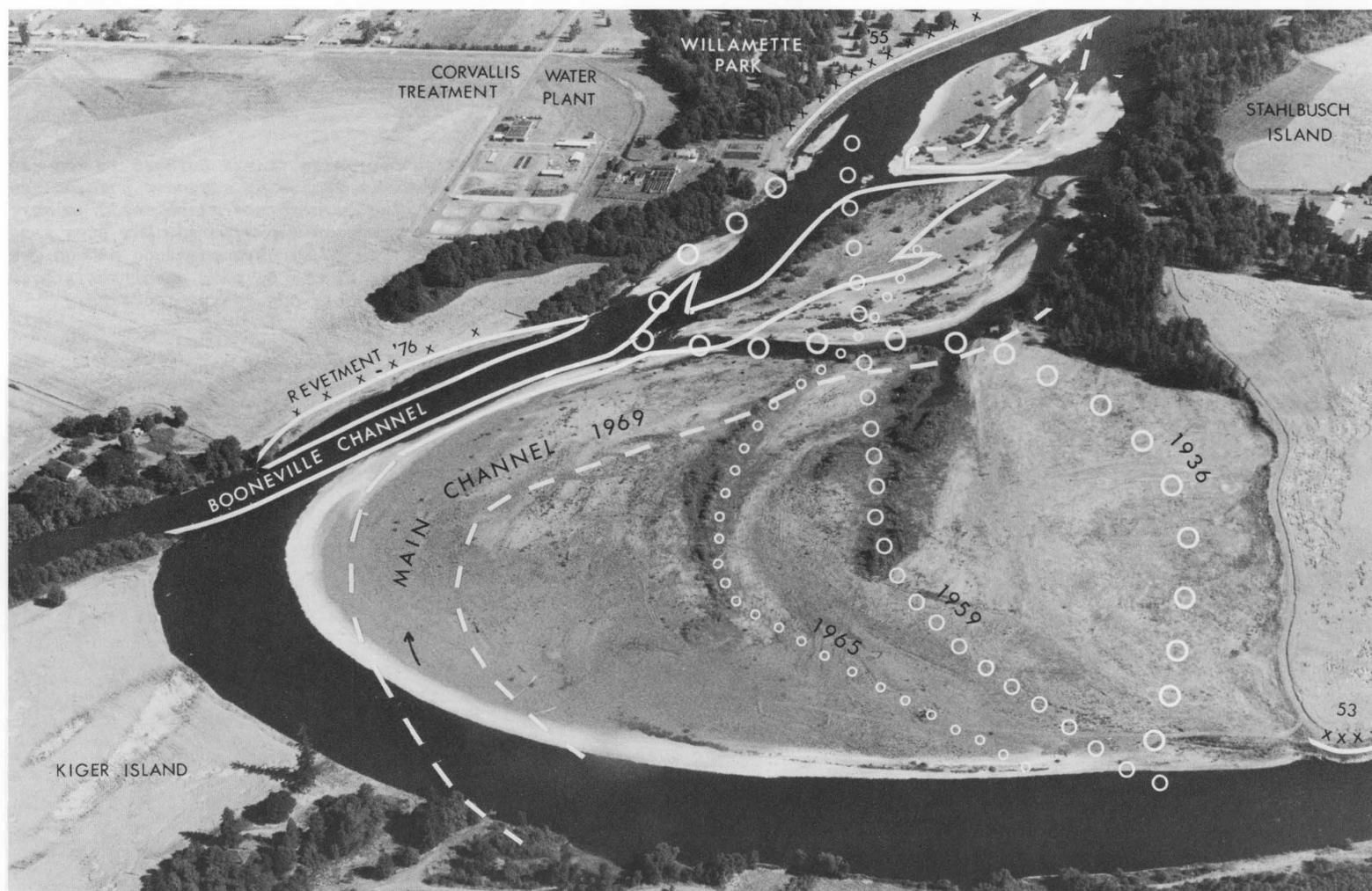


Figure 54. This 1978 photo shows channel changes in Willamette River near Corvallis water treatment plant and approximate locations of previous main channel courses. Bar which separated Booneville Channel from main Willamette River channel is shown as it was in 1969. In 1971, Willamette River cut through to Booneville Channel and since then has seriously affected plant's water intake system. A \$1.7 million revetment is planned to direct river's flow toward water intake and to halt erosion at Kiger Island. Possibility of increased bank erosion along east bank across from treatment plant should be considered. (After Lawrence and others, 1977)



Figure 55. December 1977 photo, looking downstream at Marys River near flood stage at Avery Park bridge, Corvallis. Clearance beneath bridge is approximately 5 ft. Trees and brush along banks retard flow. Increased stream-bank erosion results from trees having fallen from bank under saturated soil conditions.

increased local erosion (Figure 55). Fallen trees and other debris are common within the Marys River, Muddy Creek, and other low-discharge streams. They impede flow and may direct local bank scour.

The undisturbed smaller streams and creeks, which are naturally left with much bank vegetation, generally do not present large erosion problems (Hixson, personal communication, 1978). Slight problems are more common where creeks meander through flatland areas and near the break in slope where creeks enter flat terrain from low foothill areas.

Where streams flow over bed rock or across pediments, erosion in the form of undercutting and shallow slumping occurs. In the foothills and higher terrain regions of the County, soil creep and mass movement processes become dominant.

Luckiamute River: At Kings Valley the Luckiamute River and its tributaries are often entrenched through the generally thin alluvial material into the underlying bed rock. The meandering nature of the Luckiamute indicates that stream-bank erosion can be critical locally and must be considered in the planning process.

Recommendations

Mitigation of stream-bank erosion should be based on a more complete assessment of the specific river system involved, including the likely effects of any such measures on conditions upstream or downstream. Future studies of the Willamette River may reveal thresholds of stability which can guide forthcoming planning measures. For example, a particular river system may have threshold slopes where its channel changes from straight to meandering. For a particular reach near this threshold, channel straightening might increase the slope to favor meandering and therefore lead to an increase in erosion rather than a decrease.

Table 13. Scale of earthquake intensities and magnitudes

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)

Major erosional and depositional processes along lowland streams are floodway erosion, meander development, and bar formation (Figures 49, 50, and 53). Floodway scour routes which convey flood waters across meander loops, as at Irish Bend, are potential sites of erosion and channel changes during large floods. Excavations in these areas modify streamflow and may increase the potential for erosion. Gravel operations in them must be protected by berms which are high enough to redirect flood waters and capable of withstanding erosion. Otherwise, the pits may be reclaimed by the river channel.

Stream-bank erosion along meanders found in streams of all sizes (Willamette River, Marys River, and creeks) must be considered in development. Mitigation includes placement of riprap, avoidance of the area, or innovative channel maintenance. In urban areas, where runoff is altered and creeks are often relocated, adequate access for channel maintenance must be preserved. Adequacy of small discharge channels to handle infrequent emergency emptying of reservoirs or water tanks should also be considered.

In assessing stream-bank erosion, upstream and downstream channel changes must be considered. Even though controlled by stabilization (revetment) or realignment, rivers tend to regain their original patterns and shapes. Natural or artificial channelization (straightening) steepens channels; and as meandering (sinuosity) is reduced, flow velocity and potential for erosion are increased. The steeper channel often results in incision, greater erosion, and increased sediment yield upstream where adjustments to a lower base level occur.

Gravel bars develop in channels, on the inner bends of meanders, at the mouths of some tributary streams, and near snags or log jams. For example, sediment deposited at the mouth of the Marys River has required expensive removal to keep the boat dock serviceable. In areas of unstable channels, the seasonal removal of gravel as it accumulates can be an effective means of reducing stream-bank erosion in the immediate area and should be considered in formulating gravel resource policies. Berms constructed around the site for water quality purposes should be designed to avoid channel obstruction during flooding.

Channel problems arising from structural flood control measures can be minimized by innovative design. For example, on smaller rivers, such as the Marys River, composite channels can be constructed by placing levees away from the stream channel while the natural channel is left untouched. The composite channel can accommodate a range of discharges including low flow in the natural channel and flood flow within the banks of the levee. The hazard of greatly increased deposition, which plagues many redesigned channels during low flow, is eliminated or greatly reduced. Erosion along straightened channels can be reduced by the construction of numerous small dams or drop structures which incrementally lower the grade of the stream. When natural armoring of a channel is disturbed, it must generally be restored or replaced to avoid increased bed erosion. Levee designs must include a consideration of increased erosion potential where the channel is constricted.

Earthquakes

General

The shaking of the earth's surface accompanying the release of energy resulting from slippage along an active fault is called an earthquake. The specific location of energy release within the earth is called the focus, and the geographic location above the focus on the earth's surface is called the epicenter. Because the crustal structure and tectonic behavior of Oregon is very complex and the historic record is short, knowledge of future earthquake activity is understandably incomplete.

Mercalli scale—intensity

Earthquake intensity is a measure of the size of an earthquake at a particular place as determined by its effect on persons, structures, and earth material. Mercalli intensity is indicated on a scale of Roman numerals from I through XII. Intensity observations made in this way are subject to inaccuracies because of different distances from the epicenter, the varying nature of underlying rocks and regolith, and the subjectivity of the viewers. Although the Mercalli scale is imprecise when limited observations are available, it is widely used because it is universally applicable and requires no equipment. Reliance on numerous observations minimizes inconsistent and inaccurate data. Table 13 describes the various effects of the Mercalli scale intensities.

Richter scale—magnitude

The Richter scale is a measure of earthquake energy based on records from seismometers. Instead of indicating intensity with Roman numerals (I to XII), as on the Mercalli scale, the Richter scale indicates magnitude with decimal numbers (Table 13) on a logarithmic scale. Each digit represents a 10-fold increase in the amplitude of the seismic waves and an approximate 32-fold increase in the amount of energy released. Thus, an earthquake of magnitude of 6.0 is 32 times greater than an earthquake of magnitude 5.0. The Richter scale is arbitrarily chosen to display small magnitude earthquake events and is open-ended. The scale ranges from less than 1 for small quakes to greater than 9 for the largest earthquake recorded so far, according to a proposed revision. Several other types of magnitude scales are also in use, each based on a different part of the seismic wave train. Because these other scales cannot measure accurately very large earthquakes near the upper end of the magnitude range, a new unit of measure, the seismic moment, is being used to measure the seismic energy emitted from an entire fault.

An earthquake event has one magnitude (energy release) but may display various intensities (effects) as a function of geologic setting (Figure 56). To convert observations stated as intensity on the Mercalli scale to magnitude on the Richter scale, several empirically derived equations are available including:

$$\begin{aligned} m &= (0.43)I + 2.9 \quad (\text{Stacey, 1969}) \\ M_B &= (2/3)I + 1 \quad (\text{Gutenberg and Richter, 1965}) \end{aligned}$$

M values are Richter magnitudes, and I values are Mercalli intensities. For quakes of low intensity, the Stacey equation gives higher values for magnitude than does the Gutenberg and Richter equation. The Stacey equation is based on shallow quakes (less than 70 km deep) and may be more applicable to the study area, provided numerous reliable observations are available from areas underlain by firm ground.

Earthquake potential

The potential for future earthquakes can be estimated on the basis of the historic seismic record and calculations based on the dimensions of active surface faults. Comparisons with other regional areas throughout the world having similar geologic settings and earthquake recurrence intervals may also be made. No active faults are exposed at the surface in Benton County, according to available information (see GEOLOGIC UNITS - Bedrock Structure). Accordingly, estimates of future seismicity are based almost entirely on the historic record, which is very short and possibly misleading.

The largest earthquake ever recorded in the Pacific Northwest occurred April 13, 1949. Its epicenter was in the Puget Sound area, and it was felt over an area of 150,000 sq mi. It had a Richter magnitude of 7.1 and a Mercalli intensity of VIII near the epicenter (Figure 56). Damage was confined mostly to marshy, alluvial, or filled ground. Portland experienced a maximum Mercalli intensity of VII, and most of the Willamette Valley south of Portland experienced a maximum intensity of VI. In Corvallis, intensities IV, V, and VI were reported; plaster fell, hanging objects swayed, dishes rattled, and trees and bushes were moderately shaken.

The Pacific Northwest's second largest earthquake occurred April 29, 1965. It, too, had its epicenter near Puget Sound. The Richter magnitude was 6.5, the Mercalli intensity was VII-VIII. The intensity in Corvallis and Philomath was V (felt by nearly everyone), although no tremors were reported felt in Alsea, Wren, or Albany.

Table 14 is a summary of selected earthquakes felt in Benton County. It shows that the largest intensities reported so far were associated with larger earthquakes originating in the Puget Sound area. A local shock, May 12, 1942, occurred at Corvallis and was strongly felt (V) but caused no damage.

Figure 57 shows earthquake epicenters in Oregon from 1841 to 1970. A seismic risk map for the State of Oregon (Figure 58) shows that Benton County lies in Zone 2, an area in which quakes with intensities as high as VII on the Mercalli scale are possible. Quakes of this intensity can crack walls. With saturated ground conditions such as are common in much of the Willamette Valley during the winter months, the damage to structures could be considerably greater in areas where liquefaction or lurching could occur. Initiation of destructive landslides in the foothills also is a possibility. As more information is acquired, the assessment of seismic risk within Oregon will continue to be refined.

Table 14 and Figures 57 and 58 indicate that major earthquake activity affecting Benton County so far is associated either with earthquakes occurring near Portland and off the Oregon coast or with larger

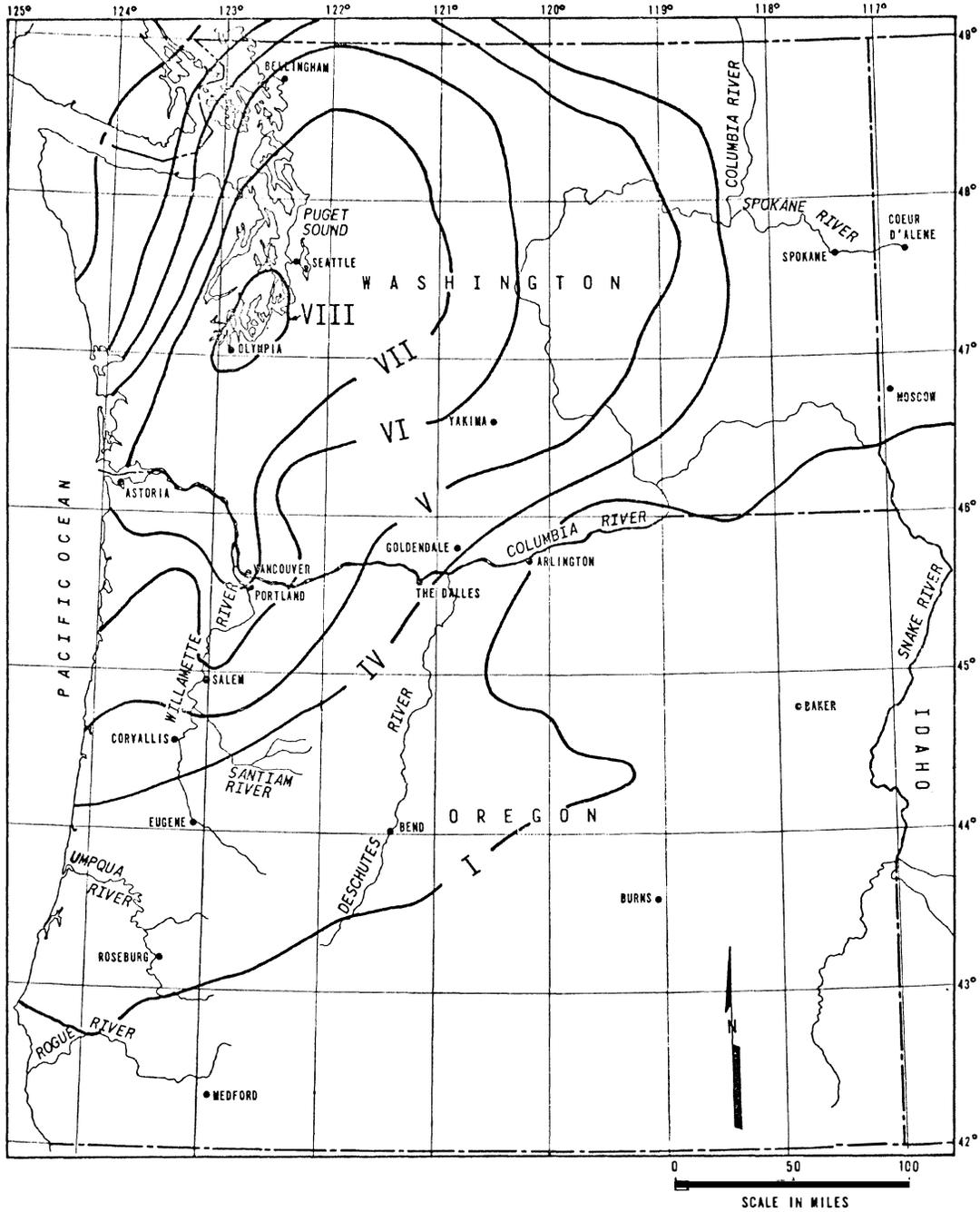


Figure 56. Isoseismals - 1949 Olympia, Washington, earthquake (Richter magnitude 7.1). (After U.S. Department of Commerce, 1949)

Table 14. Selected summary of earthquakes felt in Benton County, Oregon *

Date	Epicenter **	Mercalli intensity *** (Richter magnitude)	Mercalli intensity in Benton County	Comments
1891 Sept. 16	Salem	IV	--	Brief, distinct shock followed by wavelike motion; windows rattled.
1896 April 2	McMinnville	VI	--	People awakened; two or three shocks with loud rumbling noise from west.
1921 Feb. 25	Cascadia 44.4°N. 122.4°W.	V	--	Felt by nearly all in 6-by-12-mi area.
1930 July 18	Perrydale 45°N. 123.2°W.	VI	--	Cracked plaster, rattled windows near Perrydale.
1942 May 12	Corvallis 44.6°N. 123.4°W.	V	V	Local shock, strongly felt.
1949 April 13	Puget Sound, Wash. 47.1°N. 122.7°W.	VIII (7.1)	VI (Corvallis)	Largest earthquake of record in Pacific Northwest; felt over 150,000-sq-mi area; intensity VII in Portland; Corvallis intensities IV-VI; most of Willamette Valley experienced maximum intensity VI.
1953 Nov. 4	At sea, a few hundred miles off Oregon coast	--	III (Corvallis)	Short but sharp tremor.
1953 Dec. 15	Portland	VI	--	Salem, light vibration I-III; not felt in Albany or Corvallis.
1957 March 22	Alsea	III	--	Two light tremors reported 4 hr after principal shock (magnitude 5.3, intensity VII) hit San Francisco; tremors felt while aftershocks in San Francisco still occurring.
1957 Nov. 16	Coast Range between Tillamook and Portland 45.3°N. 123.8°W.	VI (Salem)	IV (Corvallis)	One of largest documented earthquakes for Coast Range; reported not felt in Albany or Monroe.
1961 Aug. 18	East of Salem 44.7°N. 122.5°W.	VI (Albany and Lebanon) (4.5)	IV (Corvallis)	Plaster cracks at some residences in Albany; felt over considerable area of northwestern Oregon; Berg and Baker (1963) list epicenter in Albany with intensity III-IV.

Table 14. Selected summary of earthquakes felt in Benton County, Oregon * (continued)

Date	Epicenter **	Mercalli intensity *** (Richter magnitude)	Mercalli intensity in Benton County	Comments
1962 Nov. 5	Portland-Vancouver 45.6°N. 122.7°W.	VI (5.0)	IV (Corvallis, Philomath, and Alsea)	Largest shock to occur in Oregon since recent installations of several new seismic stations in Pacific Northwest; provided first significant data to construct travel-time curves for Oregon; felt over 20,000 sq mi.
1963 March 7	Coast Range between Tillamook and Salem 44.8°N. 124.4°W.	V (West Salem) (4.6)	IV (Corvallis)	One of largest documented earthquakes for Coast Range; minor quake felt from Portland to Eugene and in some coastal areas.
1965 April 29	Puget Sound, Wash. 47.4°N. 122.3°W.	VII-VIII (6.5)	V (Corvallis and Philomath)	Second largest earthquake of record in Pacific Northwest; Portland intensity V; not felt in Alsea, Wren, or Albany.
* Information from	Berg and Baker Couch and Lowell Coffman and von Hake Bodle Coast and Geodetic Survey (1945-1966)	(1963) (1971) (1973) (1946)		

** "From the late 1920's until 1962 some of the larger earthquakes in Oregon were located with seismographs of the University of California which at that time included those at Corvallis. However, because of the epicentral distances, station limitations, and uncertainties in travel-times, the instrumentally located epicenters of that period are probably as inaccurate as those estimated from felt effects. The available instrumental results during that period do suggest, however, that no earthquakes greater than magnitude 5 passed unnoticed in Oregon. After 1963, earthquakes in Oregon were located with seismograph stations located principally in the Pacific Northwest " (Couch and Lowell, 1971, p. 64-65)

Epicenter locations in degrees of latitude (N.) and longitude (W.) are given where they appear in the record.

*** Maximum Mercalli intensities at or near epicenter. Cities recording maximum intensities are given in parentheses when different from epicenter (see *). Richter magnitudes are given in Arabic numerals where they are reported in the literature.

earthquakes occurring in the Puget Sound area. Thus, ground response from earthquakes originating outside of Benton County must also be addressed to a reasonable degree in planning.

Active faults are faults which have moved in the recent past and for which the geological and seismological evidence indicates probable movement again in the near future. The recent past includes the historical period and sometimes the Holocene epoch (the last 10,000 years). Potentially active faults are faults along which no known historical ground-surface ruptures or earthquakes have occurred but which show strong indications of geologically recent activity.

No active faults are known in Benton County. There are, however, many inherent problems in active fault recognition. Therefore, this observation cannot be applied blindly in determining site suitability for major construction or critical facilities such as nuclear power plants. Field studies of faulting indicate that ruptures can be absorbed or amplified through rock or regolith with little relationship between surface fault traces and displacements noted at depth. These and other complexities sometimes necessitate trenching or geophysical exploration across suspected fault traces.

Factors affecting earthquake intensity

Earthquake hazard is determined by the time, location, and magnitude of probable earthquakes and by the type of construction. The primary earthquake hazards are ground shaking and fault rupture. Secondary hazards include landslides, differential ground movement, lurching, liquefaction, ground failures, floods from dam and levee failures, and fires. The most prevalent hazard is violent shaking.

Response spectra and design earthquakes

Response spectra are graphical representations of the response of structures to earthquake ground motions. Expressed as velocity, acceleration, displacement, or other related variables, their development has been a major accomplishment of engineering seismology. Design earthquakes are quantitative estimates of the ground shaking a structure will be required to endure, based on magnitude, maximum acceleration, duration of strong shaking, available recorded strong-motion data, and other factors.

Response spectra and design earthquakes are usually used only in the plan and design of vital or sensitive structures for which the general conclusions cited elsewhere in this section cannot blindly be applied.

Other factors: magnitude, frequency, and duration

Maximum ground acceleration at one site does not alone determine intensity. Intensity also depends on frequency characteristics of ground motion and duration of the earthquake. Since stiff and soft soil deposits exhibit maximum response at different frequencies, lateral forces and damage in the same general area may develop selectively; for example, multistory structures on relatively soft soil deposits may be severely affected, but adjacent stiffer structures on the same deposits may hardly be affected. Soil strength studies indicate that duration is very important in soil response. Magnitude affects duration much more than it affects peak acceleration. Although it has long been observed that duration of motions in alluvium increases with distance over large distances, new information suggests that, in small and moderate quakes, under some circumstances there may be a decrease in duration with distance up to a certain distance, then an increase.

Effect of distance: As seismic waves are radiated through the earth from the point of origin (focus) they are attenuated (diminished with distance) as a function of dispersion, friction, depth, bedrock structure, and other factors. Short-period motions tend to be filtered out, with the result that the maximum value of the response spectrum tends to develop at progressively higher values of the fundamental period (see GEOLOGIC HAZARDS - Earthquakes: Response spectra and design earthquakes).

General ground response: The primary cause of death, injury, and structural damage during earthquakes is shaking ground. Permanent ground deformations may occur as a result of (1) tectonic forces (uplift, subsidence, folding, tilting); (2) settlement (compaction); and (3) ground failures (landslides,

lateral spreading, bearing capacity failures due to liquefaction and loss of shear strength).

Local geology: Local geology has a predominant effect on periods of motion; under the right conditions, resonance effects (amplified ground motion occurring within period range of structures) can be severe. Topographic effects and focusing effects related to bedrock geometry can also occur. Near the epicenter, earthquake effects may be determined by the local geology.

Soil (regolith) response: While it has generally been observed that ground accelerations developed on surfaces of soil deposits during earthquakes are often greater than those in adjacent rock outcrops, there is still considerable controversy on the effect of local soil and geology on damage. Evernden and others (1973) show that in the historic record maximum intensities are generally limited to areas of firm or unstable ground as opposed to areas of solid bed rock. In general, Mercalli ratings for earthquakes represent the response of semiconsolidated alluvium.

Most landslides triggered by earthquakes are those associated with liquefaction or mobilization of cohesionless soils. Bedding planes, joints, other weaknesses, and the presence of ground water are major factors in landslide release during earthquakes.

Ground settlement often results in differential settlements in engineering structures, as between bridge abutments and piers. The horizontal movements induced by quakes are believed to be largely responsible for settlements. Ground cracking or rupture are generally prominent features of shallow focus earthquakes and are often associated with poorly compacted backfill.

Liquefaction: The transformation of granular material from a solid state into a liquefied state as a result of an increase in pore water pressure is called liquefaction. Because intergranular contact is effectively lost in this condition, sand loses strength completely. Liquefaction can develop in any zone of a deposit where the necessary combination of in situ conditions and vibratory motion occurs, either at the surface or at depth. The behavior of a saturated sand deposit under earthquake conditions (cyclic loading) is dependent on its geologic and seismic history and grain structure, as well as its placement density. Less is known about the dynamic response of cohesive silty-clay-sand materials than clean cohesionless sands. Generally, denser deposits are less likely to liquefy than less dense materials. Manifestation of liquefaction in saturated sand deposits may include boils, mudspouts at the surface, water seepage through ground cracks or quicksand-like deposits over large areas. The geometry of the situation and the duration of induced ground vibrations are very important in determining whether liquefaction will occur.

Building damage: The extent of earthquake damage (intensity) is not simply a function of magnitude; under certain conditions, including ground faulting or hazardous geological and soil conditions in populated areas, a magnitude 6.5 earthquake can cause severe local damage.

In general, wood frame buildings stand up well during earthquakes due to their inherent flexibility; buildings with earthquake-resistant features generally perform better than those without. Unreinforced masonry, including brick, concrete block, and stone, perform poorly. Damage to wooden buildings with few stories depends mainly on maximum ground surface acceleration or velocity induced by the quake and varies within local areas with changes in surface acceleration or velocity levels resulting from different soil (regolith) patterns.

Shallow foreshocks and aftershocks of a size close to that of the main shock can damage structures left undamaged or weakened by it. Since it is not economically feasible to make structures completely earthquake-proof, the public ultimately decides how much risk is acceptable.

Recommendations

Adherence to the relevant provisions of the Uniform Building Code is recommended. These include, from the 1976 edition, sections 2312 (earthquake regulations), 2130 (wall anchorage), 3704 (anchorage of chimneys), and 1807k (anchorage of mechanical and electrical equipment in high-rise structures). Future revisions may include reassessment of seismic potential based upon more nearly complete data and refinement of building and design specifications based upon more accurate assessment and evaluation of

ground conditions. Presently, the Uniform Building Code does not address ground response or resonance phenomena between structures and the regolith upon which they are built. Additional up-to-date information will be contained in the Applied Technology Council (A.T.C. III) Code, to be published soon.

Seismic site evaluation for major structures is complex and utilizes extensive and thorough input from geology, seismology, and soils engineering. It is not discussed here because it is thoroughly described in the literature (Bolt, 1978).

An excellent reference for planners and engineers on the state of the art of earthquake knowledge and research is Learning from Earthquakes, 1977 Planning and Field Guides, by the Earthquake Engineering and Research Institute. It attempts to maximize the learning that can occur from new earthquakes (building response, ground response, liquefaction, etc.) through thorough and systematic observations (detailed in the field guides) that should immediately follow a future earthquake. Such detailed observations, if accurate, provide invaluable information upon which to base decisions regarding land use and building codes.

Further research can be expected to play a major role in earthquake assessment within the Willamette Valley. Oregon State University is in the process of setting up a statewide seismograph network (seismic net) which will provide much better data on seismic activity in Oregon than are now available. This is expected to greatly enhance our understanding of fault structures and their capabilities for future activity.

The general conclusions advanced here should in no way prejudice the findings of more involved and specific studies in the future.

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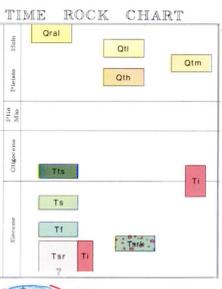
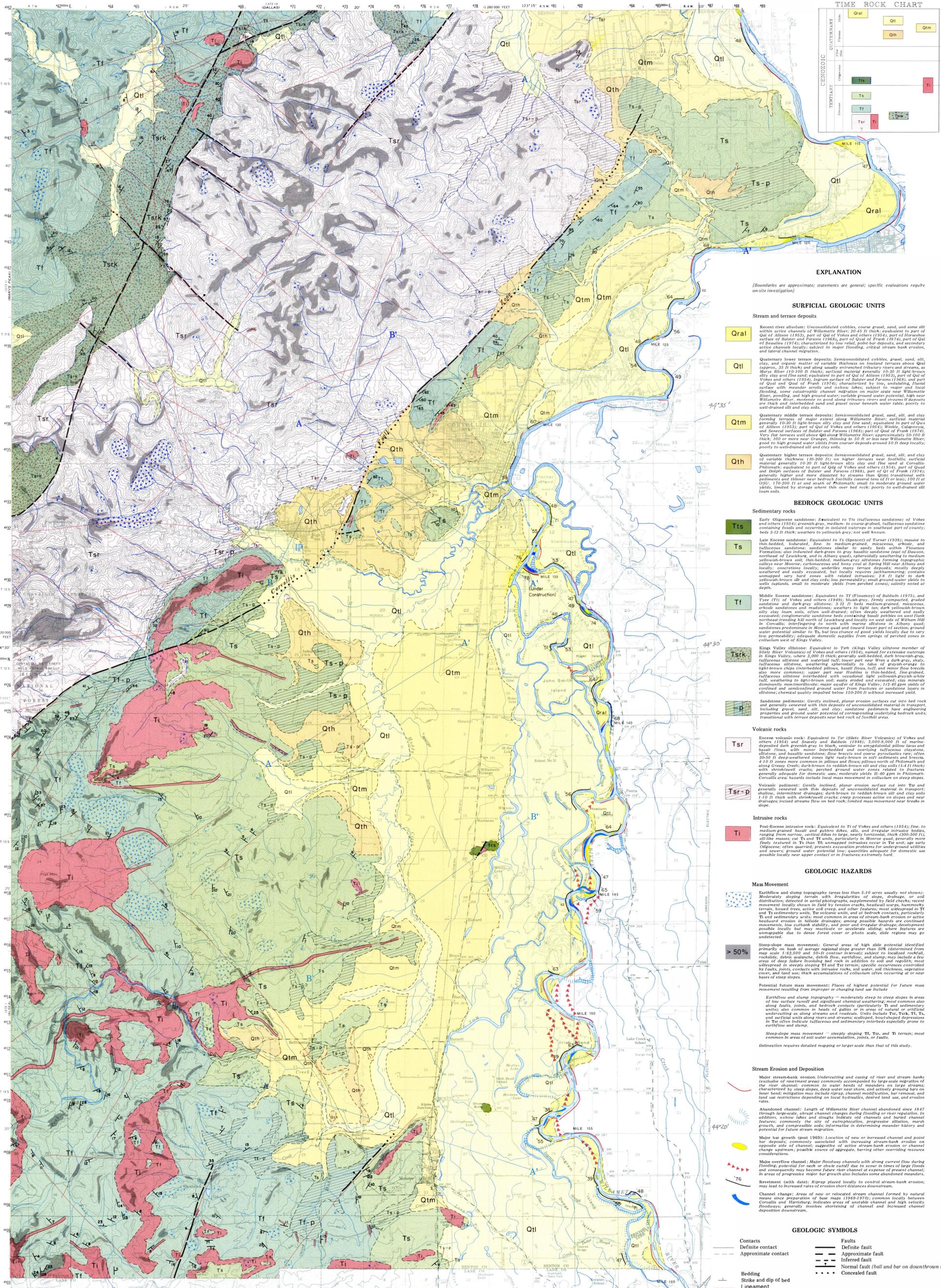
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MAP SHOWING GEOLOGY AND GEOLOGIC HAZARDS of EASTERN BENTON COUNTY OREGON

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



EXPLANATION

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

SURFICIAL GEOLOGIC UNITS

- Stream and terrace deposits**
- Qral** Recent river alluvium: Unconsolidated cobbles, coarse gravel, sand, and some silt within active channels of Willamette River; 10-25 ft thick; equivalent to part of Qal of Allison (1953); part of Qal of Vokes and others (1954); part of Horseshoe surface of Beaulieu (1974); characterized by low relief, point-bar deposits, and secondary active channel locally; subject to major flooding, critical stream bank erosion, and lateral channel migration.
 - Qtl** Quaternary lower terrace deposits: Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter of variable thickness on isolated terraces above Qral (approx. 35 ft thick) and along usually entrenched tributary rivers and streams, as well as along Willamette River; 10-30 ft thick; equivalent to part of Qal of Vokes and others (1954); part of Qal of Allison (1953); part of Horseshoe surface of Beaulieu (1974); characterized by low, undulating, fluvial surface with meander scars and oxbow lakes; subject to major flooding, some catastrophic channel migration on major scale near Willamette River; moderate to good sand and gravel deposits; moderate to high near Willamette River; moderate to good along tributary rivers and streams; deposits are well-sorted and well-sorted sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.
 - Qtm** Quaternary middle terrace deposits: Semiconsolidated gravel, sand, silt, and clay terraces; 10-30 ft thick; equivalent to part of Qal of Vokes and others (1954); part of Qal of Allison (1953); part of Horseshoe surface of Beaulieu (1974); characterized by low, undulating, fluvial surface; moderate to good sand and gravel deposits; moderate to high near Willamette River; moderate to good along tributary rivers and streams; deposits are well-sorted and well-sorted sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.
 - Qth** Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay terraces; 10-30 ft thick; equivalent to part of Qal of Vokes and others (1954); part of Qal of Allison (1953); part of Horseshoe surface of Beaulieu (1974); characterized by low, undulating, fluvial surface; moderate to good sand and gravel deposits; moderate to high near Willamette River; moderate to good along tributary rivers and streams; deposits are well-sorted and well-sorted sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.

BEDROCK GEOLOGIC UNITS

- Tts** Early Eocene sandstone: Equivalent to Tts (tuffaceous sandstone) of Vokes and others (1954); greenish-gray, medium to coarse grained, tuffaceous sandstone containing fossils and scattered siltstone in southeast part of county; beds 3-12 ft thick; weathers to yellowish gray; not well known.
- Ts** Late Eocene sandstone: Equivalent to Ts (Spencer) of Turner (1938); massive to thin bedded, indurated, fine to medium grained, micaceous, silty and tuffaceous sandstone, sandstone similar to sandy beds within Floumoy Formation; indurated, medium to coarse grained, micaceous, silty and tuffaceous sandstone; weathers to yellowish gray; not well known.
- Tf** Middle Eocene sandstone: Equivalent to Tf (Floumoy) of Baldwin (1975), and Tye (Tf) of Vokes and others (1954); blue-gray, finely compacted, graded sandstone and dark gray siltstone; 3-12 ft beds; medium grained, micaceous, silty and tuffaceous sandstone; weathers to light tan; dark yellowish brown silty clay loam soils, often well-drained; often deeply weathered or locally excavated; conglomeratic sandstone beds containing pebbles on west flank north-trending hill north of Lewisburg; and in Albany (1968); part of Qal of Vokes and others (1954); intertongues to north with marine siltstone in Albany area; sandstone predominates in Monroe creek and toward lower part of section; ground water potential similar to Ts, but less chance of good yields locally due to very low permeability; adequate domestic supplies from springs of perched zones in collium west of Kings Valley.
- Tsrk** Kings Valley siltstone: Equivalent to Tsrk (Kings Valley siltstone member of Siletz River Volcanics) of Vokes and others (1954); 3,000-5,000 ft of marine-deposited dark gray to black, vesicular, unconsolidated silty loam and basal flow, with minor interbedded and overlying tuffaceous claystone, tuffaceous sandstone and siltstone; lower part near Brien a dark gray, silty, tuffaceous siltstone, weathering spiculously to talus of grayish-orange to light tan; thin bedded, medium gray siltstone forming topographic valleys near Monroe; carbonaceous and loam coal at Spring Hill; contains locally, concretions locally; underlies many terrace deposits; mostly deeply weathered and easily excavated, but locally resistant to farming; contains unappreciated hard zones with related intrusions; 3-8 ft light to dark yellowish brown silt and clay soils; low permeability; small ground water yields (uplands, small to moderate yields from perched zones); salinity noted at depth.
- Ts-p** Sandstone pediments: Gently inclined, planar erosion surfaces cut into bed rock and generally covered with thin deposits of unconsolidated material in steep slopes; shallow intermittent drainage; reddish brown silt and clay soils 1-10 ft thick with shrink/swell cracks; creep processes active on slopes and near drainage; incised streams flow on bed rock; limited mass movement near breaks in slopes.

Volcanic rocks

- Tsr** Eocene volcanic rock: Equivalent to Tsr (Siletz River Volcanics) of Vokes and others (1954) and Siletz and Baldwin (1948); 3,000-5,000 ft of marine-deposited dark gray to black, vesicular, unconsolidated silty loam and basal flow, with minor interbedded and overlying tuffaceous claystone, tuffaceous sandstone and siltstone; lower part near Brien a dark gray, silty, tuffaceous siltstone, weathering spiculously to talus of grayish-orange to light tan; thin bedded, medium gray siltstone forming topographic valleys near Monroe; carbonaceous and loam coal at Spring Hill; contains locally, concretions locally; underlies many terrace deposits; mostly deeply weathered and easily excavated, but locally resistant to farming; contains unappreciated hard zones with related intrusions; 3-8 ft light to dark yellowish brown silt and clay soils; low permeability; small ground water yields (uplands, small to moderate yields from perched zones); salinity noted at depth.
- Tsr-p** Sandstone pediments: Gently inclined, planar erosion surfaces cut into bed rock and generally covered with thin deposits of unconsolidated material in steep slopes; shallow intermittent drainage; reddish brown silt and clay soils 1-10 ft thick with shrink/swell cracks; creep processes active on slopes and near drainage; incised streams flow on bed rock; limited mass movement near breaks in slopes.

Intrusive rocks

- Ti** Post-Eocene intrusive rock: Equivalent to Ti of Vokes and others (1954); fine to medium grained, vertical dikes to large, nearly horizontal, thick (300-500 ft), silty masses, cut by Tsr and Tsr-p units, particularly in Monroe area; generally massive; finely textured in Tsr than Tsr-p; unappreciated intrusions occur in Tsr units; use early Oligocene; often quarried; presents excavation problems for underground utilities and sewers; ground water potential low; quantities adequate for domestic use possible locally near upper contact or in fractures; extremely hard.

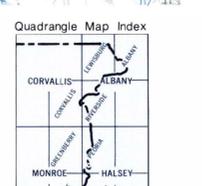
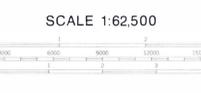
GEOLOGIC HAZARDS

- Mass Movement**
 - Earthflow and slump topography** (areas less than 5-10 acres usually not shown): Moderately steep terrain with irregularities of slope, drainage, or soil distribution; detected in aerial photographs, substantiated by field check; units are locally shown in field by tension cracks, headwall scarps, hummocky terrain, and sedimentary units. The volcanic units, and of bedrock contacts, particularly Tsr and Tsr-p units, are most common. In Monroe area, headwall scarps and hummocky terrain are common. In Kings Valley area, headwall scarps and hummocky terrain are common. In Kings Valley area, headwall scarps and hummocky terrain are common.
 - Steep-slope mass movement**: General areas of high slope potential identified primarily on basis of average regional slope greater than 50% (determined from map scale 1:62,500 and 50-ft contour interval); subject to localized rockfalls, rockslides, debris avalanches, debris flows, and debris slides; may include areas of deep failure involving bed rock in addition to soil and regolith; most widespread in steeply sloping Tsr and Tsr-p terrain; specific occurrences controlled by faults, joints, contacts with intrusive rocks, soil water, soil thickness, vegetation cover, and land use; thick accumulations of collium often occurring at or near base of steep slopes.
 - Potential future mass movement**: Places of highest potential for future mass movement resulting from improper or changing land use include:
 - Earthflow and slump topography** - moderately steep to steep slopes in areas of low surface runoff and high potential chemical weathering; most common along faults, joints, and bedrock contacts (particularly Tsr and Tsr-p units); also common in beds of siltstone or in areas of regolith; common undercutting along streams and roadsides. Units include Tsr, Tsr-p, Tsr, and Tsr-p units along rivers and streams; also common in beds of siltstone in Tsr often indicate tuffaceous and sedimentary interbeds especially prone to earthflow and slump.
 - Steep-slope mass movement** - steeply sloping Tsr, Tsr, and Tsr-p terrain; most common in areas of soil water accumulation, joints, or faults.
- Stream Erosion and Deposition**
 - Major stream-bank erosion**: Undercutting and caving of river and stream banks (exclusive of treatment areas) commonly accompanied by large-scale migration of the river channel; common to outer bends of meanders on large streams; characterized by steep slopes, undercuts, and debris flows; may include debris flows; mitigation may include riprap, channel modification, bar removal, and land use restrictions depending on local hydrology, desired land use, and erosion rates.
 - Abandoned channel**: Length of Willamette River channel abandoned since 1847 through large-scale, abrupt channel change during flooding or major flood; in addition, oxbow lakes and sloughs indicate old channel and buried channel features; commonly the site of eutrophication, progressive siltation, and marsh growth, and compressible soils; informative in determining meander history and potential for future stream migration.
 - Major bar growth** (post 1969): Location of new or increased channel and point bar deposits commonly associated with increasing stream bank erosion on opposite side of channel; suggestive of active stream-bank erosion or channel change upstream; possible source of aggregate, barring other overriding resource considerations.
 - Major overflow channel**: Major floodway channels with strong current flow during flooding; potential for neck or chute cutoff due to scour in times of large floods and consequently may become future river channel at expense of present channel; in areas of progressive major bar growth also indicates some abandoned meanders.
 - Retrievement (with date)**: Riprap placed locally to control stream bank erosion; may lead to increased rates of erosion short distances downstream.
 - Channel change**: Area of new or relocated stream channel formed by natural means since preparation of base maps (1969-1970); common locally between Corvallis and Harrisburg; indicates areas of unstable channel and high velocity floodways; generally involves shortening of channel and increased channel deposition downstream.

GEOLOGIC SYMBOLS

- Contacts**
 - Definite contact
 - Approximate contact
- Bedding**
 - Strike and dip of bed
 - Lineament
- Faults**
 - Definite fault
 - Approximate fault
 - Inferred fault
 - Normal fault (ball and bar on downthrow side)
 - Concealed fault

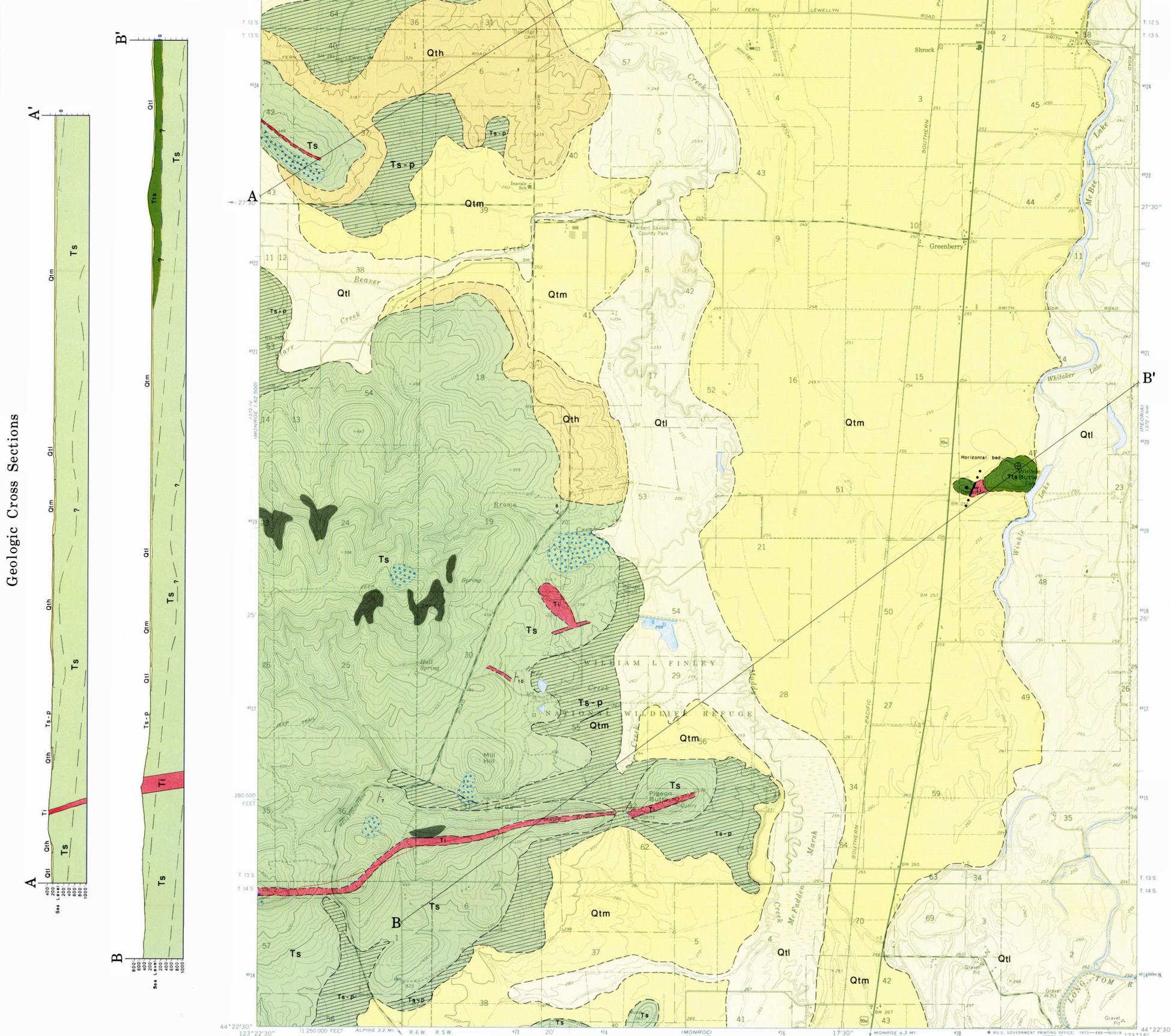
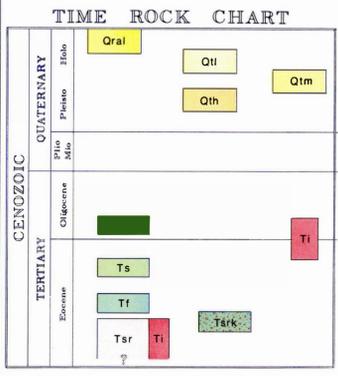
Base Map from USGS 15' series (Topographic)
Willamette River channel revised from 7 1/2' U.S.G.S. quadrangles (1969, 1970).
Topography by multiple methods from aerial photographs taken 1939. Culture revised by USGS from aerial photographs taken 1954. Field check 1956.
Polyconic projection. 1927 North American datum 10,000-foot grid based on Oregon coordinate system, north zone.
1000-meter Universal Transverse Mercator grid ticks, zone 10.



Geology by Jim Bela modified after Vokes, Myers, and Hoover, 1954.
CARTOGRAPHY by Paul E. Staub, 1978.
Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries C. A. Schumacher, Chief Cartographer

MAP SHOWING GEOLOGY AND GEOLOGIC HAZARDS of the GREENBERRY QUADRANGLE OREGON

GREENBERRY QUADRANGLE
OREGON - BENTON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
NEAR MONROE 15 QUADRANGLE



EXPLANATION

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

SURFICIAL GEOLOGIC UNITS

Stream and terrace deposits

- Qal** Recent river alluvium: Unconsolidated cobbles, coarse gravel, sand, and silt within active channels of Willamette River; 20-45 ft thick, equivalent to part of Qol of Allison (1953); part of Qol of Vokes and others (1964); part of Horseshoe surface of Balster and Parsons (1968); part of Qol of Frank (1974); part of Qol of Housh (1974); characterized by low relief, point-bar deposits, and secondary active channels locally; subject to major flooding, critical stream bank erosion, and lateral channel migration.
- Qol** Quaternary lower terrace deposits: Semiconsolidated cobbles, gravel, sand, silt, clay, and organic matter of variable thickness on lowland terraces above Qal (approx. 35 ft thick) and along usually entrenched tributary rivers and streams, as Meigs River (10-100 ft thick); surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qol of Allison (1953), and part of Qol of Vokes and others (1964); part of Qol of Frank (1974); characterized by low, undulating, fluvial surface with meander scrolls and oxbow lakes; subject to major and local flooding; some catastrophic channel migration on major scale near Willamette River; ponding, and high ground water; variable ground water potential, high near Willamette River; moderate to good along tributary rivers and streams if deposits are thick and interbedded sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.
- Qtm** Quaternary middle terrace deposits: Semiconsolidated gravel, sand, silt, and clay terraces of major extent along Willamette River; surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to Qol of Allison (1953); part of Qol of Vokes and others (1964); Winkle, Calapooya, and Senecal surfaces of Balster and Parsons (1968); part of Qol of Frank (1974). Very flat terraces well above Qal along Willamette River; approximately 50-100 ft thick; 100 or more near Oranger; thinning to 50 ft or less near Willamette River; good to high ground water yields from coarser deposits around 50 ft deep locally; poorly to well-drained silt and clay soils.
- Qth** Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 ft) on higher terraces near foothills; surficial material generally 10-30 ft light-brown silty clay and fine sand of Corallite-Pillomath; equivalent to part of Qol of Vokes and others (1964); part of Qol of Balster and Parsons (1968); part of Qol of Frank (1974); generally higher and more dissected by streams than Qtm; transitional with pediments and thinner near bedrock foothills (several tens of ft or less); 100 ft at OSE; 170-200 ft at and south of Pillomath; small to moderate ground water yields; limited by storage where thin over bed rock; poorly to well-drained silt loam soils.

Bedrock geologic units

- Ts** Early Oligocene sandstone: Equivalent to Ts (tuffaceous sandstone) of Vokes and others (1954); greenish-gray to black, medium to coarse grained, tuffaceous sandstone containing fossils and occurring in isolated outcrops in southeast part of county; beds 3-12 ft thick; weathers to yellowish gray; not well known.
- Ts-p** Late Eocene sandstone: Equivalent to Ts (Spencer) of Turner (1938); massive to thin-bedded, indurated, fine to medium-grained, micaceous, arkosic, and tuffaceous sandstone; sandstones similar to sandy beds within Floumoy Formation; also indurated dark-green to gray basic sandstone (east of Douglas, northeast of Lewistown, and in Albany quad); spheroidally weathering to floumoy yellowish-brown soil; thin-bedded, medium gray siltstones forming topographic valleys near Monroe; carbonaceous and bony coal at Spruce Hill near Albany and locally; concretions locally; underlies many terrace deposits; mostly deeply weathered and easily excavated; locally requires jackhammering; contains unmappped very hard zones with related intrusives; 2 ft light to dark yellowish-brown silt and clay soils; low permeability; small ground-water yields to wells; uplands, small to moderate yields from perched zones; salinity noted at depth.
- Ti** Middle Eocene sandstone: Equivalent to Ti (Floumoy) of Balduin (1975), and Type (Ti) of Vokes and others (1954); black-gray, firmly compacted, graded sandstone and dark-gray siltstone; 3-12 ft beds medium-grained, micaceous, arkosic sandstones and mudstones; weathers to light tan, dark brownish-brown clay loam soils, often well-drained, often deeply weathered, and easily excavated; conglomeratic mudstone beds containing basalt pebbles on west flank northeast trending hill north of Lewisburg and locally on west side of Wilburn Hill in Corvallis; interfingering to north with marine siltstone in Albany quad; sandstones predominate in Monroe quad and lower part of sections; ground water potential similar to Ts, but less chance of good yields locally due to very low permeability; adequate domestic supplies from springs of perched zones in colluvium west of Kings Valley.
- Ts-r** Kings Valley siltstone: Equivalent to Tark (Kings Valley siltstone member of Siletz River Volcanics) of Vokes and others (1954); named for extensive outcrops in Kings Valley, where 3,000 ft thick; generally well-bedded, dark brownish-gray, tuffaceous siltstone and waterlain tuff; lower part near Wren a dark gray, shaly, tuffaceous siltstone, weathering spheroidally to talus of grayish-orange to light-brown chips (interbedded pillows, tuff, and minor flow breccia also more common); upper part near Hoskins is thin-bedded, fine-grained, tuffaceous siltstone interbedded with occasional light yellowish-gray silt loam; weathers to light brown soil; easily eroded and excavated; clay minerals dominantly montmorillonite; major aquifer of Kings Valley; 112-40 gpm yields of confined and semi-confined ground water from fractures or sandstone layers in siltstone; chemical quality impaired below 150-200 ft without increased yield.
- Ts-r-p** Sandstone pediments: Gently inclined, planar erosion surfaces cut into bedrock and generally veneered with thin deposits of unconsolidated material in transport, including gravel, sand, silt, and clay; sandstone pediments have engineering properties and ground water potential of corresponding underlying bedrock units; transitional with terrace deposits near bedrock foothills areas.
- Ts-r** Eocene volcanic rock: Equivalent to Tsr (Siletz River Volcanics) of Vokes and others (1954) and Snavely and Balduin (1948); 3,000-9,000 ft of marine-deposited dark greenish-gray to black, vesicular to amygdaloidal pillow lavas and basalt flows with minor interbedded and overlying tuffaceous claystone, siltstone, and basic sandstone; flow breccia and coarse pyroclastic raps; often 20-50 ft deep weathered zones light rusty-brown in soft sediments and breccia; 20-50 gpm more common in colluvium and flows; zones north of Pillomath and along Greasy Creek; dark brown to reddish-brown silt and clay soils (1-4 ft thick) with thin-bedded cracks; perched ground water zones related to fractures generally adequate for domestic uses; moderate yields 15-60 gpm in Pillomath-Corvallis area; hazards include local mass movement in colluvium on steep slopes.
- Ti** Volcanic pediment: Gently inclined, planar erosion surface cut into Tsr and generally veneered with thin deposits of unconsolidated material in transport; shallow, intermittent drainage; dark-brown to reddish brown silt and clay soils 1-10 ft thick with well-developed cracks; creep processes active on slopes and near drainage; incised streams flow on bed rock; limited mass movement near breaks in slope.
- Post-Eocene intrusive rock:** Equivalent to Tl of Vokes and others (1954); fine to medium-grained basalt and gabbro dikes, sills, and irregular intrusive bodies, ranging from narrow, vertical dikes to large, nearly horizontal, thick (300-500 ft), sill-like masses; cut Tsr and Tl units, particularly in Monroe quad; generally more finely textured in Tl than Tsr; Tl intrusives occur in Tl soil; use early Oligocene; often quarried; presents excavation problems for underground utilities and sewers; ground water potential low; quantities adequate for domestic use possible locally near upper contact or in fractures; extremely hard.

EXPLANATION

Mass Movement

- Earthflow and slump topography (areas less than 5-10 acres usually not shown):** Moderately sloping terrain with irregularities of slope, drainage, or soil distribution; detected in aerial photographs, supplemented by field checks; recent movement locally shown in field by tension cracks, headcut scarp, hummocky terraces, banded trees, active soil creep, and other features; most widespread in Tl and Tl sedimentary units, Tsr volcanic units, and at bedrock contacts, particularly Tl and sedimentary units; most common in areas of stream-bank erosion or active headward erosion in hillside drainages; among possible hazards are continued movements, low cutbank stability, and poor and irregular drainage; development possible locally but may reactivate or accelerate sliding; where features are unmappped due to dense forest cover or photo scale, slide regions may go undetected.
- Steep-slope mass movement:** General areas of high slide potential identified primarily on basis of average regional slope greater than 50% (determined from map scale 1:82,500 and 50-ft contour interval); subject to localized rockfall, rockslide, debris avalanche, debris flow, earthflow, and slump; may include a few areas of deep failure involving bed rock in addition to soil and regolith; most widespread in steeply sloping Tl and Tsr terrain; specific occurrences controlled by faults, joints, contacts with intrusive rocks, soil water, soil thickness, vegetation cover, and land use; thick accumulations of colluvium often occurring at or near bases of steep slopes.
- Potential future mass movement:** Places of highest potential for future mass movement resulting from improper or changing land use include:
 - Earthflow and slump topography - moderately steep to steep slopes in areas of low surface runoff and significant chemical weathering; most common also along faults, joints, and bedrock contacts (particularly Tl and sedimentary units); also common in heads of gullies or in areas of natural or artificial undercutting as along streams and roadsides. Units include Tsr, Tl, Tl, and surficial units along rivers and streams; scalloped, bowl-shaped depressions in Tl often indicate tuffaceous and sedimentary intrusives especially prone to earthflow and slump.**
 - Steep-slope mass movement - steeply sloping Tl, Tsr, and Tl terrain; most common in areas of soil water accumulation, joints, and faults.**
- Delineation requires detailed mapping or larger scale than that of this study.**

GEOLOGIC HAZARDS

Stream Erosion and Deposition

- Major stream-bank erosion:** Undercutting and caving of river and stream banks (exclusive of recent areas) commonly accompanied by large-scale migration of the river channel; common to outer bends of meanders on large streams; characterized by steep slopes, deep water near shore, and actively growing bars on inner bend; mitigation may include riprap, channel modification, bar removal, and land use restrictions depending on local hydraulics, desired land use, and erosion rates.
- Abandoned channel:** Length of Willamette River channel abandoned since 1847 through large-scale, abrupt channel changes during flooding or river regulation. In addition, oxbow lakes and sloughs indicate old channels and buried channel features; commonly the site of eutrophication, progressive siltation, marsh growth, and compressible soils; informative in determining meander history and potential for future stream migration.
- Major bar growth (post 1969):** Location of new or increased channel and point bar deposits; commonly associated with increasing stream-bank erosion on opposite side of channel; suggestive of active stream-bank erosion or channel change upstream; possible source of aggregate, barring other overriding resource considerations.
- Major overflow channel:** Major floodway channels with strong current flow during flooding; potential for neck or chute cutoff due to scour in times of large floods and consequently may become future river channel at expense of present channel. In areas of progressive major bar growth also includes some abandoned meanders.
- Revetment (with date):** Riprap placed locally to control stream-bank erosion; may lead to increased rates of erosion short distances downstream.
- Channel change:** Areas of new or relocated stream channel formed by natural means since preparation of base maps (1969-1970); common locally between Corvallis and Hartburg; indicates areas of unstable channel and high velocity floodways; generally involves shortening of channel and increased channel deposition downstream.

Geology by Jim Bela; modified after Vokes, Myers, & Hoover, 1954.
CARTOGRAPHY by Paul E. Staub, 1978.

ROAD CLASSIFICATION

- Primary highway, all weather, hard surface
- Light-duty road, all weather, improved surface
- Secondary highway, all weather, unimproved road, fair or dry weather
- U. S. Route

GEOLOGIC SYMBOLS

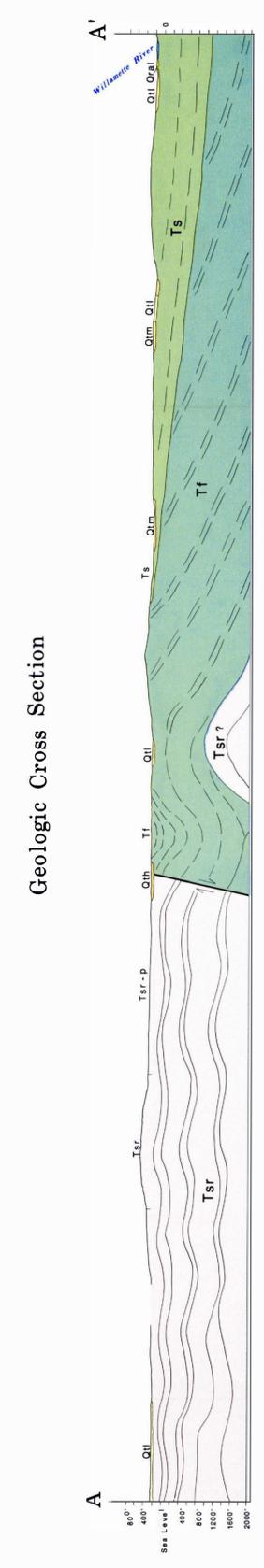
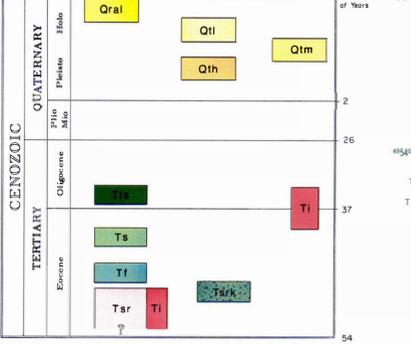
- Contacts: Definite contact, Approximate contact
- Bedding: Strike and dip of bed, Lineament
- Faults: Definite fault, Approximate fault, Inferred fault, Normal fault (ball and bar on downthrown side), Concealed fault

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries
C. A. Schumacher, Chief Cartographer

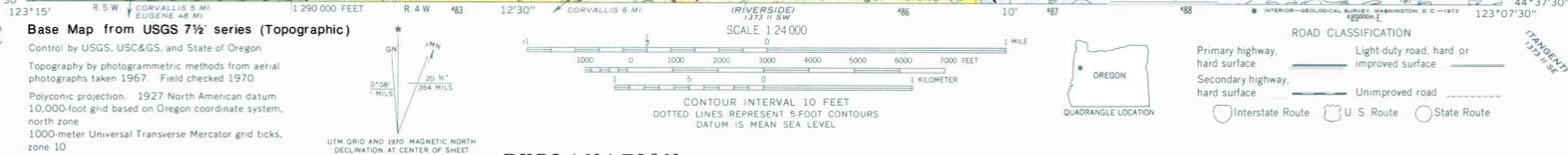
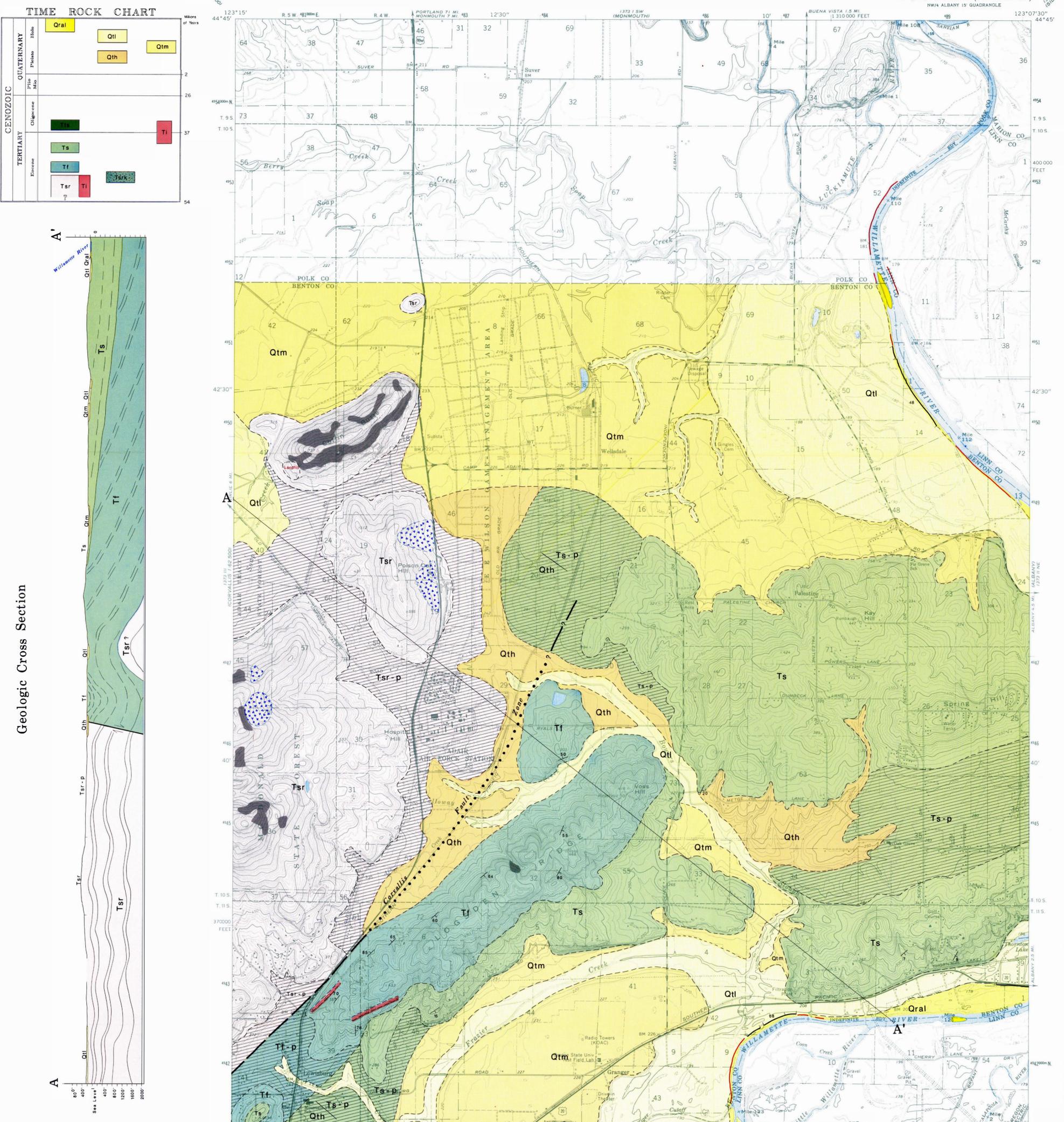
MAP SHOWING GEOLOGY AND GEOLOGIC HAZARDS of the LEWISBURG QUADRANGLE OREGON

LEWISBURG QUADRANGLE
OREGON
7.5 MINUTE SERIES (TOPOGRAPHIC)
NW 1/4 ALBANY 15 QUADRANGLE

TIME ROCK CHART



Geologic Cross Section



EXPLANATION

SURFICIAL GEOLOGIC UNITS

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

Qal Recent river alluvium: Unconsolidated cobbles, coarse gravel, sand, and some silt within active channels of Willamette River; 20-45 ft thick; equivalent to part of Qal of Allison (1983), part of Qal of Vokes and others (1984), part of Horseshoe surface of Balster and Parsons (1968), part of Qal of Frank (1974), part of Qal of Beallian (1974); characterized by low relief, point-bar deposits, and secondary active channels locally; subject to major flooding, critical stream bank erosion, and lateral channel migration.

Qh Quaternary lower terrace deposits: Semiconsolidated cobbles, sand, silt, clay, and organic matter of variable thickness on lowland terraces above Qal (approx. 35 ft thick) and along usually entrenched tributary rivers and streams, as Mars River (10-100 ft thick); surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qal of Allison (1983), part of Qal of Vokes and others (1984), part of Qal of Balster and Parsons (1968), and part of Qal and Qal of Frank (1974); characterized by low, undulating, fluted surface with meander scrolls and oxbow lakes; subject to major and local flooding, some catastrophic channel migration on major scale near Willamette River, ponding, and high ground water; variable ground water potential, high near Willamette River, moderate to good along tributary rivers and streams; deposits are thick and interbedded sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.

Qm Quaternary middle terrace deposits: Semiconsolidated gravel, sand, silt, and clay forming terraces of major extent along Willamette River; surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qm of Allison (1983), part of Qm of Vokes and others (1984), part of Qm of Balster and Parsons (1968), and part of Qm of Frank (1974); very flat terraces well above Qh along Willamette River; approximately 50-100 ft thick; 100 or more near Granger, thinning to 50 ft or less near Willamette River; good to high ground water yields from coarser deposits around 50 ft deep locally; poorly to well-drained silt and clay soils.

Ql Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 ft) on higher terraces near footwall; surficial material generally 10-30 ft light-brown silty clay and fine sand at Corvallis; Philomath; equivalent to part of Ql of Vokes and others (1984), part of Ql of Allison (1983), part of Ql of Frank (1974), and part of Ql of Balster and Parsons (1968); generally higher and more dissected by streams; transitional to Tt; thinning to 10-20 ft at and south of Philomath; small to moderate ground water yields, limited by storage where thin over bed rock; poorly to well-drained silt loam soils.

BEDROCK GEOLOGIC UNITS

Tt Early Oligocene sandstone: Equivalent to Tt (tuffaceous sandstone) of Vokes and others (1984); greenish-gray, medium to coarse-grained, tuffaceous sandstone containing fossils and occurring in isolated outcrops in southeast part of county; beds 3-12 ft thick; weathers to yellowish gray; not well known.

Ts Late Eocene sandstone: Equivalent to Ts (Spencer) of Turner (1938); massive to thin-bedded, indurated, fine to medium-grained, micaceous, arkosic, and tuffaceous sandstone; sandstone similar to sandy beds within Fluorite Formation; also indurated dark green to gray basaltic sandstone (east of Dawson, northeast of Lewisburg, and in Albany quad), spherulitic weathering to medium yellowish-brown soil; thin bedded, medium-gray siltstones forming topographic salters near Monroe; carbonaceous and bony coal at Spring Hill near Albany and locally; concretions locally; underlies many terrace deposits; mostly deeply weathered and easily excavated, but locally requires jackhammering contains unmaped very hard zones with related intrusives; 2-8 ft light to dark yellowish-brown silt and clay soils; low permeability; small ground water yields to wells; uplands, small to moderate yields from perched zones; salinity noted at depth.

Tl Middle Eocene sandstone: Equivalent to Tl (Flournoy) of Baldwin (1975), and Tye (Ti) of Vokes and others (1949); bluish-gray, firmly compacted, graded sandstone and dark gray siltstone; 3-12 ft beds medium-grained, micaceous, arkosic sandstone and mudstone; weathers to light tan, dark yellowish-brown silty clay, loam soils, often well-drained; often deeply weathered and easily excavated; coniferous sandstone beds containing fossil pebbles on west flank northeast-trending hill north of Lewisburg and locally on west side of Witham Hill in Corvallis; intertonguing to north with marine siltstone in Albany quad; sandstone predominate in Monroe quad and toward lower part of section; ground water potential similar to Ts, but less change of good yields locally due to very low permeability; adequate domestic supplies from springs of perched zones in colluvium west of Kings Valley.

Tsr Kings Valley siltstone: Equivalent to Tsr (Kings Valley siltstone member of Silette River Volcanics) of Vokes and others (1984); named for extensive outcrops in Kings Valley, where 3,000 ft thick, generally well-bedded, dark brownish-gray, tuffaceous siltstone and waterlain tuff; lower part near When a dark-gray, silty, tuffaceous siltstone; weathering spherulitic to thin of grayish-orange, to light brown chips interbedded pillows, basal flows, tuff, and minor flow breccia also more common; upper part near Hoskins is thin-bedded, fine-grained, tuffaceous siltstone interbedded with occasional light yellowish-gray white tuff, weathering to light brown soil, easily eroded and excavated; clay minerals dominantly montmorillonite; major outlier of Kings Valley; 12-40 gpm yields of confined and semi-confined ground water from fractures or sandstone layers in sandstone; chemical quality impaired below 150-200 ft without increased yield.

Tsr-p Sandstone pediments: Gently inclined, planar erosion surfaces cut into bed rock and generally underlain by thin deposits of unconsolidated material in transport, including gravel, sand, silt, and clay; sandstone pediments have engineering properties and ground water potential of corresponding underlying bedrock units; transitional with terrace deposits near bed rock of foothill areas.

Ti Volcanic rocks

Ti Eocene volcanic rock: Equivalent to Ti (Silette River Volcanics) of Vokes and others (1984) and Silette and Baldwin (1984); 3,000-8,000 ft of marine deposited dark greenish-gray to black, vesicular to amygdaloidal pillow lavas and basalt flows; minor interbedded and overlying tuffaceous claystone, siltstone, and basaltic sandstone; flow breccia and coarse pyroclastics rare; often 20-50 ft deep weathered zones light ruddy brown in soft sediments and breccia along Greasy Creek; dark brown to reddish-brown silt and clay soils (1-4 ft thick) with shrink/swell cracks; perched ground water zone related to fractures generally adequate for domestic use; moderate yields 15-60 gpm in Philomath-Corvallis area; hazards include local mass movement in colluvium on steep slopes.

Ti Volcanic sediment: Gently inclined, planar erosion surface cut into Ts and generally veneered with thin deposits of unconsolidated material in transport, including gravel, sand, silt, and clay; sandstone pediments have engineering properties and ground water potential of corresponding underlying bedrock units; transitional with terrace deposits near bed rock of foothill areas.

Intrusive rocks

Ti Post-Eocene intrusive rock: Equivalent to Ti of Vokes and others (1984); fine to medium-grained basalt and diabase dikes, sills, and irregular intrusives bodies, ranging from narrow, vertical dikes to large, nearly horizontal, thick (200-500 ft), sill-like masses; cut Ts and Tl units, particularly in Monroe quad, generally more finely textured in Ts than Tl; unmapped intrusives occur in Ts unit; use early Oligocene; often quarried; presents excavation problems for underground utilities and sewers; ground water potential low; quantities adequate for domestic use possible locally near upper contact or in fractures; extremely hard.

MASS MOVEMENT

Earthflow and slump topography (areas less than 5.10 acres usually not shown): Moderately steep terrain with irregularities of slope, drainage, or soil distribution; detected in aerial photographs, supplemented by field checks; recent movement locally shown in field by tension cracks, headwall scarps, hummocky terrain, banded trees, active soil creep, and other features; most widespread in Tl and Ts sedimentary units, Tertiary units, and at bedrock contacts, particularly Tl and sedimentary units; most common in areas of stream bank erosion or active headward erosion in hillside drainages; among possible hazards are continued movements, low cutbank stability, and poor and irregular drainage; development possible locally but may result in accelerated sliding, where features are unmapable due to dense forest cover or photo scale; slide regions may go undetected.

Steep-slope mass movement: General areas of high slide potential identified primarily on basis of average regional slope greater than 50% (determined from map scale 1:24,000 and 50-ft contour interval); subject to localized rockfall, rockslide, debris avalanches, debris flow, earthflow, and slumps may include a few areas of deep failure involving bed rock in addition to soil and regolith; most widespread in steeply sloping Tl and Ts terrain; specific occurrences controlled by faults, joints, contacts with intrusives, soil water, soil thickness, vegetation cover, and land use; thick accumulations of colluvium often occurring at or near bases of steep slopes.

Potential future mass movement: Places of highest potential for future mass movement resulting from improper or changing land use include:

- Earthflow and slump topography - moderately steep to steep slopes in areas of low surface runoff and significant chemical weathering; most common also along faults, joints, and bedrock contacts (particularly Tl and sedimentary units); also common in heads of gullies or in areas of natural or artificial undercutting along streams and roadsides. Units include Tsr, Tl, Tt, Ts, and surficial units along rivers and streams; scalloped, bowl-shaped depressions in Ts often indicate tuffaceous and sedimentary interbeds especially near to earthflow and slump.
- Steep-slope mass movement - steeply sloping Tl, Tsr, and Tl terrain; most common in areas of soil water accumulation, joints, or faults.

Delimitation inquires of detailed mapping or larger scale than that of this study.

Stream Erosion and Deposition

Major stream-bank erosion: Undercutting and caving of river and stream banks (exclusive of reclamation areas) commonly accompanied by large-scale migration of the river channel; common to outer bends of meanders on large streams; characterized by steep slopes, deep water near shore, and actively growing bars on inner bend; mitigation may include riprap, channel modification, bar removal, and land use restrictions depending on local hydraulics, desired land use, and erosion rates.

Abandoned channel: Length of Willamette River channel abandoned since 1847 through large-scale abrupt channel changes during flooding or river regulation. In addition, oxbow lakes and sloughs indicate old channels and buried channel features; commonly the site of eutrophication, progressive siltation, marsh growth, and compressible soils; informative in determining meander history and potential for future stream migration.

Major bar growth (post 1969): Location of new or increased channel and point bar deposits; commonly associated with increasing stream-bank erosion on opposite side of channel; suggestive of active stream-bank erosion or channel change upstream; possible source of aggregate, barring other overriding resource considerations.

Major overflow channel: Major floodway channels with strong current flow during flooding; potential for neck or chute cutoff due to occur in times of large floods and consequently may become future river channel at expense of present channel; in areas of progressive major bar growth also includes some abandoned meanders.

Revetment (with date): Riprap placed locally to control stream-bank erosion; may lead to increased rates of erosion short distances downstream.

Channel change: Areas of new or relocated stream channel formed by natural means since preparation of base maps (1969-1970); common locally between Corvallis and Harrisburg; indicates areas of unstable channel and high velocity floodways; generally involves shortening of channel and increased channel deposition downstream.

Geology by Jim Bela; modified after Vokes, Myers, & Hoover, 1954.

CARTOGRAPHY by Paul E. Staub, 1978.

CONTACTS

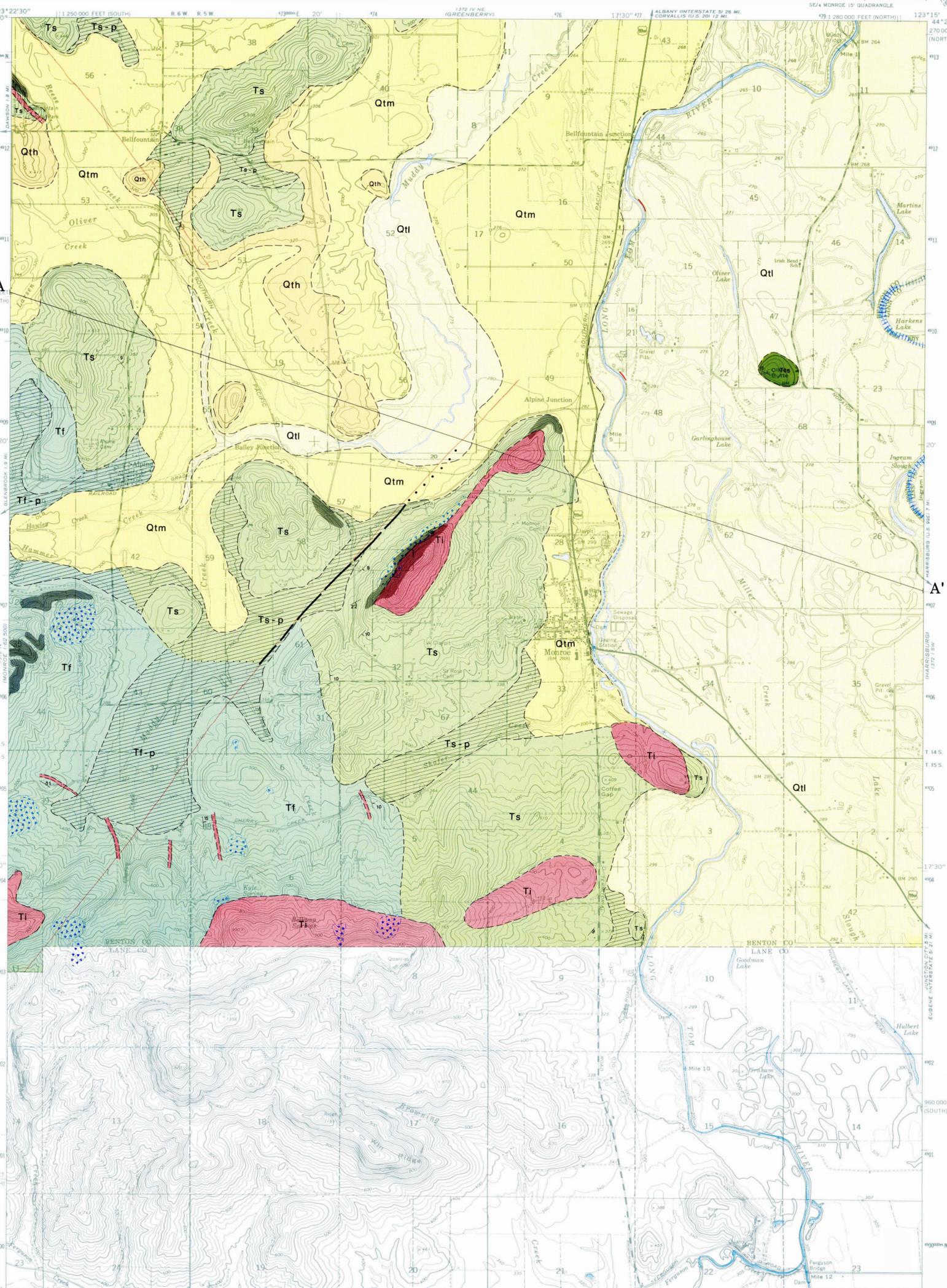
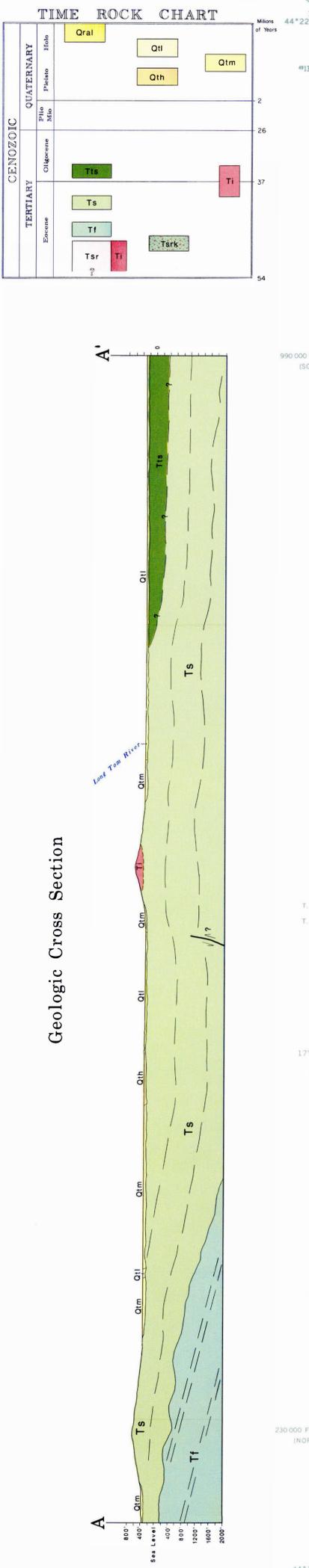
- Definite contact
- Approximate contact
- Bedding
- Strike and dip of bed
- Lineament

GEOLOGIC SYMBOLS

- Faults
- Definite fault
- Approximate fault
- Normal fault (ball and bar on downthrown side)
- Ceased fault

MAP SHOWING GEOLOGY AND GEOLOGIC HAZARDS of the MONROE QUADRANGLE OREGON

MONROE QUADRANGLE
OREGON
7.5 MINUTE SERIES (TOPOGRAPHIC)



Control by USGS, USC&GS, and State of Oregon
Topography by photogrammetric methods from aerial photographs taken 1967. Field checked 1969.
Polyconic projection, based on North American datum, 10,000-foot grids based on Oregon coordinate system, north and south zones.
1:250,000-meter Universal Transverse Mercator grid ticks, zone 10.

EXPLANATION

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

SURFICIAL GEOLOGIC UNITS

Stream and terrace deposits

- Qal** Recent river alluvium: Unconsolidated cobbles, coarse gravel, sand, and some silt within active channels of Willamette River; 30-45 ft thick; equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), part of Horseshoe surface of Bolter and Parsons (1968), part of Qal of Frank (1974), part of Qal of Allison (1974), characterized by low relief, point-bar deposits, and secondary active channels locally; subject to major flooding, critical stream bank erosion, and lateral channel migration.
- Qtl** Quaternary lower terrace deposits: Semiconsolidated gravel, sand, silt, clay, and organic matter of variable thickness on lowland terraces above Qal (approx. 35 ft thick) and along seasonally entrenched tributary rivers and streams, at Mars River (10-100 ft thick); surficial material generally 10-20 ft light-brown silty clay and fine sand; equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), Ingram surface of Bolter and Parsons (1968), and part of Qal and Qal of Frank (1974); characterized by low, undulating, fluted surface with meander scrolls and oxbow lakes; subject to major and local flooding, some catastrophic channel migration on major scale near Willamette River, ponding, and high ground water; variable ground water potential; high near Willamette River, moderate to good along tributary rivers and streams; deposits are thick and interbedded sand and gravel occur beneath water table; poorly to well-drained silt and clay soils.
- Qth** Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 ft) on higher terraces near foothills; surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), White, Calapooia, and Seneca surfaces of Bolter and Parsons (1968), part of Qal of Frank (1974). Very flat terraces well above Qal along Willamette River; approximately 50-100 ft thick; 100 or more near Crater; thinning to 50 ft or less near Willamette River; good to high ground water yields from coarser deposits around 50 ft deep locally; poorly to well-drained silt and clay soils.
- Qtm** Quaternary middle terrace deposits: Semiconsolidated gravel, sand, silt, and clay forming terraces of major extent along Willamette River; surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), White, Calapooia, and Seneca surfaces of Bolter and Parsons (1968), part of Qal of Frank (1974). Very flat terraces well above Qal along Willamette River; approximately 50-100 ft thick; 100 or more near Crater; thinning to 50 ft or less near Willamette River; good to high ground water yields from coarser deposits around 50 ft deep locally; poorly to well-drained silt and clay soils.
- Qts** Quaternary higher terrace deposits: Semiconsolidated gravel, sand, silt, and clay of variable thickness (10-200 ft) on higher terraces near foothills; surficial material generally 10-30 ft light-brown silty clay and fine sand; equivalent to part of Qal of Allison (1953), part of Qal of Vokes and others (1954), White, Calapooia, and Seneca surfaces of Bolter and Parsons (1968), part of Qal of Frank (1974). Very flat terraces well above Qal along Willamette River; approximately 50-100 ft thick; 100 or more near Crater; thinning to 50 ft or less near Willamette River; good to high ground water yields from coarser deposits around 50 ft deep locally; poorly to well-drained silt and clay soils.

BEDROCK GEOLOGIC UNITS

Sedimentary rocks

- Ts** Early Oligocene sandstone: Equivalent to Ts (tuffaceous sandstone) of Vokes and others (1954); greenish gray, medium to coarse grained, tuffaceous sandstone containing fossils not occurring in isolated outcrops in southern part of county; beds 3-12 ft thick; weathers to yellowish gray; not well known.
- Ts** Late Eocene sandstone: Equivalent to Ts (Spencer) of Turner (1938); massive to thin-bedded, indurated, fine to medium-grained, micaceous, arkosic, and tuffaceous sandstone; sandstone similar to sandy beds within Phalaris Formation; also indurated dark green to gray basaltic sandstone (east of Phalaris, north of Lewisburg, and in Albany quad); spherulitic weathering to medium yellowish brown soil; thin bedded, medium to coarse grained, tuffaceous sandstone; outcrops near Monroe; carbonaceous and bony wood at Spring Hill near Albany and locally; concretions locally; underlies many terrace deposits; mostly steeply weathered and easily excavated, but locally requires jackhammering; contains unmaped very hard some with related structures; 2-8 ft light to dark yellowish-brown silt and clay soils; low permeability; small ground water yields to wells (shallow), small to moderate yields from perched zones; salinity noted at depth.

Volcanic rocks

- Tf** Middle Eocene volcanics: Equivalent to Tf (Flourmill) of Baldwin (1975), and Tye (Tt) of Vokes and others (1949); bluish gray, finely compacted, graded sandstone and dark gray siltstone; 3-12 ft beds medium grained, micaceous, arkosic sandstone and mudstone; weathers to light tan, dark yellowish-brown silty clay loam soils, often well-drained; often deeply weathered and easily excavated; conglomeratic sandstone beds containing basalt pebbles on west flank northeast trending all north of Lewisburg and locally on west side of Witham Hill in Corvallis; intertongued to north with marine siltstone in Albany quad; sandstone predominate in Monroe quad and toward lower part of section ground water potential similar to Ts, but less chance of good yields locally due to very low permeability; adequate domestic supplies from springs of perched zones in colluvium west of Kings Valley.
- Tsrk** Kings Valley siltstone: Equivalent to Tsrk (Kings Valley siltstone member of Siletz River Volcanics) of Vokes and others (1954), named for extensive outcrops in Kings Valley, where 3,000 ft thick, generally well-bedded, dark brownish-gray, tuffaceous siltstone and waterlain tuff; lower part near Wren a dark gray, silty, tuffaceous siltstone, weathering spherulitically to talus of grayish-orange to light brown chips (interbedded pillow, basal flows, tuff, and minor flow breccia also more common); upper part near Hoskins is thin-bedded, fine-grained, tuffaceous siltstone interbedded with occasional light yellowish-gray-white tuff, weathering to light brown soil, easily eroded and excavated; clay minerals dominantly non-illuminite; major aquifer of Kings Valley; 12-40 gpm yields of confined and semi-confined ground water from fractures or sandstone layers in sandstone; chemical quality impaired below 150-200 ft without increased yields.
- Tsr** Sandstone pediments: Gently inclined, planar erosion surface cut into bed rock and generally covered with thin deposits of unconsolidated material in transport, including gravel, sand, silt, and clay; sandstone pediments have engineering properties and ground water potential of corresponding underlying bedrock units; transitional with terrace deposits near bed rock of foothill areas.
- Tsr-p** Volcanic sediment: Gently inclined, planar erosion surface cut into Tsr and generally covered with thin deposits of unconsolidated material in transport, including gravel, sand, silt, and clay; sandstone pediments have engineering properties and ground water potential of corresponding underlying bedrock units; transitional with terrace deposits near bed rock of foothill areas.
- Ti** Post-Eocene intrusive rock: Equivalent to Ti of Vokes and others (1954); fine to medium grained basalt and gabbro dikes, sills, and irregular intrusive bodies ranging from narrow, vertical dikes to large, nearly horizontal, thick (200-600 ft), sill like masses; cut Ts and Tt units, particularly in Monroe quad, generally more finely textured in Ts than Tt; unmaped intrusions occur in Tt unit; see early Oligocene; often quarried; presents excavation problems for underground utilities and sewers; ground water potential low; quantities adequate for domestic use possible locally near upper contact or in fractures; extremely hard.

MASS MOVEMENT

- Earthflow and slump topography (areas less than 5-10 acres usually not shown):** Moderately steep terrain with irregularities of slope, drainage, or soil distribution; detected in aerial photographs, supplemented by field checks; recent movement locally shown in field by tension cracks, hoodoo scarp, hummocky terrain, bowed trees, active soil creep, and other features; most widespread in Tt and Ts sedimentary units, but volcanic units, and at bedrock contacts, particularly Tt and sedimentary units; most common in areas of stream bank erosion or active localised erosion in hillside drainages; among possible hazards are continued movements, low culbank stability, and poor and irregular drainage; development possible locally but may necessitate or accelerate sliding, where features are unmapable due to dense forest cover or photo scale, slide regions may go undetected.
- Steep-slope mass movement:** General area of high slide potential identified primarily on basis of average regional slope greater than 50% (determined from map scale 1:24,000 and 50-ft contour interval); subject to localized rockfall, rockslide, debris avalanche, debris flow, earthflow, and slump; may include a few areas of deep failure involving bed rock in addition to soil and regolith; most widespread in steeply sloping Tt and Tsr terrain; specific occurrences controlled by faults, joints, contacts with intrusive rocks, soil water, soil thickness, vegetation cover, and land use; thick accumulations of colluvium often occurring at or near bases of steep slopes.
- Potential future mass movement:** Places of highest potential for future mass movement resulting from improper or changing land use include:
 - Earthflow and slump topography - moderately steep to steep slopes in areas of low surface runoff and significant chemical weathering; most common also along faults, joints, and bedrock contacts (particularly Tt and sedimentary units); also common in heads of gulches or in areas of natural or artificial undercutting as along streams and roadsides. Units include Tsr, Tsr, Tt, Ts, and surficial units along rivers and streams; scalloped, bowl-shaped depressions in Tt often indicate tuffaceous and sedimentary interbeds especially prone to earthflow and slump.
 - Steep-slope mass movement - steeply sloping Tt, Ts, and Tsr terrain; most common in areas of soil water accumulation, joints, or faults.

Delimitation requires detailed mapping or larger scale than that of this study.

GEOLOGIC HAZARDS

Stream Erosion and Deposition

- Major stream-bank erosion:** Undercutting and caving of river and stream banks (exclusive of recent landslides) commonly accompanied by large-scale migration of the river channel; common to outer bends of meanders on large streams; characterized by steep slopes, deep water near shore, and actively growing bars on inner bend; mitigation may include riprap, channel modification, bar removal, and land use restrictions depending on local hydraulics, desired land use, and erosion rates.
- Abandoned channel:** Length of Willamette River channel abandoned since 1847 through large-scale, abrupt channel changes during flooding or river regulation; in addition, oxbow lakes and sloughs indicate old channels and buried channel features; commonly the site of eutrophication, progressive siltation, marsh growth, and compressible soils; informative in determining meander history and potential for future stream migration.
- Major bar growth (post 1969):** Location of new or increased channel and point bar deposits; commonly associated with increasing stream-bank erosion on opposite side of channel; suggestive of active stream-bank erosion or channel change upstream; possible source of aggregate, barring other overriding considerations.
- Major overflow channel:** Major floodway channels with strong current flow during flooding; potential for neck or chute cutoff due to scour in times of large floods and consequently may become future river channel at expense of present channel; in areas of progressive major bar growth also includes some abandoned meanders.
- Revetment (with date):** Riprap placed locally to control stream-bank erosion; may lead to increased rates of erosion short distances downstream.
- Channel change:** Areas of new or relocated stream channel formed by natural means since preparation of base maps (1969-1970); common locally between Corvallis and Harburg; indicates areas of unstable channel and high velocity floodways; generally involves shortening of channel and increased channel deposition downstream.

Prepared and Published by the Cartographic Section of the Department of Geology and Mineral Industries
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