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Geologic Framework of the Willamette Lowland Aquifer System, Oregon and Washington

By MARSHALL W. GANNETT *and* RODNEY R. CALDWELL

REGIONAL AQUIFER-SYSTEM ANALYSIS—PUGET-WILLAMETTE LOWLAND

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which, in aggregate, underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and, accordingly, transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number beginning with Professional Paper 1400.

Charles G. Groat
Director

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[Plates are in pocket]

Base map modified from the following sources: hydrography from 1:250,000 topographic quadrangles, 1:100,000 topographic quadrangles and Digital Line Graphs (DLGs), and 1:24,000 topographic quadrangles; counties from 1:500,000 DLGs; roads from 1:250,000 DLGs; cities from Geographic Names Information System data base; and other digital sources. Universal Transverse Mercator projection, Zone 10, North American Datum 1927.

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Multiply	*By*	*To Obtain*
	Length	
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute (gal/min)	0.002228	cubic foot per second (ft^3/s)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

GEOLOGIC FRAMEWORK OF THE WILLAMETTE LOWLAND AQUIFER SYSTEM, OREGON AND WASHINGTON

By Marshall W. Gannett and Rodney R. Caldwell

ABSTRACT

This report describes regional hydrogeologic units of the Willamette Lowland aquifer system in western Oregon and southwestern Washington. This investigation is one part of a comprehensive hydrogeologic investigation of the Puget-Willamette Lowland in Oregon, Washington, and British Columbia, Canada, conducted as part of the U.S. Geological Survey Regional Aquifer-System Analysis program.

The Willamette Lowland is a structural and erosional lowland between uplifted marine rocks of the Coast Range and volcanic rocks of the Cascade Range. The Willamette Lowland study area encompasses approximately 5,680 square miles, 3,700 square miles of which are underlain by basin-fill deposits. The Coast Range, to the west of the lowland, consists of several thousand feet of Tertiary marine sandstone, siltstone, shale, and associated volcanic and intrusive rocks. The Cascade Range, to the east of the lowland, consists of volcanic lava flows, ash-flow tuffs, and pyroclastic and epiclastic debris. Continental and marine strata interfinger beneath and adjacent to the Willamette Lowland. In the northern two-thirds of the lowland, the marine sedimentary rocks and Cascade Range volcanic rocks are overlain by up to a thousand feet of lava of the Columbia River Basalt Group. Folding and faulting during and after incursion of the Columbia River Basalt Group formed four major depositional basins. These basins, separated in most places by uplands capped by the Columbia River Basalt Group, have locally accumulated more than 1,600 feet of fluvial sediment derived from the Cascade and Coast Ranges or transported into the region by the Columbia River. During Pleistocene time, large-volume glacial-outburst floods, which originated in western Montana, periodically flowed down the Columbia River drainage and inundated the Willamette Lowland. These floods deposited up to 250 feet of silt, sand, and gravel in the Portland Basin, and up to 130 feet of silt, known as the Willamette Silt, elsewhere in the Willamette Lowland.

Five regional hydrogeologic units were delineated and mapped in the Willamette Lowland on the basis of lithologic information from field-located water wells, geotechnical boreholes, petroleum exploration wells, and published geologic and geophysical maps. These units are (1) the basement confining unit, (2) the Columbia River basalt aquifer, (3) the Willamette confining unit, (4) the Willamette aquifer, and (5) the Willamette Silt unit.

The basement confining unit consists of low-permeability marine sedimentary rocks and associated marine volcanic and intrusive rocks. This unit also includes low-permeability volcanic rocks of the western Cascade Range.

The Columbia River basalt aquifer consists of accordantly layered basalt flows, which generally are characterized by low vertical permeability and high lateral permeability. The Columbia River basalt aquifer underlies the northern half of the Willamette Lowland and is locally capable of producing large amounts of water.

The Willamette confining unit and the Willamette aquifer are contained within the basin-fill deposits of the Willamette Lowland. The Willamette aquifer, the principal water-bearing unit in the region, is composed predominantly of sand and gravel with lesser amounts of silt and clay, whereas the Willamette confining unit is dominated by silt and clay with substantially less sand and gravel. The Willamette aquifer includes regions of predominantly coarse-grained material up to 200 to 400 feet thick that are located where major drainages debouch into the Willamette Lowland from the Cascade Range. In most places, these thick deposits are hydraulically connected by thinner, but more widespread, gravel deposits near or at the top of the pre-flood, basin-fill section. The coarse-grained deposits that compose the Willamette aquifer are interpreted as the proximal facies of alluvial fans that existed for much of the depositional history of the lowland, and which prograded across much of the valley floor during Pleistocene time. Elsewhere in the section, the basin-fill deposits are dominated by fine-grained materials assigned chiefly to the Willamette confining unit. The fine-grained deposits formed primarily as distal fan facies and deposits of low-gradient streams on the valley floor.

The Willamette Silt unit consists of silt and fine sand deposited in the central and southern Willamette Valley by late Pleistocene glacial-outburst floods. In the Portland Basin, the flood deposits are coarser grained and are considered part of the Willamette aquifer. In the Tualatin Basin, the fine-grained flood deposits directly overlie the lithologically similar Willamette confining unit and are considered part of that unit.

INTRODUCTION

In 1978, the U.S. Geological Survey began a series of investigations of regional aquifer systems under the Regional Aquifer-System Analysis (RASA) program. Prior to the RASA program, most ground-water investigations covered local or subregional flow systems, and information on regional flow systems was lacking. The RASA program was designed to provide information necessary for understanding and managing ground-water resources on a regional scale. The Puget-Willamette Lowland was one of the 28 regional aquifer systems in the Nation identified for study under the RASA program (Sun, 1986).

PURPOSE AND SCOPE

The purpose of this report is to present a general geologic overview of the Willamette Lowland and describe the regional hydrogeologic units delineated herein for the Willamette Lowland aquifer system. Knowledge of the geologic framework is necessary to understanding regional ground-water flow and to evaluate the flow system quantitatively; the information also will be useful for regional ground-water management and planning.

Regionally significant hydrogeologic units are emphasized in this report. Less extensive aquifers, which may be locally important, are not shown on maps, although selected ones are described in the text. The accompanying maps provide a general guide to the nature of aquifer materials in a particular area, but, because of local variability, are not intended to provide site-specific information.

LOCATION AND EXTENT OF STUDY AREA

The Puget-Willamette Lowland is a regional geologic depression that extends north from the area of Eugene, Oregon (44° N lat.), to the Fraser River area in southern British Columbia, Canada (49°15′ N lat.) (fig. 1). It comprises two major late Cenozoic sedimentary basins separated by bedrock uplands. These basins, also referred to as "lowlands," are the Willamette Lowland, in Oregon and southwestern Washington, and the Puget Sound Lowland in Washington and southwestern British Columbia. The Willamette Lowland and the Puget Sound Lowland form two hydrologically and geologically distinct aquifer systems within the Puget-Willamette Lowland, and are being studied separately as parts of the Puget-Willamette Lowland RASA (Vaccaro, 1992).

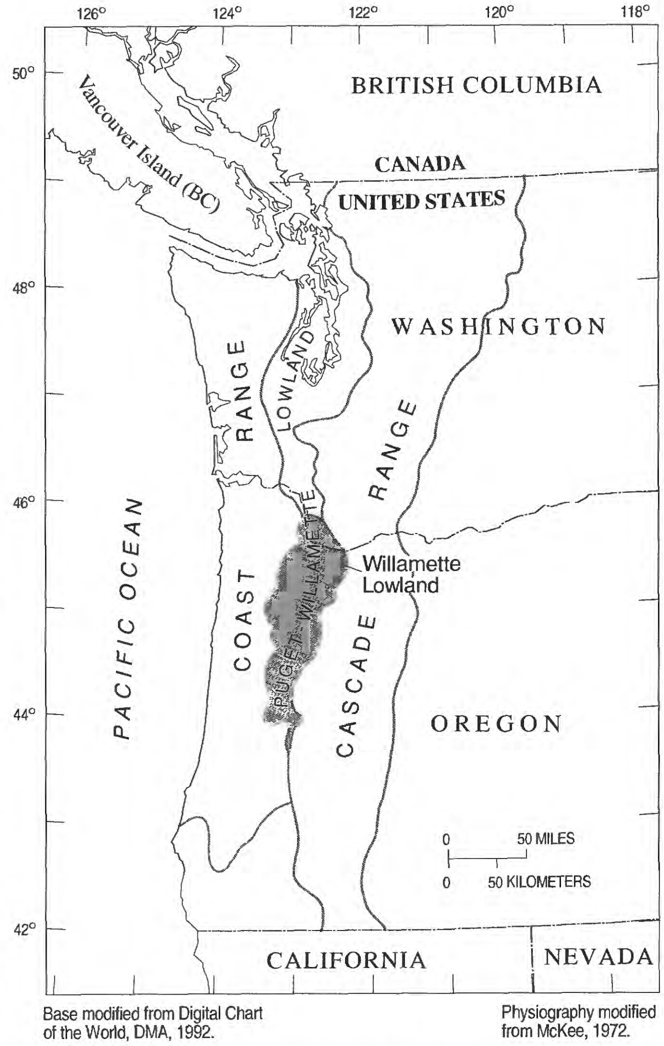

FIGURE 1.—Physiographic setting of the Willamette Lowland.

The Willamette Lowland, the southern of the two subprovinces, extends from the southern boundary of the Puget-Willamette Lowland, near Eugene, Oregon, north to the Lewis River in southern Washington. Most of the Willamette Lowland is in Oregon and lies within the Willamette River Basin (fig. 2). The Willamette Lowland lies between the Coast Range and the Cascade Range physiographic provinces.

The study area (fig. 2) is approximately 130 mi (miles) north-south by 40 to 45 mi east-west, encompassing 5,680 mi^2 (square miles); about one-half the area of the Willamette River drainage basin. The study area includes the alluvial basins in the Willamette Lowland, which cover approximately 3,100 mi^2, as well as the hydrologically important Columbia River Basalt Group lavas in uplands surrounding the alluvial basins. The study area boundaries are in areas of low-permeability volcanic and marine sedimentary rocks in the surrounding highlands.

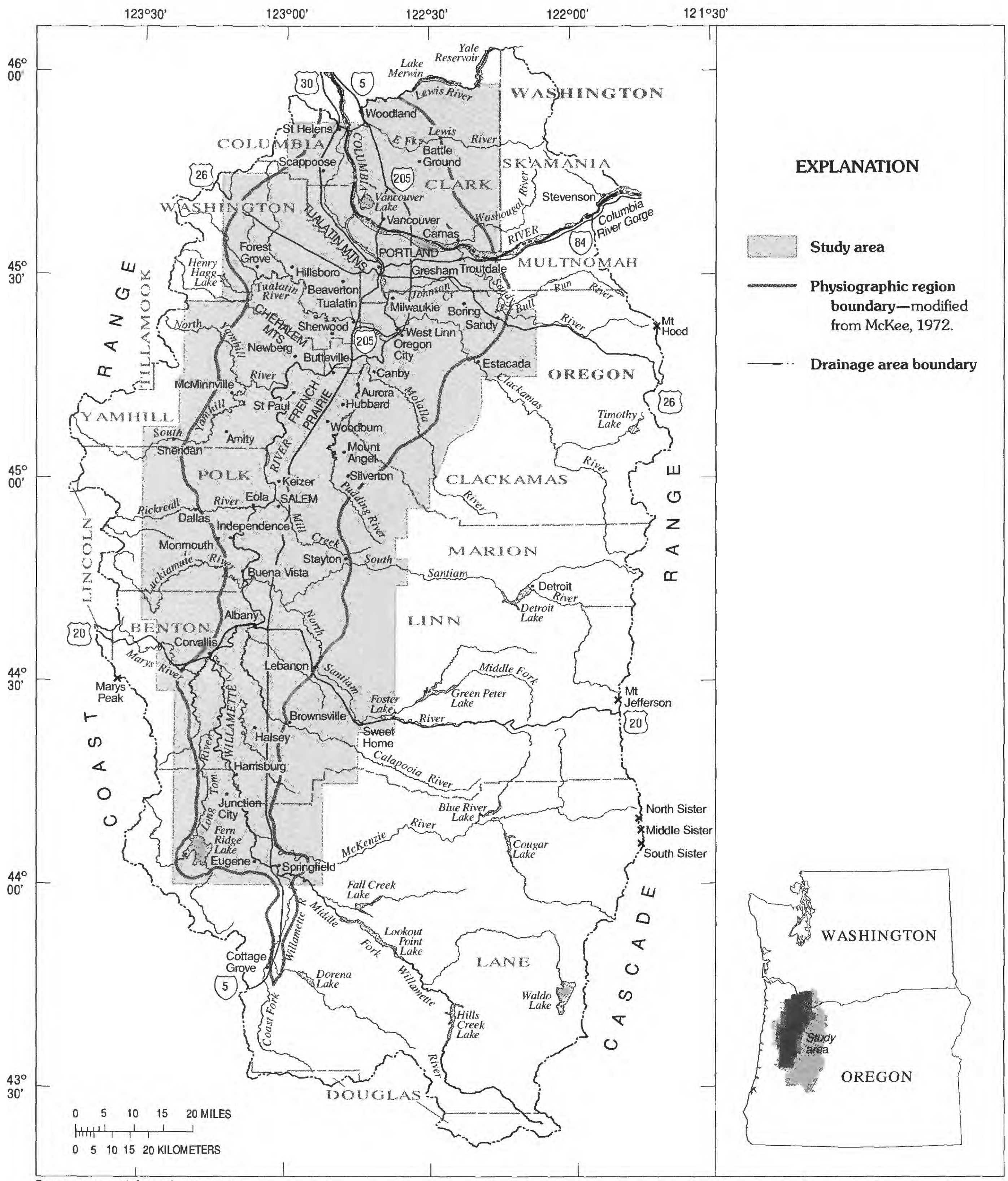

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FIGURE 2.—Outlines of the Willamette Lowland physiographic province and the study area with major geographic features in the Willamette River drainage basin, Oregon, and adjacent drainages in southwestern Washington.

No regionally significant aquifers have been identified in these units, and together these low-permeability rocks are considered the basement confining unit (Vaccaro, 1992). For the most part, the boundaries of the study area do not correspond to surface drainage divides.

Virtually all of the available ground-water information, including well drillers' logs and existing ground-water reports, is restricted to the part of the basin included in the study area. The study area includes almost all of the populated and cultivated areas within the Willamette River Basin. Most of the basin outside the study area consists of rugged, forested terrain.

GEOGRAPHY

The Willamette Lowland is bounded on the west by the Coast Range and on the east by the considerably higher Cascade Range. The southern boundary of the Willamette Lowland lies just south of Eugene, Oregon, where the Cascade and Coast Ranges converge. The northern boundary, north of the Lewis River in southwestern Washington, also is defined by an upland formed by the convergence of the Coast and Cascade Ranges.

The Willamette Lowland includes four broad basins with flat valley floors: the Portland Basin, the Tualatin Basin, the central Willamette Valley, and the southern Willamette Valley (fig. 3). The southern Willamette Valley includes a small, partially enclosed subbasin known as the Stayton Subbasin. These basins are separated by low bedrock hills. The valley floors slope generally northward toward the Columbia River with altitudes ranging from approximately 450 ft (feet) near Eugene, to less than 50 ft near Portland. The average altitude of the uplands and hills separating the basins ranges from 500 to 1,000 ft. The altitude of the foothills adjacent to the lowland ranges from 50 to 1,500 ft. The altitude of the crest of the Coast Range averages 1,200 to 2,000 ft but reaches 4,097 ft west of Corvallis. The altitude of the Cascade Range crest averages about 4,500 ft, but several stratovolcanos reach altitudes of 10,047 to 11,235 ft.

The climate in the Willamette Lowland is largely controlled by eastward moving air masses that originate over the Pacific Ocean, resulting in a moderate, humid, midlatitude marine climate. The marine air loses moisture as it passes over the Coast Range, resulting in a dryer, less humid climate in the Willamette Lowland than on the coast. Precipitation in the Coast Range adjacent to the Willamette Lowland ranges from approximately 80 to 180 inches per year. Precipitation in the Willamette Lowland ranges from 37 to 80 inches per year, averaging about 46.1 inches per year. Precipitation in the Cascade Range is approximately 60 to 200 inches per year. Most precipitation in the Cascade Range above an altitude of about 1,500 ft falls as snow. Precipitation throughout the area is seasonal, with a distinct dry summer period and a wet winter period. About 80 percent of the precipitation occurs during the months of October through March. The lowest average monthly temperatures generally are in January and the highest generally in July. Mean daily minimum and maximum temperatures at Salem in January are about 31° and 45°F (degrees Fahrenheit) respectively. Mean daily minimum and maximum temperatures at Salem in July are about 51° and 83°F respectively.

The Willamette River is the principal stream draining the Willamette Lowland. It originates in the southern part of the basin, primarily in the Cascade Range, and enters the southern Willamette Valley east of Eugene. The Willamette River flows generally northward along the western side of the valley to its mouth at the Columbia River near Portland. Principal tributary streams from the Cascades include, from south to north, the McKenzie, Calapooia, South Santiam, North Santiam, Pudding, Molalla, and Clackamas Rivers. Principal tributaries from the Coast Range include the Coast Fork of the Willamette River; the Long Tom, Marys, and Luckiamute Rivers; Rickreall Creek; and the Yamhill and Tualatin Rivers. The part of the Willamette Lowland in southwestern Washington is drained by the Lewis River and several creeks that drain directly to the Columbia River. The average discharge of the Willamette River is approximately 32,180 cubic feet per second, which equals 40 inches per year from a drainage area of 11,100 mi^2. This discharge represents a large part of the total annual precipitation.

METHODOLOGY

The hydrogeologic units described in this report were delineated using subsurface lithologic data from borehole logs and surface geologic information obtained mainly from published and unpublished reports and geologic maps. Geologic maps of various scales are available for the entire study area, with overlapping coverage available for much of the area. In general, large-scale maps were used in favor of smaller-scale maps, and preference was given to more recently published maps. In some cases, discrepancies between maps were resolved by field reconnaissance. Lithologic descriptions from water-well drillers' logs (well logs) were the largest source of subsurface information; more than 3,000 field-located water wells were used in mapping hydrogeologic units in the subsurface.

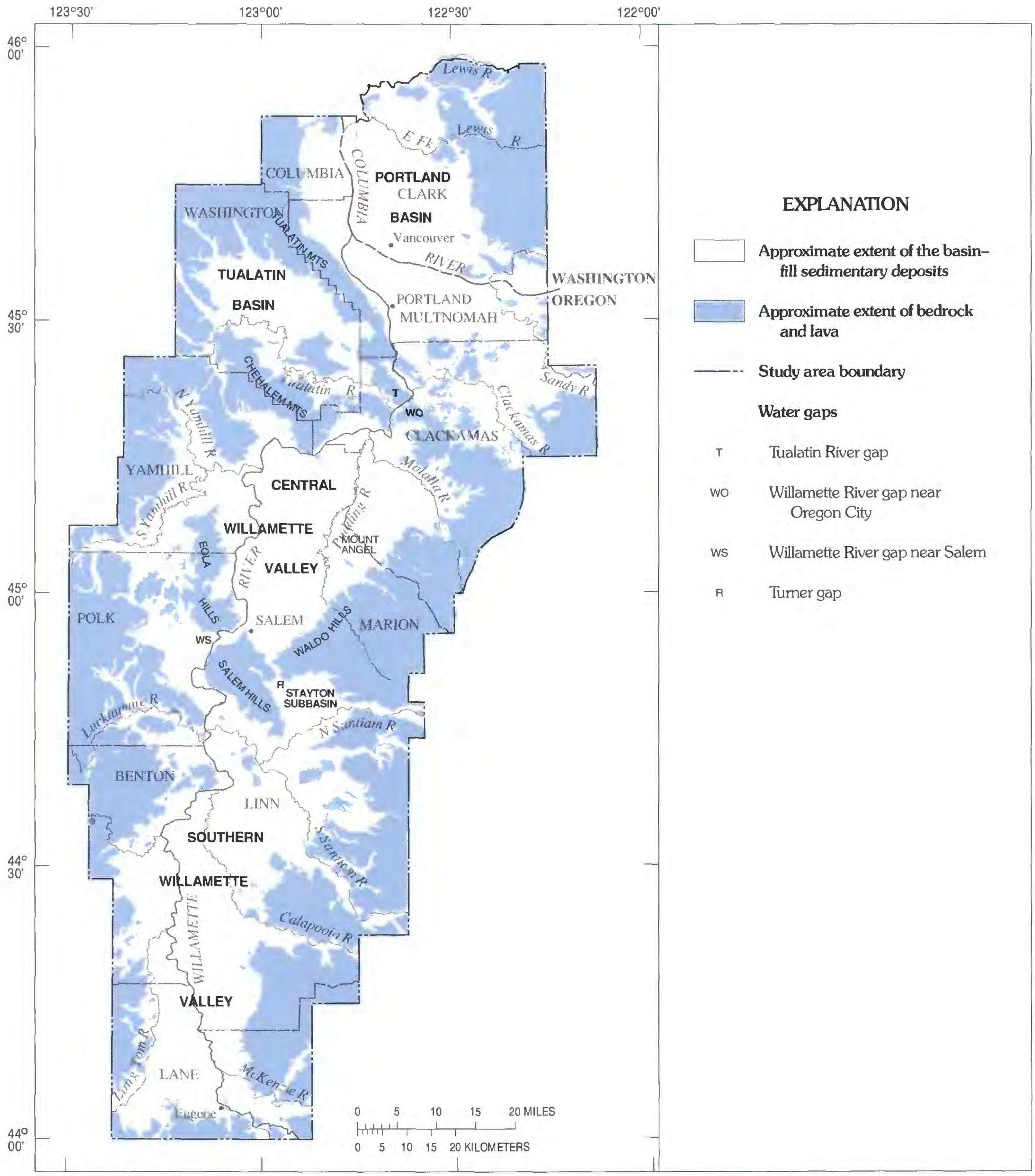

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FIGURE 3.—Subbasins and major water gaps within the Willamette Lowland.

Elevations of wells were determined from 1:24,000 scale quadrangle maps. Lithologic descriptions from geotechnical borings, primarily for highway bridge construction, and from several oil and gas exploration wells also provided valuable information. Data were analyzed and maps generated with the aid of a computer-based geographic information system.

Except for the Portland Basin, previous ground-water studies of the Willamette Lowland have consisted mainly of surficial mapping and qualitative descriptions of the subsurface. In contrast, this study maps the extent and thickness of hydrogeologic units in the subsurface. New data were collected and interpretations made for the Tualatin Basin, central Willamette Valley, and southern Willamette Valley. For the Portland Basin, a recently completed ground-water investigation was the source of new information, including geologic framework and hydrogeologic maps (Swanson and others, 1993), flow-system analysis and numerical modeling (McFarland and Morgan, 1996; Morgan and McFarland, 1996), and recharge estimates (Snyder and others, 1994).

ACKNOWLEDGMENTS

The authors wish to acknowledge the following individuals: Bernie Kleutsch (Oregon Department of Transportation) provided geotechnical boring logs from highway projects in the study area. Ian Madin (Oregon Department of Geology and Mineral Industries) provided field-located well information and shared his insights on the geology of the Tualatin and Portland Basins. Paul Crenna and Tom Popowski (Oregon State University) also provided field-located well data. The authors would also like to thank George Priest (Oregon Department of Geology and Mineral Industries) and David Sherrod and William Scott (U.S. Geological Survey) for some valuable discussions during the course of this study. The efforts of Jacqueline Olson, who prepared the illustrations and plates, and Donna Mussog, who did the report layout, are greatly appreciated.

GEOLOGY OF THE WILLAMETTE LOWLAND

PREVIOUS INVESTIGATIONS

Geologists have been working in the Willamette Lowland for over 100 years, and a complete synopsis of all previous work is beyond the scope of this report. This discussion is limited to works of regional significance or those that were otherwise particularly useful in this investigation. A bibliography completed as part of this study (Morgan and Weatherby, 1992) includes a comprehensive list of references for geological and water-related topics for the area.

Numerous individuals have contributed to the current understanding of the ground-water resources of the Willamette Lowland. Piper (1942) produced the earliest geologic map and ground-water assessment of the entire Willamette Valley. Although more detailed maps are now available, Piper's general ideas about the nature of the basin-fill sediments and the occurrence of ground water in the valley are still valid. Several U.S. Geological Survey Water-Supply Papers and State of Oregon ground water reports have provided valuable geologic mapping and evaluation of the ground-water hydrology in specific areas in the Willamette Valley (fig. 4).

In addition to Piper's (1942) map, several other notable geologic maps have provided the basis for much of the subsequent mapping and map compilation. Allison (1953) created a detailed geologic map of the Albany quadrangle and described three separate alluvial terraces, and Allison and Felts (1956) continued that mapping into the Lebanon quadrangle. Trimble (1957, 1963) mapped Portland and adjacent areas, building, in part, on earlier work by Treasher (1942) and Hodge (1938). Vokes and others (1951, 1954) and Baldwin and others (1955) produced oil and gas investigations maps of the Coast Range that include the southern and western edges of the Willamette Valley. Peck and others (1964) provided the first map of the entire western Cascade Range adjacent to the Willamette Valley. Hodge (1938) and Lowery and Baldwin (1952) contributed to the understanding of the geology of the lower Columbia River.

There are a number of publications dealing with the unique Quaternary geology in the Willamette Lowland. Allison (1932, 1933, 1935) was first to recognize the exotic glacial-flood origin of extensive Quaternary deposits in the valley. Allison (1978a,b) presents a thorough summary of late Pleistocene sediments and floods in the area. Glenn (1965) described the stratigraphy and mineralogy of late Quaternary sediments in the northern Willamette Valley and provided mineralogical evidence for the exotic, glacial outburst origin of the fine-grained Quaternary silts that blanket much of the valley. Balster and Parsons (1968, 1969) categorized geomorphic surfaces in the Willamette Valley, and described the stratigraphy of Quaternary deposits in the southern Willamette Valley. McDowell (1991) provided a summary of the Quaternary geology of the valley.

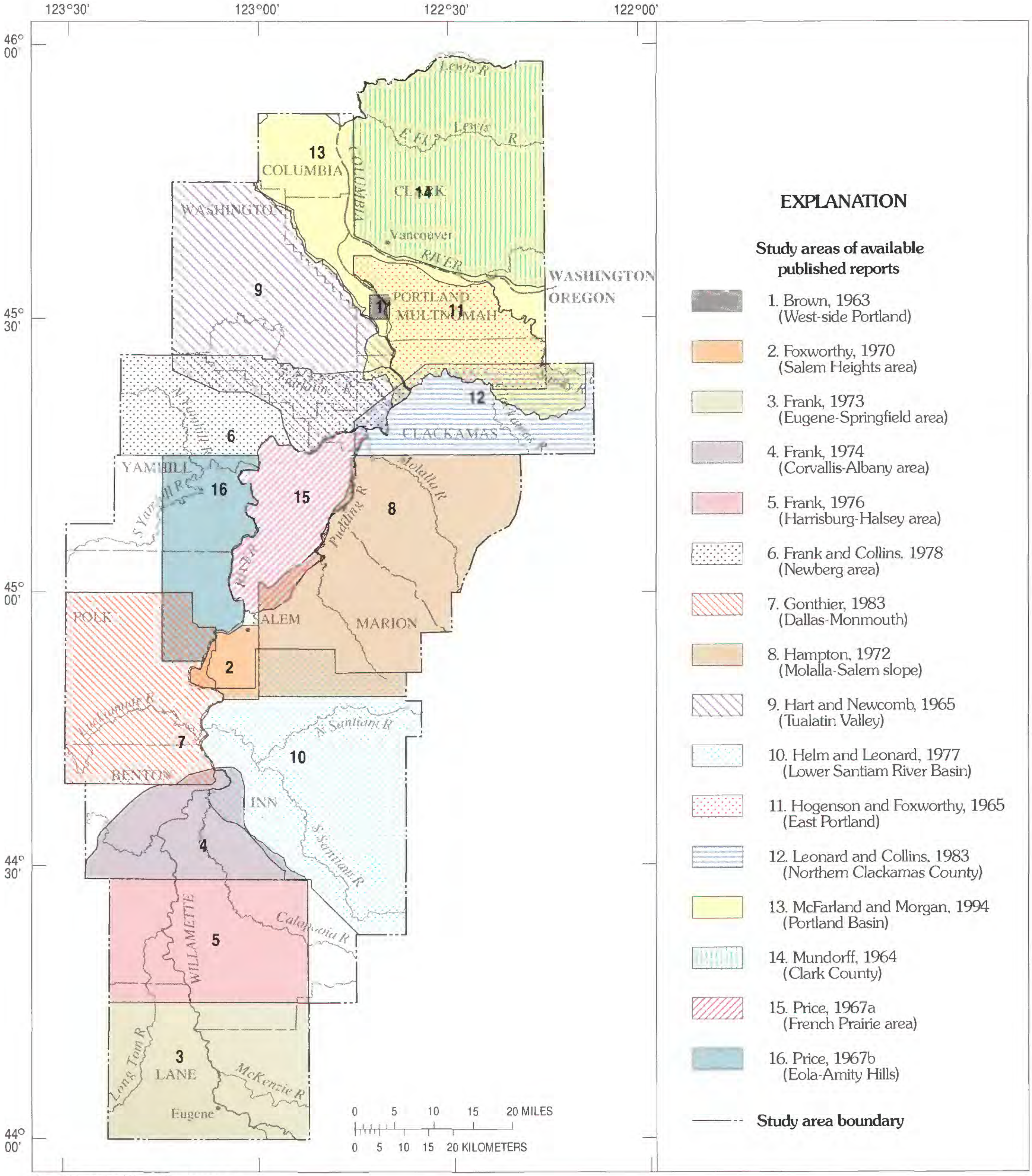

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FIGURE 4.—Study areas of U.S. Geological Survey Water-Supply Papers and State of Oregon Ground-Water Reports in the Willamette Lowland.

DEPOSITIONAL HISTORY

Western Oregon is an active continental margin, where oceanic crust is obliquely underthrusting the North American continental plate (fig. 5). Plate convergence has resulted in the development of a deep fore-arc basin east of the subduction zone. This basin locally has accumulated more than 23,000 ft of sedimentary and volcanic rock since the middle Eocene (Niem and Niem, 1984; Snavely, 1987). Subduction along the continental margin resulted in development of the Cascade Range volcanic arc. Volcanism in the Cascade Range appears to have commenced sometime between 43 and 35 million years ago (late Eocene to early Oligocene) (Priest, 1989). Uplift of the fore-arc basin and creation of the Coast Range began in the latest Eocene to early Oligocene (Niem and Niem, 1984). By the early Miocene, regional uplift had restricted marine sedimentation to the western flank of the Coast Range and adjacent continental shelf (Snavely, 1987). Uplift resulted in an overall eastward dip of marine sediments in the eastern part of the Coast Range that continues beneath the Willamette Valley and into the western Cascade Range. During the middle Miocene, Columbia River Basalt Group lava flows entered western Oregon from eruptive vents in eastern Oregon, Washington, and Idaho through the Cascade Range (Tolan and Beeson, 1984; Beeson and others, 1989a). Tectonic activity intensified during late Miocene and Pliocene time, resulting in additional uplift, folding, and faulting of the Coast Range and Cascade volcanic arc (Niem and Niem, 1984). This activity locally resulted in subsidence of the area between these two ranges, establishing the Willamette Lowland as a major depositional basin for continental sediment. Physiographic basins within the Willamette Lowland have filled with sediment from a number of sources, including the Coast and Cascade Ranges as well as the Columbia River. The uppermost basin-fill deposits are the result of giant glacial-outburst floods from the upper Columbia River drainage that inundated the Willamette Lowland during late Pleistocene time (Allison, 1935, 1953, 1978a,b; Glenn, 1965).

The origin, lithology, and distribution of major geologic units in the study area are discussed in the following paragraphs. For the purposes of this report, some conventionally or formally recognized units have been combined into groupings that are considered of regional significance. A correlation chart showing the major geologic units in the Willamette Valley is shown in figure 6. The generalized cross-section through the central Willamette Valley in figure 7 shows the relation of most of these units. A generalized geologic map of the study area is shown on plate 1.

EOCENE VOLCANIC ROCKS OF THE COAST RANGE

Eocene volcanic rocks of the Siletz River volcanics and the lower Tillimook volcanics are the oldest rocks in the Willamette Lowland. These remnants of Eocene oceanic crust exposed in the Coast Range are the basement rocks of much of western Oregon and Washington (Snavely, 1987). The Eocene volcanics, which exceed 10,000 ft in thickness, consist of a lower section of tholeiitic basalt and a thinner upper section of alkalic basalt (Snavely and others, 1968). The lower tholeiitic section is predominantly composed of submarine pillow lavas, interbedded tuff breccias, and locally interspersed massive basalt sills and in-filled lava tubes. The tholeiite of this lower section is petrochemically similar to ocean ridge basalt. This lower sequence primarily reflects submarine volcanism, but there are a few subaerial flows as well with oxidized tops and soil zones.

The upper alkalic basalt sequence consists largely of volcanic breccia, lapilli tuff, tuff, and pillow lavas. This unit also includes swarms of dikes, single dikes, sills, massive flows, sandstone, and conglomerate. The presence of massive flows, soil zones, mudflows, and conglomerate indicates that part of this upper sequence was erupted subaerially. This unit is thought to represent oceanic islands and seamounts.

MARINE SEDIMENTARY ROCKS

More than 23,000 ft of middle Eocene to early Oligocene marine sandstone, siltstone, claystone, and shale were deposited on top of Eocene volcanics in the developing fore-arc basin (Niem and Niem, 1984). These sedimentary rocks represent strandline, deltaic, slope and deep marine deposition.

In the southern part of the study area, Eocene volcanic rocks are overlain by up to 5,000 ft of rhythmically bedded arkosic and lithic turbidite sandstone and siltstone of the middle and upper Eocene Tyee Formation (Vokes and others, 1951; Snavely and Wagner, 1964; Baldwin, 1981; Armentrout and others, 1983). The Tyee Formation is overlain by the late Eocene Yamhill Formation, which is composed of up to 4,000 ft of micaceous, thin-bedded sandstone and siltstone (Baldwin, 1981).

Unconformably overlying the Tyee and Yamhill Formations is a sequence of middle and upper Eocene marine tuffaceous mudstone, siltstone, and sandstone that includes the Spencer Formation and the Nestucca Formation (Baldwin and others, 1955; Walker and MacLeod, 1991). Approximately 4,500 ft of Spencer Formation strata is exposed in the west-central border area of the Willamette Valley (Vokes and others, 1954). More than 2,000 ft of the Nestucca Formation is exposed in the Sheridan-McMinnville area.

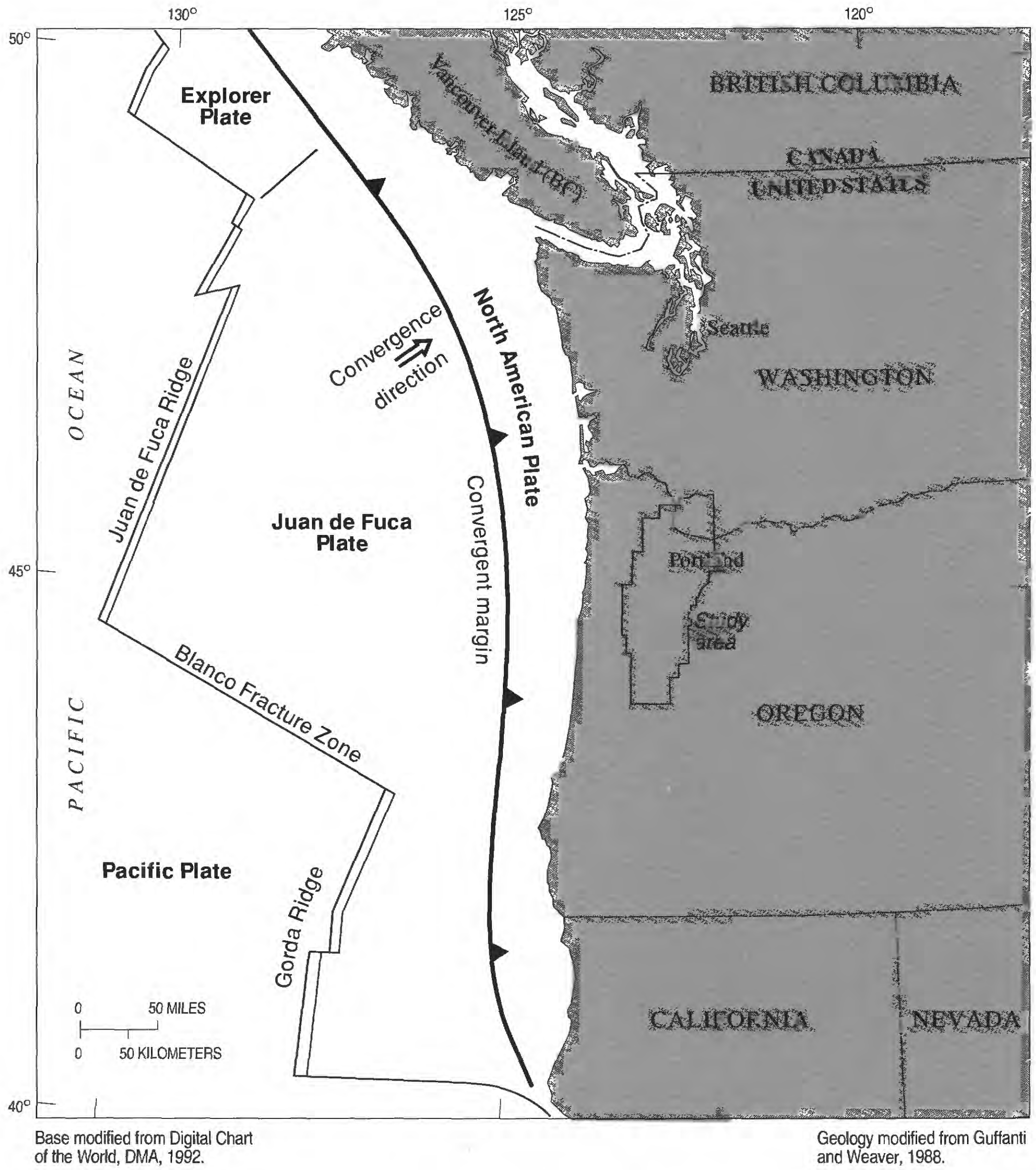
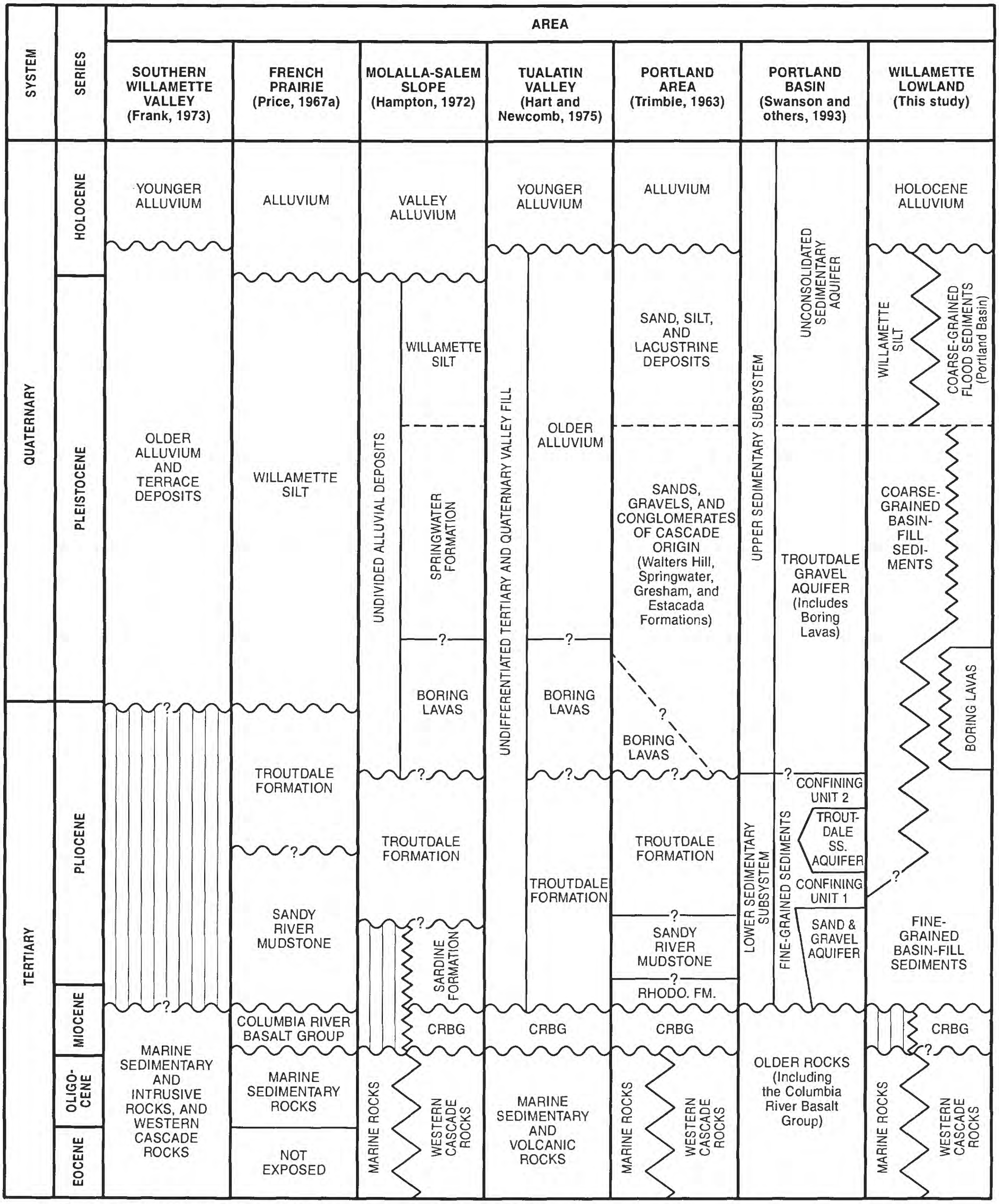


FIGURE 5.—Tectonic setting of the Oregon and Washington continental margin. (Modified from Guffanti and Weaver, 1988.)

Along the eastern edge of the Eola Hills, and north to the Chehalem Mountains, the Nestucca and Spencer Formations are overlain by an unnamed sequence of Oligocene and upper Eocene tuffaceous shale, siltstone, sandstone, and conglomerate with local basaltic debris (Walker and MacLeod, 1991; Brownfield and Schlicker, 1981a,b; Hart and Newcomb, 1965). In the southern valley, the Spencer Formation is overlain by the Oligocene Eugene Formation which crops out along the eastern margin of the valley from Eugene north to Lebanon. The Eugene Formation consists predominantly of coarse to fine-grained, arkosic, micaceous sandstone and siltstone and, locally, is highly pumiceous (Vokes and others, 1951; Walker and MacLeod, 1991). South of the Salem Hills and in the Cascade foothills east of the central valley, western Cascade Range volcanic rocks are overlain by over 1,300 ft of Oligocene and lower Miocene marine tuffaceous, arkosic sandstone with lesser conglomerate, sandstone, siltstone, and claystone (Hampton, 1972; Miller and Orr, 1984a,b; Orr and Miller, 1984, 1986; Peck and others, 1964; Walker and MacLeod, 1991).

Upper Eocene to middle Miocene tuffaceous and arkosic sandstones, tuff, siltstone, and minor conglomerate lenses are exposed in the Coast Range north of the Tualatin Basin and underlying Columbia River Basalt Group flows in the Tualatin Mountains (Trimble, 1963; Walker and MacLeod, 1991). A well drilled in the Tualatin Mountains penetrated 1,200 ft of fossiliferous sediments below the Columbia River Basalt Group lavas.



NOTE: CRBG = COLUMBIA RIVER BASALT GROUP FM.= FORMATION
RHODO. FM.= RHODODENDRON FORMATION SS. = SANDSTONE

FIGURE 6.—Selected geologic units in parts of the Willamette Lowland as delineated by previous investigators, and as generalized in this study.

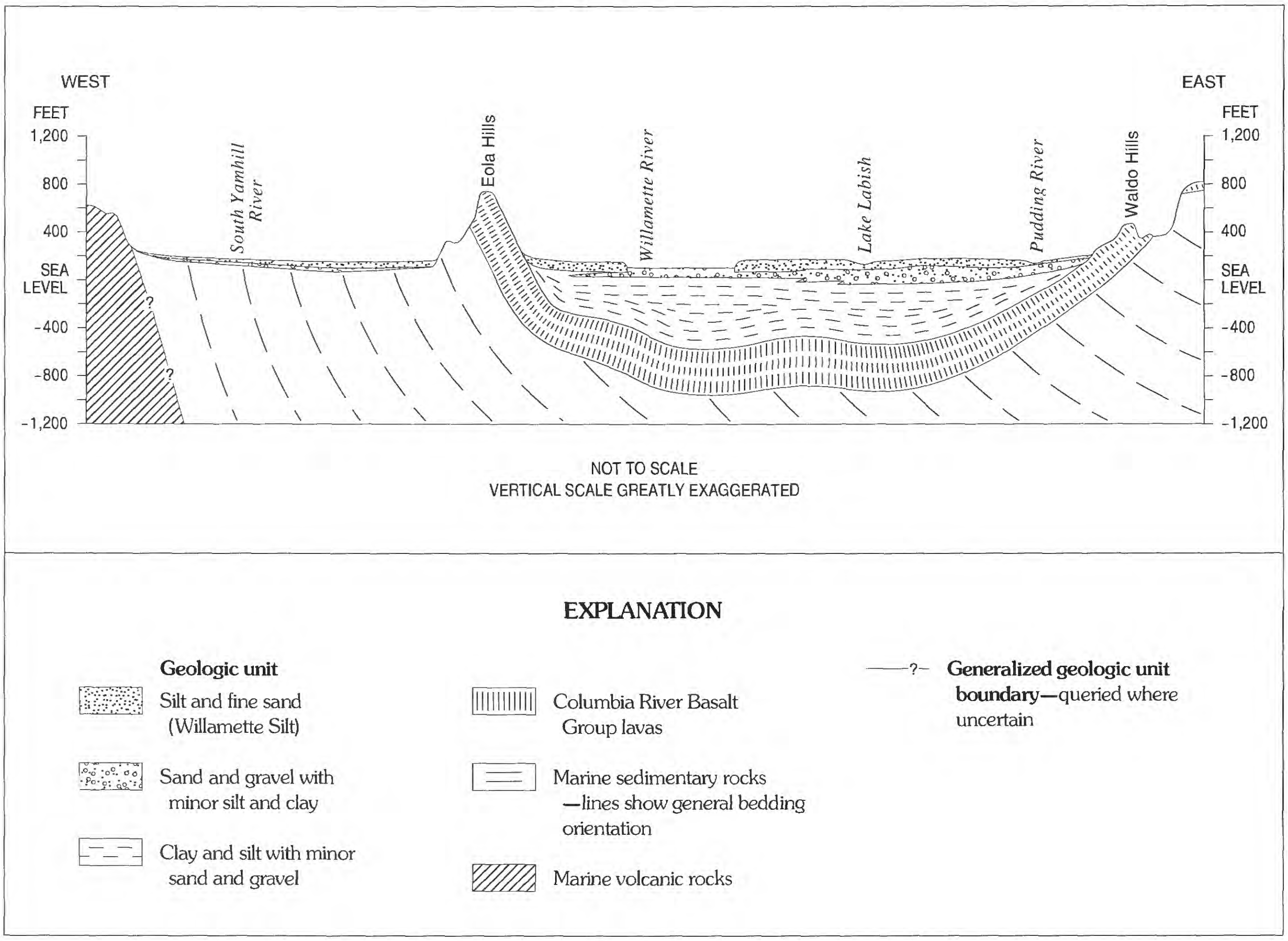


FIGURE 7.—A generalized geologic section west-east through the central Willamette Lowland.

Marine sedimentary rocks in the Coast Range adjacent to the Willamette Valley were intruded during the Oligocene by sheets, dikes, and sills of massive, granophyric ferrogabbro, diabase, dense basalt, and diorite (Baldwin and others, 1955; Baldwin, 1964; MacLeod, 1981; Brownfield, 1982a; Brownfield and Schlicker, 1981b; Walker and MacLeod, 1991). These massive intrusions compose as much as half of the exposed rock in the Coast Range west of McMinnville and Forest Grove in the northern part of the study area. These intrusions are included in the same map unit as the enclosing sedimentary rocks on plate 1.

VOLCANIC ROCKS OF THE WESTERN CASCADE RANGE

Along the eastern edge of the Willamette Lowland, the products of Cascade arc volcanism constitute a complex assemblage of flows, breccias, and pyroclastic and epiclastic sediments (Peck and others, 1964; Walker and Duncan, 1989; Sherrod and Smith, 1989). Volcanic activity migrated eastward during the period from 35 million years ago to the present, to its current location in the High Cascades. Cascadian volcanism continues in the Holocene.

Oligocene to upper Miocene volcanic rocks of the western Cascade Range are exposed in the foothills along much of the eastern side of the Willamette Lowland (pl. 1). Regional geologic maps of the western Cascade Range are provided by Peck and others (1964), Sherrod and Smith (1989), and Walker and MacLeod (1991). Cascade Range volcanics are represented by three map units on plate 1; these include the upper Eocene Fisher Formation, the Oligocene to lower Miocene Little Butte Volcanic Series, and the middle to upper Miocene Sardine Formation. In general, the age of volcanics exposed along the margin of the study area decreases from south to north from Eugene to the Columbia River. The Little Butte Volcanic Series and the Sardine Formation are locally separated by lava of the Columbia River Basalt Group.

The Fisher Formation is exposed west of Eugene along the southern margin of the Willamette Valley and is generally regarded as the oldest unit in the study area resulting from Cascade Range volcanism. The Fisher Formation consists of up to 7,000 ft of primarily andesitic lapilli tuffs and breccias, basaltic and lesser rhyolitic fragmental debris, and conglomerate (Vokes and others, 1951). This unit also includes lava flows of chiefly andesitic composition, and locally vented material (Hoover, 1963; Sherrod and Smith, 1989). It is lithologically similar to overlying Oligocene volcanic rocks.

The Little Butte Volcanic Series is the name used by Peck and others (1964) for a complex sequence of Oligocene to lower Miocene volcanic rocks that form much of the western Cascade Range. This unit is up to 15,000 ft thick but is generally 5,000 to 10,000 ft thick in the study area. The Little Butte Volcanic Series makes up most of the western Cascade Range in the study area from Eugene to the North Santiam River.

The Little Butte Volcanic Series consists primarily of andesitic and dacitic lapilli tuff with less abundant flows, breccia, and small intrusions of basalt and andesite. Approximately three-quarters of the unit consists of massive lapilli tuff with lesser vitric tuff, water-laid tuff, welded tuff, and volcanic conglomerate. Peck and others (1964) report that pumice, ash, and glass shards were devitrified in almost all samples examined. Approximately one-quarter of the Little Butte Volcanic Series is composed of flows and breccias of olivine basalt, basaltic andesite, and pyroxene andesite. The flows are typically vesicular and amygdaloidal with cavity fillings of chalcedony, zeolite, calcite, and clay.

The middle and upper Miocene Sardine Formation composes much of the western Cascade Range in the study area north of the North Santiam River (pl. 1). The Sardine Formation is composed of flows, breccia, and tuff of hypersthene andesite, and is generally less than 3,000 ft thick (Peck and others, 1964). Andesitic tuff breccia is the most common lithology from Detroit north to the Columbia River (Sherrod and Smith, 1989). Ash-flow tuff and massive tuff breccia, thought to originate as mudflows, are abundant in the Sandy, Clackamas, and Molalla River drainages. The Sardine Formation overlies the Little Butte Volcanic Series with angular unconformity and is conformable on the Columbia River Basalt Group (Peck and others, 1964).

The Oligocene shoreline, where continental volcanogenic rocks from the Cascade Range contacted marine sedimentary rocks of the fore-arc basin, coincided approximately with the modern Willamette Lowland. The contact between marine sedimentary rocks and continental volcanogenic rocks is now obscured by basin-fill deposits in the southern Willamette Valley (Sherrod and Smith, 1989). The contact between marine and nonmarine deposits is exposed northeast of Salem in the Cascade foothills where Miller and Orr (1984a,b) and Orr and Miller (1984, 1986) have mapped strandline deposits.

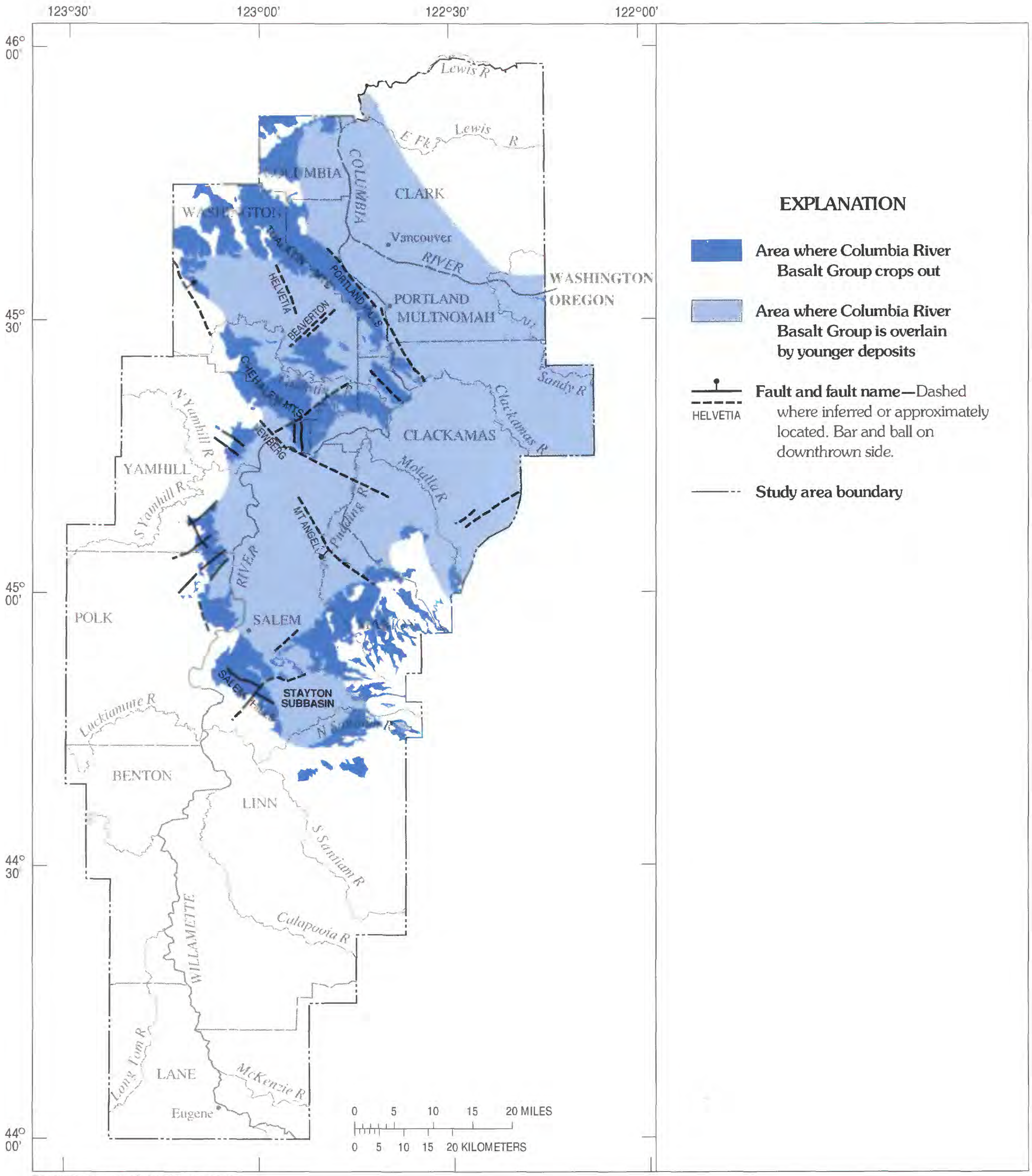
COLUMBIA RIVER BASALT GROUP

Miocene basalt flows of the Columbia River Basalt Group are exposed at the margins of the northern Willamette Lowland. They extend northward from Hungry Hill, east of Albany, to the northernmost part of the study area beneath the Portland Basin (pl. 1). On the east side of the study area, Columbia River Basalt Group flows pinch out against underlying lower Miocene and Oligocene marine sediments or the Little Butte Volcanic Series. From the Portland Basin, the unit can be traced eastward in the subsurface through the Cascade Range into north-central Oregon. The westernmost extent of Columbia River Basalt Group in the study area is defined by outcrops in the Salem and Eola Hills, the Chehalem Mountains, and Coast Range foothills west of the Tualatin Basin.

The Columbia River Basalt Group forms the uplands separating the four major basins. These uplands include: the Tualatin Mountains, which separate the Portland Basin and the Tualatin Basin; the Chehalem Mountains, which separate the Tualatin Basin and the central Willamette Valley; and the Salem Hills, which separate the southern Willamette Valley and central Willamette Valley. The Columbia River Basalt Group underlies thick basin-fill deposits in the central Willamette Valley, the Tualatin Basin, and the Portland Basin, as well as in the Stayton Subbasin in the southern Willamette Valley (fig. 8).

The Columbia River Basalt Group varies in thickness throughout the northern Willamette Lowland. This variation resulted in part from preexisting topographic obstructions and from channeling of flows during late stages of the eruptive episode. Also, faulting and downwarping occurred during deposition of the unit. The total thickness of the Columbia River Basalt Group in the Portland Basin is approximately 1,000 ft (Trimble, 1963); a similar thickness has been reported from the central part of the Tualatin Basin (Schlicker and Deacon, 1967). Data from oil and gas wells reviewed for this study indicate that the unit ranges from 300 to 900 ft thick in the central Willamette Valley.

The Columbia River Basalt Group in the Willamette Lowland consists of a series of accordantly layered lava flows. Individual flows range in thickness from 10 to 100 ft and average about 50 ft. The thickness and sequence of flows varies throughout the Willamette Lowland. Columbia River Basalt Group flows are typically black to dark gray, fine- to medium-grained, aphyric to sparsely phyric basalt, and commonly exhibit columnar and (or) irregular, hackly jointing.



Basemap source information on page v.

FIGURE 8.—The approximate extent of the Columbia River Basalt Group in the Willamette Lowland.

Individual flows typically have fractured bases and vesicular, brecciated upper surfaces. The upper part of one flow and the lower part of an overlying flow form a relatively permeable interflow zone. Interbedded sediments or paleosols are locally present between flows (Hampton, 1972; Beeson and others, 1985).

BASIN-FILL DEPOSITS

Physiographic basins in the Willamette Lowland have filled with sediment from a number of sources, including the Coast and Cascade Ranges and the Columbia River drainage. The lithology, mineralogy, and grain-size distribution of sediment is different for each of these sources. The sediment from the Coast Range is primarily clay, silt, and fine sand derived from weathering and erosion of marine sandstone, siltstone, and shale. There are a few thin gravel deposits from the Coast Range, probably derived from basaltic volcanic and intrusive rocks. Sediment from the Cascade Range is composed entirely of volcanic clasts and includes all grain sizes. Nearly all of the coarse sand and gravel in the southern and central Willamette Valley is from the Cascade Range. The Columbia River sediment, which is largely restricted to the Portland Basin, includes clasts of all grain sizes, and includes rock types exotic to the region, such as quartzite, granite, and metamorphic rocks (Hodge, 1938; Trimble, 1963; Tolan and Beeson, 1984). Fine-grained sediment deposited by the Columbia River commonly is micaceous. The thickness and grain size of basin-fill deposits in the Willamette Lowland varies areally and with depth. The thickness and nature of basin-fill deposits are different in each of the subbasins within the lowland. Basin-fill deposits of each subbasin are discussed in the following paragraphs.

Trimble (1963) assigned basin-fill sediments in the Portland Basin to several formations, including the Sandy River Mudstone and the Troutdale, Walters Hill, Springwater, Gresham, and Estacada Formations (fig. 6). These units are locally interbedded with and overlain by basalt flows of the Boring Lava (Treasher, 1942). In most places below an elevation of about 400 ft, these units are overlain by late Pleistocene catastrophic flood deposits. A generalized geologic section through the Portland Basin is shown in figure 9.

The lower part of basin-fill sediment in the Portland Basin consists largely of micaceous arkosic siltstone, mudstone, and claystone. These rocks range from several hundred to more than 1,200 ft thick. Trimble (1963) assigned these strata to the Sandy River Mudstone, whereas Mundorff (1964) assigned similar beds in Clark County, Washington, to the lower member of the Troutdale Formation. These sedimentary rocks are exposed in the Portland Basin along the Sandy and Clackamas Rivers and their tributaries. Swanson and others (1993) note that the siltstones are massive or have thin sand interbeds and that silty sand beds show cross-bedding and ripples. They note that exposures in the Sandy and Clackamas Rivers contain weakly consolidated, medium-grained, micaceous arkosic sand beds a few inches to 10 to 15 ft thick and show cross-bedding.

Although fine-grained deposits dominate the lower part of the section in the Portland Basin, they locally include significant coarse-grained interbeds. Where the Columbia River enters the Portland Basin, sediment in the upper part of the fine-grained section grades laterally into a sequence of silty to gravelly sand locally as much as 200 ft thick (Hartford and McFarland, 1989; Swanson and others, 1993). A layer of vitric sand and quartzite-bearing basaltic conglomerate averaging 100 to 200 ft thick occurs near the top of the fine-grained section in the southern part of the Portland Basin. This unit thins toward the west and northwest, and grades into fine-grained sediments near the center of the basin (Swanson and others, 1993).

The fine-grained sediment of the Sandy River Mudstone is overlain by sandstone and conglomerate generally assigned to the Troutdale Formation (Trimble, 1963; Tolan and Beeson, 1984; Swanson and others, 1993). These rocks are considered the upper member of the Troutdale Formation by Mundorff (1964). The formation consists primarily of quartzite-bearing basaltic conglomerate, vitric sandstone, and micaceous sandstone. This unit underlies the entire Portland Basin and averages about 100 to 400 ft in thickness (Swanson and others, 1993). Sandstone and conglomerate of the Troutdale Formation may be as much as 900 ft thick in east Portland (Trimble, 1963). The coarse materials of the Troutdale Formation thicken toward the east. Tolan and Beeson (1984) indicate that the Troutdale Formation is about 1,200 ft thick locally in the Columbia River Gorge east of the Portland Basin. The Troutdale Formation is exposed along the Sandy and Clackamas Rivers and their tributaries, as well as locally in the Tualatin Mountains and the lower parts of volcanic hills in the area (pl. 1). In Clark County, Washington, the Troutdale Formation is exposed along the north bank of the Columbia River and along the northeastern margin of the basin.

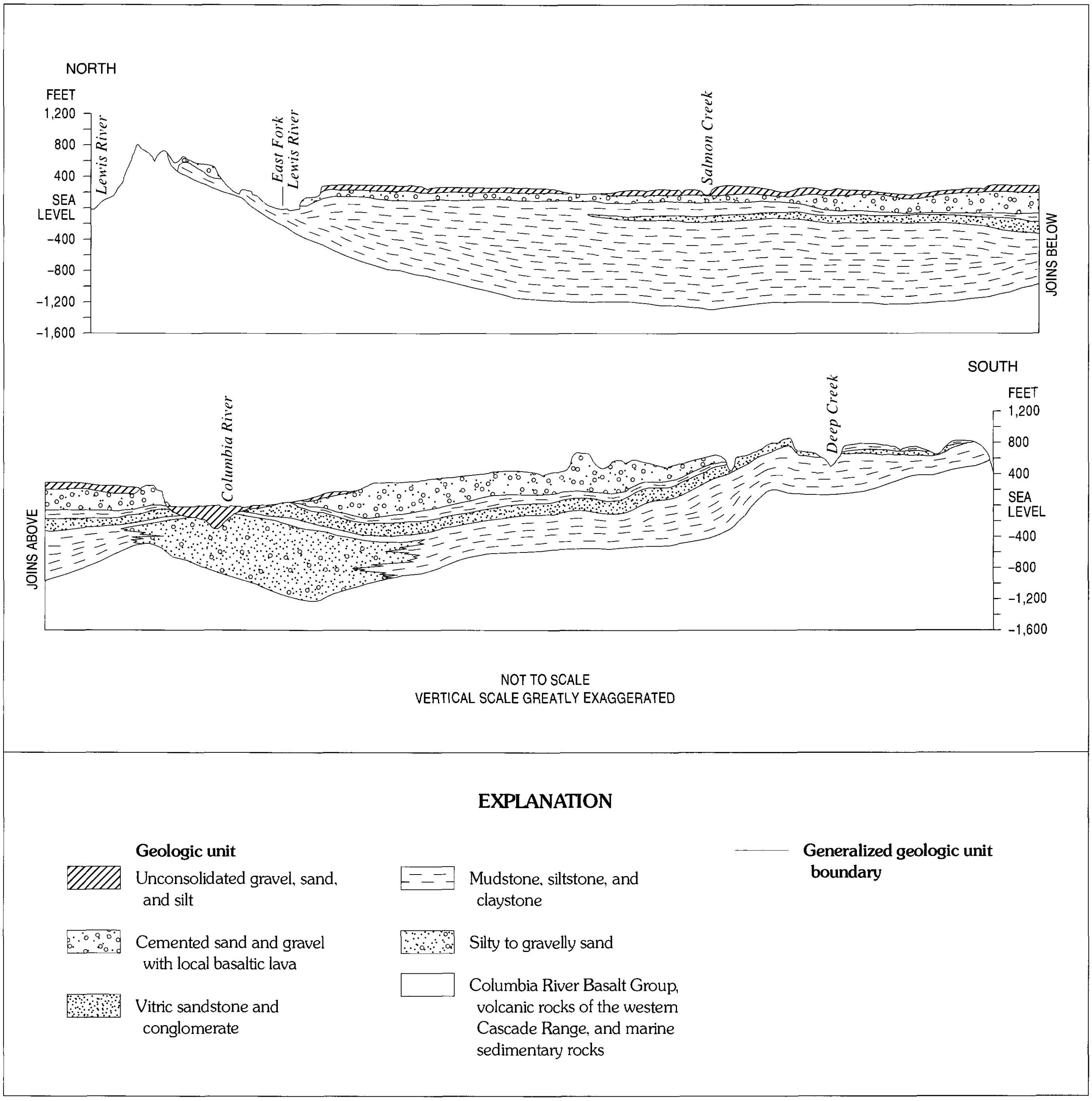


FIGURE 9.—A generalized geologic section north-south through the Portland Basin. (Modified from Swanson and others, 1993, Plate 2.)

Tolan and Beeson (1984) show that there are two distinct facies in the Troutdale Formation. One facies is characterized by conglomerate containing clasts exotic to the region and is considered to have been deposited by the ancestral Columbia River. The other facies includes materials of exclusively local origin and is considered to represent deposition by streams originating in the Cascade Range. The Columbia River facies is predominant in the Portland Basin and lower Columbia River Gorge, and the Cascade facies dominates the eastern side of the Portland Basin south of the Columbia River Gorge and the southern part of the Portland Basin.

Overlying the Troutdale Formation in the eastern part of the Portland Basin are volcanic-clast conglomerate and mudflow deposits from the Cascade Range. These deposits occur primarily on the gently sloping plain between the Sandy and Clackamas Rivers, and on terrace surfaces in the Clackamas River Valley. These materials include the Springwater, Gresham, and Estacada Formations of Trimble (1963). Similar deposits were mapped by Mundorff (1964) as part of the Troutdale Formation in Clark County, Washington. Trimble (1963) describes these deposits in the Portland area as cobble gravel and bouldery cobble gravel, with interbedded mudflows locally composing a large part of the unit. These gravels are generally deeply weathered to a red soil or saprolite, locally to a depth of 75 ft. Similar weathered deposits of volcanic-clast conglomerate in the southern Willamette Valley, the Lacomb and Leffler Gravels of Allison and Felts (1956), have similar topographic positions and weathering profiles and are thought to be correlative with the deposits in the Portland Basin (Trimble, 1963).

Basin-fill sediment in the Tualatin Valley consists of clay and silt with some sand and a few gravel beds (Hart and Newcomb, 1965), and is correlated in part with the Troutdale Formation. Field-located well logs show at least 1,480 ft of fine-grained sediment in the central part of the Tualatin Basin.

In the central Willamette Valley, fine-grained sediment described as blue clay and shale dominates the lower part of the basin-fill section (Price, 1967a; Hampton, 1972) (fig. 7). Blue to gray siltstone containing very fine quartz and abundant mica was described from a 600-ft-deep interval in a well in the central Willamette Valley (Price, 1967a). Several water wells and oil and gas exploration wells in the central Willamette Valley penetrate as much as 1,000 ft of fine-grained sediment before reaching the Columbia River Basalt Group. The silt and clay is interbedded with layers of sand and fine gravel generally less than 5 ft thick (Price 1967a). The predominantly fine-grained basin-fill section in the northern part of the central Willamette Valley becomes progressively coarser grained toward the south, becoming predominantly gravel in the vicinity of Salem (Hampton, 1972). The upper part of the basin-fill section in the central Willamette Valley is generally coarser grained than the lower part of the section, consisting of alternating layers of clay, silt, sand, and gravel (Price, 1967a). This sediment is generally coarsest in the southern and eastern parts of the basin, becoming progressively finer grained toward the northwest.

Hampton (1972) assigned most of the basin-fill sediment in the eastern part of the central Willamette Valley, including fine-grained sediment low in the section, to the Troutdale Formation. Price (1967a) assigned the fine-grained sediment in the lower part of the section to the Sandy River Mudstone, and only the coarser sediment in the upper part of the section to the Troutdale Formation.

Two distinct terraces consisting of poorly sorted and cross-bedded silt, sand, and gravel are discernible in the eastern part of the central Willamette Valley approximately 50 and 100 ft above the present stream level (Hampton, 1972). Terrace deposits of weathered clay, silt, sand, and gravel also have been mapped in the southern and western parts of the central valley (Bela, 1981; Brownfield, 1982a,b). The gravel on the western and southern terraces consists largely of basalt from the Siletz River Volcanics (Brownfield, 1982a,b).

The basin-fill deposits in the southern Willamette Valley are stratigraphically similar to those of the central valley, with a lower part dominated by fine-grained sediment. More than 140 ft of clay to silty clay, sandy clay, and clayey silt, with lenses of well-sorted, unconsolidated medium to fine sand; all considered to be of fluvial origin, have been described in the lower part of the section (W.A. Niem and others, CH2M-Hill, unpub. data, 1987). The sand layers, which are commonly 2 to 4 ft thick but as much as 12 ft thick, appear to be of limited lateral extent and compose approximately 10 to 15 percent of the unit (W.A. Niem and others, CH2M-Hill, unpub. data, 1987). A 138-ft sequence of blue to blue-gray micaceous clay, minor sand, organic-rich clay, and poorly developed paleosols with rootlets in growth position was logged in a borehole near Corvallis (Yeats and others, 1991). The upper 50 to 100 ft of sediment in the southern Willamette Valley consists largely of volcanic sand and gravel interbedded with fine sand and silt (Piper, 1942; Frank, 1973). Piper (1942) noted that basin-fill deposits in the southern Willamette Valley comprise a series of alluvial fans, and that these coarse deposits grade downvalley (northwestward) into finer grained sediment. The Linn Gravel, a laterally extensive layer of sand and gravel a few tens of feet thick, occurs throughout much of the southern Willamette Valley near the top of the basin-fill section (Allison, 1953). This unit, also termed the Linn Member of the Rowland Formation (Balster and Parsons, 1969), corresponds in part to the coarse sediments noted in the upper part of the basin-fill section by Piper (1942) and Frank (1973).

Remnants of older geomorphic surfaces underlain by deeply weathered sand, gravel, silt, and clay have been mapped in places along the periphery of the southern and central Willamette Valley (Allison, 1953; Baldwin and others, 1955; Allison and Felts, 1956; Frank, 1974, 1976; Gonthier, 1983). These older terrace deposits vary in thickness from a few feet to as much as 200 ft. Gonthier (1983) noted that coarse-grained layers within terrace deposits in the Dallas-Monmouth area were generally less than 10 ft thick. Many of these deposits, which are commonly 100 to 200 ft above present stream level, represent remnants of ancient stream channels or alluvial fans at the margins of the valley. The relatively high elevation of these deposits, compared to those of modern-day streams, indicates that the evolution of the basin has included periods of erosion, at least near the basin margins.

Deposition of basin-fill sediments in the Willamette Lowland probably occurred over a considerable period of time, and may have started soon after emplacement of the Columbia River Basalt Group. According to Trimble (1963), fossil flora found near the upper surface of the Sandy River Mudstone in the Portland area are early Pliocene age. This would be equivalent to a late Miocene age by time divisions currently used by the U.S. Geological Survey. Fossil pollen from fine-grained sediments found in a core from the southern valley indicated a late Pliocene or early Pleistocene age (W.A. Niem and others, CH2M-Hill, unpub. data, 1987). Roberts and Whitehead (1984) assigned a probable late Miocene age to fossil pollen from silty clay encountered in a drill hole near Monroe.

The grain-size distribution and geometry of lithofacies within the basin-fill sediment in the central and southern Willamette Valley indicate that most gravel has been deposited on alluvial fans formed by streams emanating from the Cascade Range. The thickness and extent of gravel deposits indicate that the fans have been active throughout much of the history of the Willamette Lowland. Alluvial fans are associated with the Willamette, McKenzie, South Santiam, North Santiam, and Molalla Rivers. All these drainages include glaciated terrane. Where these major streams enter the valley, sand and gravel deposits 200 to 300 ft thick rest directly on bedrock. These thick gravels extend up into the valleys of the tributary drainages. In the subsurface, these coarse sediments grade laterally into, and interfinger with, progressively finer sediments toward the valley center. This lateral down-fan facies change was first noted by Piper (1942). The authors believe these coarse and fine sediments represent the proximal and distal facies, respectively, of alluvial fans which have probably existed since uplift of the Western Cascades subprovince. Uplift occurred sometime between 3.5 and 5 million years ago (Sherrod and Smith, 1989). The large alluvial fans along the eastern side of the basin all have modern topographic expression and were last in a major constructional phase during Pleistocene time. The fans have been incised by streams since that time.

A fluvial origin for fine-grained sediment in the Willamette Lowland is consistent with field observations. Although Trimble (1963) and Hart and Newcomb (1965) thought the fine-grained sediment was lacustrine, recent workers have concluded the sediment is of fluvial origin. Sedimentary structures such as cross-bedding and ripples observed in the Sandy River Mudstone along the Clackamas River indicate a fluvial origin (Peterson and Niem *in* Yeats and others, 1991; Swanson and others, 1993). Fine-grained basin-fill sediment in the southern Willamette Valley is interpreted to represent fluvial deposition on a nearly flat to gently sloping alluvial plain traversed by low-gradient streams (W.A. Niem and others, CH2M-Hill, unpub. data, 1987). Similar sediment found in a core from near Corvallis is also believed to be of fluvial origin (Yeats and others, 1991). The presence of gravel layers within the predominantly fine-grained section also suggests a fluvial origin.

During Pleistocene time, drainages that contained glaciated terrane in the Cascade Range delivered a tremendous volume of coarse sediment to the Willamette Lowland. The coarse, proximal fan facies prograded out onto the valley floor, where their deposits coalesced, probably in a braided river system, to form the Linn Gravel. The Linn Gravel, which occurs throughout the southern Willamette Valley, averages a few tens of feet thick beneath the valley plain and is the most extensive, laterally continuous Quaternary gravel deposit in the Willamette Lowland. Deposits analogous to the Linn Gravel occur along the eastern side of the central Willamette Valley on the piedmont surface at the foot of the Western Cascades, but are not continuous westward on the valley floor.

BORING LAVA

Late Pliocene and Pleistocene basaltic lava that occurs in the Portland area is generally referred to as the Boring Lava (Treasher, 1942). The Boring Lava occurs in the Portland Basin, on the plateau separating the Portland Basin from the central Willamette Valley, and along the west side of the Tualatin Mountains in the Tualatin Valley (pl. 1).

The Boring Lava consists primarily of basalt flows with minor scoriaceous pyroclastic debris. Tuff and tuff breccia are known at one locality (Trimble, 1963). The Boring Lava is typically dark gray to light gray, diktytaxitic, olivine basalt to basaltic andesite (Trimble, 1963; Peck and others, 1964; Beeson and others, 1989b). Jointing is commonly columnar, blocky, or platy (Beeson and others, 1989b; Swanson and others, 1993).

The Boring Lava unconformably rests on the eroded surface of the Pliocene Troutdale Formation and is locally overlain by Quaternary gravel and mudflow deposits of the late Pliocene or early Pleistocene Walters Hill Formation (Trimble, 1963). Well data indicate that

Boring Lava underlies and is interbedded with Cascade-derived conglomerate and mudflow deposits of the Springwater Formation (Swanson and others, 1993; Kenneth E. Lite, Oregon Water Resources Department, oral commun, 1992). Boring Lava in the Lake Oswego area is locally deeply weathered or mantled by loess (Beeson and others, 1989b).

Numerous Boring Lava eruptive centers are found throughout the Portland area. These include shield volcanos up to a few miles in diameter and remnants of cinder cones. The highland between the Portland Basin and the central Willamette Valley, south and east of Oregon City, consists of a dissected lava plain composed of flows that are thought to have emanated from a nearby small shield volcano (Trimble, 1963). The thickness of the Boring Lava ranges from about 50 ft in areas far from vents to more than 600 ft near vents (Beeson and others, 1989b); it generally is 100 to 200 ft thick (Trimble, 1963).

The age of the Boring Lava is believed to be late Pliocene to late Pleistocene (Trimble, 1963). Portable fluxgate magnetometer measurements by Beeson and others (1989b) show the Boring Lava in the Lake Oswego area to have reversed magnetic polarity, indicating an age of greater than approximately 700,000 years. Radiometric ages for the Boring Lava range from 1.0 to 2.7 million years (G.R. Priest, Oregon Department of Geology and Mineral Industries, unpub. data, 1992). Peck and others (1964) correlate the Boring Lava with lithologically similar lava in the High Cascade Range, and it is commonly considered to be a western outlier of High Cascade volcanism.

GLACIAL-OUTBURST FLOOD DEPOSITS

The uppermost basin-fill deposits in the Willamette Lowland are the result of late Pleistocene glacial-outburst floods from the upper Columbia River drainage. The source of the floodwater was Lake Missoula, a late Wisconsin glacial lake that formed when a lobe of the Cordilleran ice sheet impounded the Clark Fork River in western Montana. The ice dam failed periodically, producing giant glacial-outburst floods that inundated eastern Washington, creating the Channeled Scablands (Bretz, 1925a,b, 1969; Bunker, 1982; Waitt, 1985; Baker and others, 1991). Floodwaters continued downstream through the Columbia River Gorge and temporarily ponded in the Willamette Valley. These catastrophic floods deposited a variety of materials in the Willamette Lowland and produced a variety of depositional and erosional features (Allison, 1935, 1953, 1978a,b; Glenn, 1965). The thickness and grain size of these deposits in the Willamette Lowland generally decreases with distance from the mouth of the Columbia River Gorge east of Portland.

In the Portland Basin, flood deposits that blanket the basin floor consist largely of unconsolidated gravel and sand, although silty and clayey phases have also been mapped (Trimble, 1963). Deltaic foreset beds and cut-and-fill structures are common in the flood gravel. North of Vancouver, a belt of sediment 2 to 4 mi wide is dominated by sand-sized material. The sandy phase grades north and west into silty and clayey material. Sandy deposits have also been mapped in west Portland (Beeson and others, 1989b). The thickness of the flood deposits in the Portland Basin varies from place to place owing to pre-flood topography and post-flood erosion. The flood deposits are as much as 250 ft thick, but generally range from less than 100 ft to about 150 ft thick in most of the Portland area (Trimble, 1963).

In the Willamette Lowland outside of the Portland Basin, the flood deposits are dominated by silt composed primarily of quartz, feldspar, ferromagnesian minerals, and mica, with varying amounts of clay and fine sand (Allison, 1953; Glenn, 1965; Hart and Newcomb, 1965; Price, 1967a). These deposits, generally referred to as the Willamette Silt, are faintly bedded, with individual beds ranging in thickness from 6 to 32 inches, averaging about 14 inches (Allison, 1953; Glenn, 1965). The flood sediment contains glacial erratics ranging in size from pebbles (described as "chips" because of their angularity) to boulders (Allison, 1935, 1953).

The Willamette Silt was deposited up to an altitude of about 350 or 400 ft outside of the Portland Basin, but is too discontinuous to map above an altitude of about 325 or 350 ft (Glenn, 1965). In the Tualatin Basin, the Willamette Silt averages 60 to 90 ft thick and has a maximum thickness of about 120 ft (Madin, 1990). In the central Willamette Valley, the Willamette Silt has a maximum thickness of about 130 ft near the center of the basin and becomes thinner toward the margins (Price, 1967a) (fig. 7). The Willamette Silt thins southward from the central Willamette Valley to the southern valley, where the average thickness is about 10 to 15 ft (Allison, 1953). The Willamette Silt has been locally modified by erosion. The unit has been generally eroded away in the present flood plains of the Willamette River and its major tributaries. The silt also has been removed from the valley floor between the Turner gap and the Willamette River gap along the northeastern side of the Salem Hills (fig. 3 and pl. 8). The North Santiam River probably flowed through the Turner gap and occupied this channel for a short period after the glacial floods, eroding the silt at that time.

HOLOCENE ALLUVIUM

Holocene alluvium is present in the flood plains of all major streams in the Willamette Lowland. The lithology and thickness of the alluvium vary from place to place. In the southern Willamette Valley, the Holocene alluvium is predominantly sand and gravel, averaging a few tens of feet thick; in about 10 percent of the area, it contains sufficient silt and clay to reduce permeability (Frank, 1973, 1974, 1976). Holocene alluvium in the central Willamette Valley generally consists of sand and gravel along major streams entering the valley from the Cascade foothills, but is generally finer grained along smaller streams and along the valley-plain reaches of the Pudding River and Rock Creek (Hampton, 1972). Alluvium along the Willamette River in the central Willamette Valley consists mostly of sand and gravel, but becomes progressively finer grained and thicker downstream of the Keizer-Mission Bottom area (Price, 1967a). Alluvium along smaller streams in the central Willamette Valley consists largely of reworked silt. In the Portland area, alluvium along the Willamette and Columbia Rivers consists primarily of sand and silt that is generally less than 50 ft thick, but locally up to 100 ft thick (Trimble, 1963). Alluvium along the major tributaries in the Portland Basin consists generally of sand and gravel. In the Tualatin Valley, the Holocene alluvium is almost entirely fine grained, consisting of fine sand, silt, clay, and peaty material (Hart and Newcomb, 1965).

STRUCTURE

The central Willamette Valley, the Portland Basin, the Tualatin Basin, and the Stayton Subbasin were formed by downwarping and faulting of the Columbia River Basalt Group to elevations of 1,200 to 1,600 ft below sea level. The Columbia River Basalt Group caps the uplands surrounding the structural basins in many places (pl. 1 and fig. 8). Total relief on the Columbia River Basalt Group in the study area is as much as 3,000 ft. The development of the four structural basins was controlled largely by deformation along regional northwest- and northeast-trending structural zones along with uplift in the Coast and Cascade Ranges (Beeson and others, 1989a). Major structural features in the Willamette Lowland are shown on figure 10.

Two major structural zones that transect the region were particularly important during development of the sedimentary basins. These are the Portland Hills-Clackamas River structural zone and the Gales Creek-Mount Angel structural zone (Beeson and others, 1985). Both of these structural zones were active during and after the incursion of the Columbia River Basalt Group; this is shown by the distribution of the basalt flows. The Portland Hills-Clackamas River structural zone consists of faults and folds that developed in response to dextral regional stress. The zone is 10 to 25 mi wide and extends northwestward more than 100 mi from the Cascade Range through the Portland area (Beeson and others, 1989a). The Gales Creek-Mount Angel structural zone, which lies southwest of and parallel to the Portland Hills-Clackamas River structural zone, is somewhat narrower and consists of dip-slip faults and dextral strike-slip faults (Beeson and others, 1989a).

The Portland Basin is bounded on the northeast by uplifted and faulted volcanic rocks of the western Cascade Range and on the northwest by volcanic and sedimentary rocks of the Coast Range. It is bounded on the southwest by the Tualatin Mountains (also known as the Portland Hills), which are a faulted, asymmetric anticline formed in the Columbia River Basalt Group (fig. 10). The southeastern part of the Portland Basin is separated from the central Willamette Valley by a highland composed of Boring Lava overlying fine-grained basin-fill deposits. Although there appears to be a continuous section of as much as 800 ft of sediment between the Portland Basin and the central Willamette Valley, well data analyzed in this study suggest that a structural high of Columbia River Basalt Group lava separates the two basins in the subsurface.

The Tualatin Basin is bounded on the northeast and separated from the Portland Basin by the Tualatin Mountains, and is bounded on the southwest by northeastward dipping Columbia River Basalt Group lavas in the Chehalem Mountains. The Tualatin Basin is bounded on the west by rocks of the Coast range, and on the east by a series of structural highs formed of Columbia River Basalt Group lavas. Two major faults have been mapped southwest of the Tualatin Basin and Chehalem Mountains: the Gales Creek Fault and the Newberg Fault (Werner, 1990; Yeats and others, 1991). These lie along the Gales Creek-Mount Angel structural zone.

The central Willamette Valley is bounded on the west by the Eola Hills, where Columbia River Basalt Group lava dips toward the center of the basin. To the southeast, the central Willamette Valley is bounded by basalt that is gently dipping toward the basin and that may be locally faulted (Yeats and others, 1991). The central valley is bounded on the northwest and separated from the Tualatin Basin by the basalt uplands of the Chehalem Mountains and Parrett Mountain. To the northeast, the central valley is separated from the Portland Basin by the Boring Lava highland mentioned previously. The central Willamette Valley and the Portland Basin are hydrologically separated because the sediment underlying the Boring Lava between the two basins is almost entirely fine grained.

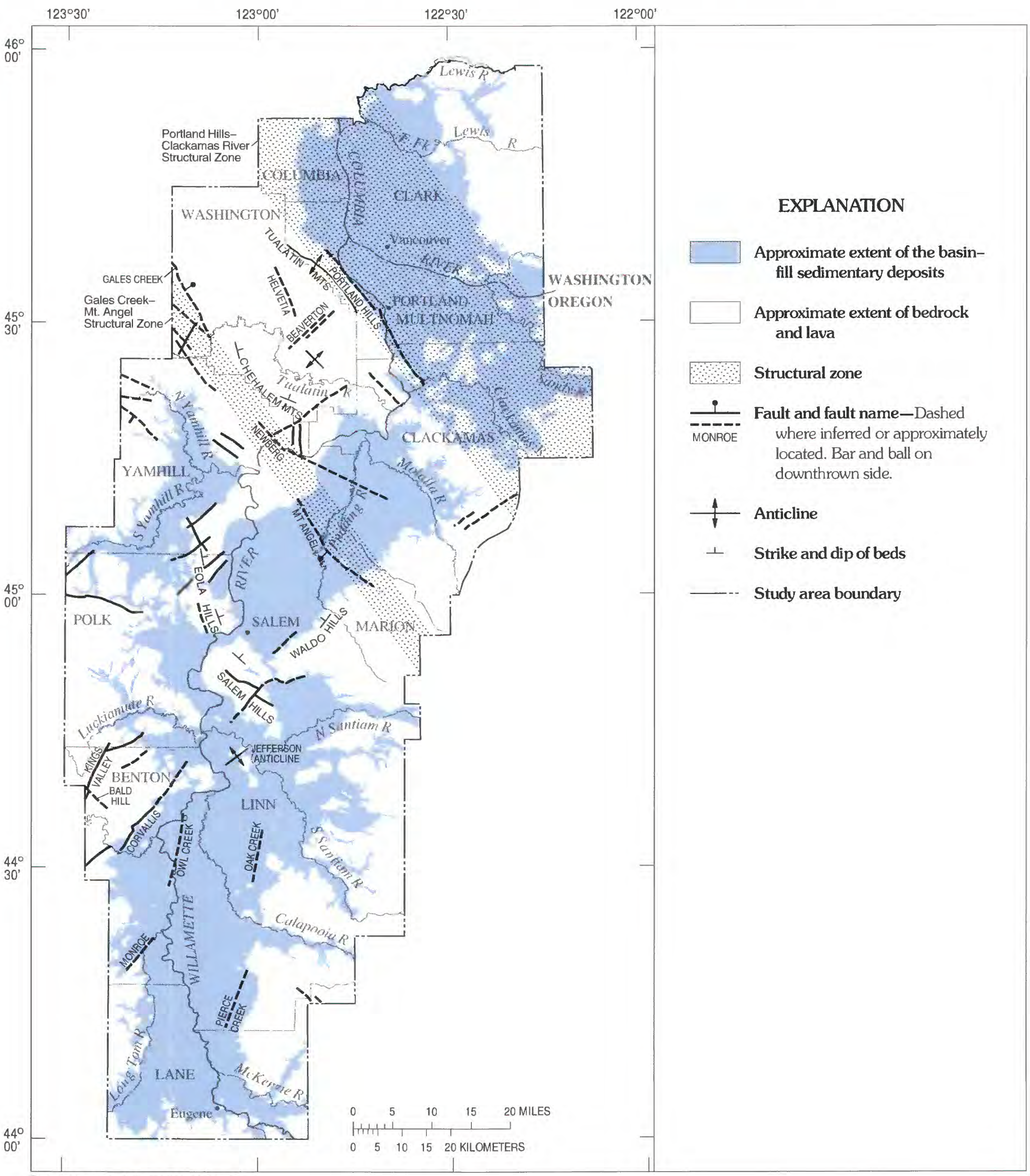


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FIGURE 10.—Selected structural features in the Willamette Lowland. (Strike and dip symbols show the approximate attitude of the Columbia River Basalt Group.)

The Portland Basin, Tualatin Basin, and the central Willamette Valley have developed, to a large extent, by downwarping of the Columbia River Basalt Group. Basalt flows exposed in the uplands generally dip toward the center of the basins. The underlying marine sedimentary rocks are commonly exposed on the scarp slopes on the sides of the uplands opposite the basins. Although relief on the Columbia River Basalt Group is considerable, most of the relief can be accounted for by dips of only 3 to 6 degrees.

Faulting has also played an important role in development of basins in the Willamette Lowland. Some faults in the area offset the basement units beneath the basin-fill deposits. Two faults, the Helvetia and Beaverton faults, offset the Columbia River Basalt Group beneath the Tualatin Basin (Yeats and others, 1991). Seismic cross-sections show reflectors within the overlying basin-fill deposits offset by approximately 60 ft. The Mount Angel fault offsets the Columbia River Basalt Group beneath the central Willamette Valley by as much as 800 ft (Hampton, 1972; Werner, 1990). Mount Angel and the small basalt exposure to the northwest are believed to be popup structures caused by local compressional forces along the fault caused either by a bend or splay (Werner 1990). Seismic reflection cross-sections (Werner, 1990) show offset of reflectors within the basin-fill deposits overlying the Columbia River Basalt Group; the nature of these reflectors is unknown. Water-well data discussed in later sections show that the Mount Angel fault has had a major influence on the distribution of facies within the basin-fill deposits in the central valley.

Water-well data suggest a possible fault north of, and parallel to, the Mount Angel fault. Basalt tentatively identified as Columbia River Basalt Group (Marvin Beeson, Portland State University, oral commun., 1991) occurs at an anomalously high altitude beneath basin-fill deposits just west of Aurora. A previously unrecognized basalt high occurs beneath basin-fill deposits several miles to the southeast of the Aurora high. These structures are aligned with LaButte, a structure similar in appearance to Mount Angel. These structures probably result from a fault parallel to, and with similar motion as, the Mount Angel fault. This may be a southeastward extension of Werner's (1990) Newberg fault.

The southern Willamette Valley, south of the Salem Hills, is largely an erosional feature. Sherrod and Pickthorn (1989) considered this area to be a strike valley formed by preferential erosion of relatively nonresistant marine and strandline deposits which lack lava flows and intrusions. The western boundary of the southern Willamette Valley is defined by the erosionally resistant. Tyee and Spencer Formations, while the southern and eastern boundaries are defined by erosionally resistant volcanic rocks (Yeats and others, 1991).

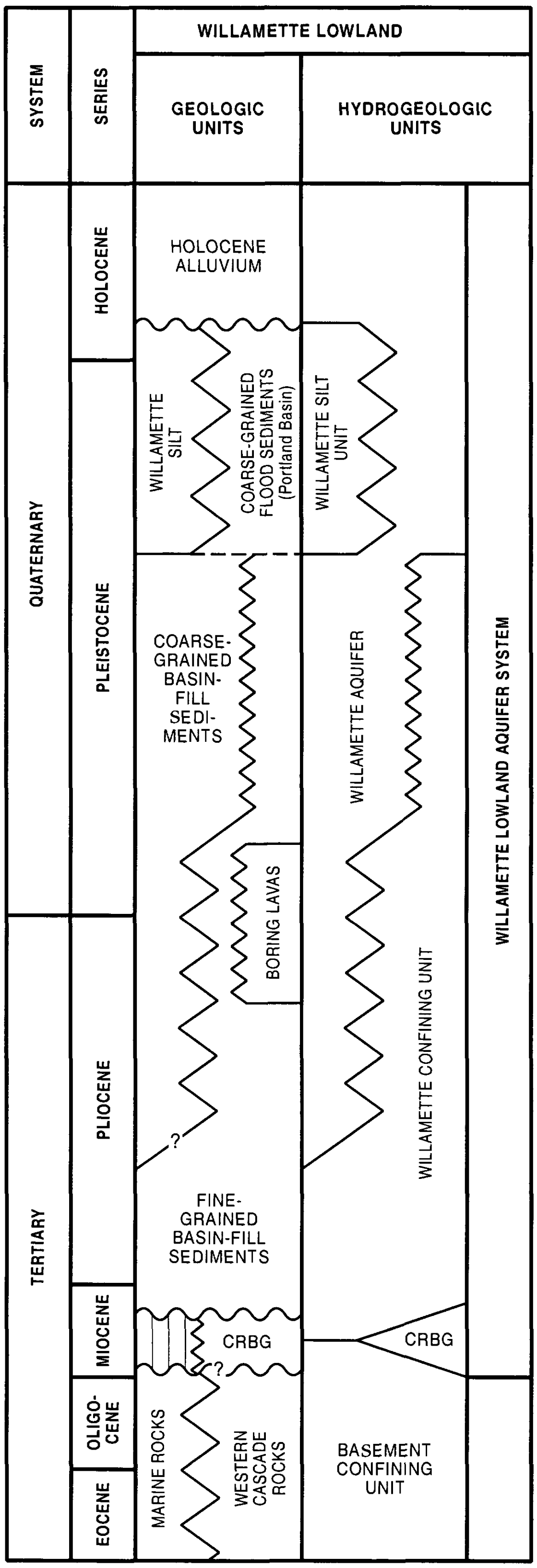
REGIONAL HYDROGEOLOGIC UNITS

The regional hydrogeologic units defined for the Willamette Lowland aquifer system are composed of one or more of the geologic units described in previous sections. Geologic units that have similar overall hydrogeologic characteristics and are adjacent or occupy similar stratigraphic positions have been combined into a single hydrogeologic unit. Thus, a hydrogeologic unit may include rock units of different ages or origins. Five regional hydrogeologic units are defined for the Willamette Lowland. These units are, from oldest to youngest: (1) the basement confining unit, (2) the Columbia River basalt aquifer, (3) the Willamette confining unit (composed of fine-grained basin-fill deposits), (4) the Willamette aquifer (composed of coarse-grained basin-fill deposits), and (5) the Willamette Silt unit. These units all exhibit relatively uniform and distinct hydrologic properties throughout the Willamette Lowland. A correlation chart shows the relation between the hydrogeologic units and the geologic units previously described (fig. 11).

BASEMENT CONFINING UNIT

The basement confining unit includes all the stratigraphic units that underlie the Columbia River Basalt Group lavas and basin-fill deposits in the Willamette Lowland. The basement unit, which bounds the aquifer units within the Willamette Lowland aquifer system, includes the marine sedimentary rocks and Eocene volcanic rocks of the Coast Range, and volcanic rocks of the western Cascade Range. Tertiary marine sandstone, siltstone, claystone, and shale are exposed in the Coast Range and underlie most of the southern and central Willamette Valley, the entire Tualatin Valley, and the western part of the Portland Basin. Marine sedimentary rocks and western Cascade volcanic rocks are exposed along the eastern margin and underlie the eastern parts of the southern and central valley. The contact relation between marine strata and Cascade Range volcanic rocks beneath the Willamette Lowland is poorly known.

The marine sedimentary rocks are generally fine grained, cemented, and have low permeability (Hampton, 1972; Price, 1967a,b; Frank, 1973, 1974, 1976; Helm and Leonard, 1977). In general, yields from wells completed in marine sediment range from 2 to 10 gpm.



NOTE: CRBG = COLUMBIA RIVER BASALT GROUP

FIGURE 11.—Relation between generalized geologic units and hydrogeologic units in the Willamette Lowland.

Little hydrologic information is available for the volcanic and intrusive rocks in the Coast Range, but well information indicates that these rocks also have low permeability (Frank, 1974; Frank and Collins, 1978). Coast Range volcanic rocks commonly contain abundant secondary minerals (Keith and Staples, 1985) that tend to reduce fracture permeability. Saline water is commonly encountered in marine sedimentary rocks beneath and adjacent to the Willamette Lowland; this saline water is not commonly encountered in basin-fill deposits (Hampton, 1972; Frank, 1973, 1974; Price, 1967a,b; Helm and Leonard, 1977; Frank and Collins, 1978; Caldwell, 1993). This contrast in water quality suggests only limited circulation of water between marine strata in the basement confining unit and the overlying Willamette confining unit and Willamette aquifer.

Volcanic rocks of the western Cascade Range are considered part of the basement confining unit because they too possess generally low permeability. These include the Fisher Formation and the Little Butte Volcanics Series. The Fisher Formation, which underlies a small part of the southern Willamette Valley, consists primarily of volcaniclastic material and yields only small quantities of water, commonly of poor quality (Frank, 1973). The Little Butte Volcanic Series, which occurs along the eastern side of the Willamette Valley, consists of pyroclastic and epiclastic volcanic debris with lesser flows, breccias, and small intrusions. Permeability is low because much of the clastic material is devitrified and flow rocks typically contain abundant secondary minerals (Peck and others, 1964). Wells completed in the Little Butte Volcanic Series in the southern Willamette Valley generally have small yields, and basalt flows and intrusions within the Little Butte Volcanic Series yield little or no water (Frank, 1973, 1976). Hampton (1972) reported that wells completed in tuff and agglomerate of the Little Butte Volcanic Series in the central Willamette Valley produce amounts of water adequate only for domestic use. North of the Columbia River, western Cascade volcanic rocks underlying the basin-fill sediment are assigned to the Skamania Volcanics. Their similar age and origin to the Little Butte Volcanic Series suggests their hydraulic characteristics are also similar. Mundorff (1964) reported low well yields from the Skamania Volcanics.

The altitude of the top of the basement confining unit was mapped in part of the Willamette Lowland. Plate 2 shows the altitude of the base of the basin-fill deposits, a surface that corresponds to the top of the basement confining unit in the southern Willamette Valley and the Yamhill River Valley east of the Eola Hills. Outside of these areas, the Columbia River Basalt Group occurs, and the altitude of the top of the basement confining unit was not mapped because there was insufficient control. Few wells penetrate through the basalt into the basement units. Differentiating fine-grained marine sedimentary rocks from the overlying fine-grained basin-fill deposits is often difficult when using information from well logs. Therefore, the altitude contours for the top of the basement confining unit in the southern Willamette Valley on plate 2 may be less precisely located than the altitude contours for other units in the Willamette Lowland.

COLUMBIA RIVER BASALT AQUIFER

The Columbia River basalt aquifer is the most lithologically uniform hydrogeologic unit in the study area. The Columbia River basalt aquifer underlies approximately 2,500 mi^2 of the northern part of the Willamette Lowland. About 1,900 mi^2 of the unit is overlain by basin-fill deposits in the central Willamette Valley, the Tualatin Basin, the Portland Basin, and the Stayton Subbasin. The Columbia River basalt aquifer is the uppermost hydrogeologic unit over about 600 mi^2, mostly in upland areas. The Columbia River basalt aquifer averages a few hundred to several hundred feet thick, but is as much as 1,000 ft thick locally in the Chehalem Mountains south of the Tualatin Basin.

The Columbia River basalt aquifer is underlain by the basement confining unit and is overlain by basin-fill deposits. In the eastern part of the Portland Basin, the Columbia River basalt aquifer is locally overlain by volcanic mudflow debris that originated in the Cascade Range (Trimble, 1963). The Columbia River basalt aquifer is locally exposed in foothills adjacent to the southern and central valley, the Portland Basin, and the Tualatin Basin. In the Portland Basin, the Columbia River basalt aquifer extends outside of the Willamette Lowland east through the Cascade Range and northwest into the Coast Range. Because few wells penetrate through the entire Columbia River basalt aquifer, there is not sufficient information available to produce a detailed map of its thickness. However, the thickness of the Columbia River basalt aquifer is shown on selected hydrogeologic sections (pl. 3). Structure contours on plate 2 show the altitude of the top of the Columbia River basalt aquifer beneath the basin-fill sediments in the central valley, Tualatin Basin, Stayton Subbasin, and most of the Portland Basin. The altitude of the top of the Columbia River Basalt Group was mapped using information from water well logs, oil and gas exploration well logs, and seismic reflection interpretations from Werner (1990) and Yeats and others (1991).

The Columbia River basalt aquifer is an important source of water in areas where it is at or near the surface. The Columbia River basalt aquifer in the Willamette Lowland generally consists of multiple individual flows 10 ft to more than 100 ft thick (Hampton, 1972; Beeson and others, 1989b). The interflow zones between successive lava flows commonly include the brecciated, vesicular top of one flow, possible sedimentary interbeds, and the rubbly base of the overlying flow. These interflow zones are, in places, porous and highly permeable; therefore, the Columbia River basalt aquifer commonly has high lateral permeability (Newcomb, 1961, 1969, 1982). Flow interiors typically consist of dense basalt crisscrossed by multitudinous cooling joints. Unless the basalt has been structurally deformed, these joints remain tightly closed. Therefore, vertical permeability is generally lower than horizontal permeability. The low permeability of the flow interiors restricts, but does not preclude, the movement of water into and between the aquifers in the interflow zones.

WILLAMETTE CONFINING UNIT

The Willamette confining unit consists of the fine-grained distal alluvial fan and low gradient stream deposits that dominate the lower part of the basin-fill sequence and parts of the lowland distant from major alluvial fans. The fine-grained sediment is considered a regional confining unit because of its widespread occurrence and low permeability. The Willamette confining unit is the volumetrically largest unit in the basin-fill sequence. The sediment of the Willamette confining unit is commonly described by drillers as blue clay, sandy clay, or shale. In the Portland Basin, the sediment of this unit has been described as mudstone, siltstone, claystone, and very fine sandstone (Trimble, 1963); and as micaceous arkosic siltstone and fine-to medium-grained sand with local clay, water-laid ash, and minor gravelly interbeds (Swanson and others, 1993). In the Portland Basin, the Willamette confining unit includes rock assigned to the Sandy River Mudstone (Trimble, 1963) and generally corresponds to the lower sedimentary subsystem defined by Swanson and others (1993).

In the Tualatin Basin, the entire basin-fill section is dominated by silt and clay with minor sand and gravel, and is assigned to the Willamette confining unit. The unit includes rocks assigned to the Troutdale Formation and Willamette Silt (Schlicker and Deacon, 1967) and mapped as undifferentiated valley fill by Hart and Newcomb (1965).

In the central Willamette Valley the fine-grained sediment of the Willamette confining unit has been described as "thick layers of dark-gray to blue clay and shale separated by thin layers of sand and fine gravel, generally less than 5 feet thick" (Price, 1967a). These rocks have been assigned to both the Sandy River Mudstone (Price, 1967a) and the lower Troutdale Formation (Hampton, 1972).

In the southern Willamette Valley, the Willamette confining unit has been described as having a distinctly blue color and consisting of clay to silty clay, sandy clay, and clayey silt, with occasional lenses of well sorted, unconsolidated medium to fine sand (W.A. Niem and others, CH2M-Hill, unpub. data, 1987). Frank (1973, 1974, 1976) assigned this sediment in the southern valley to either the older alluvium or the Eugene Formation.

The top of the Willamette confining unit (pl. 4) corresponds to the boundary between fine-grained and coarse-grained basin-fill deposits. This boundary is flat lying in parts of the lowland between major alluvial fans. Near the margins of fans, however, the boundary slopes downward, forming depressions in the top of the Willamette confining unit. These depressions occur where coarse-grained proximal alluvial fan facies dominate the upper part of the basin-fill section. The top of the Willamette confining unit corresponds to land surface in the Tualatin Basin, because the entire basin-fill section is included in the unit.

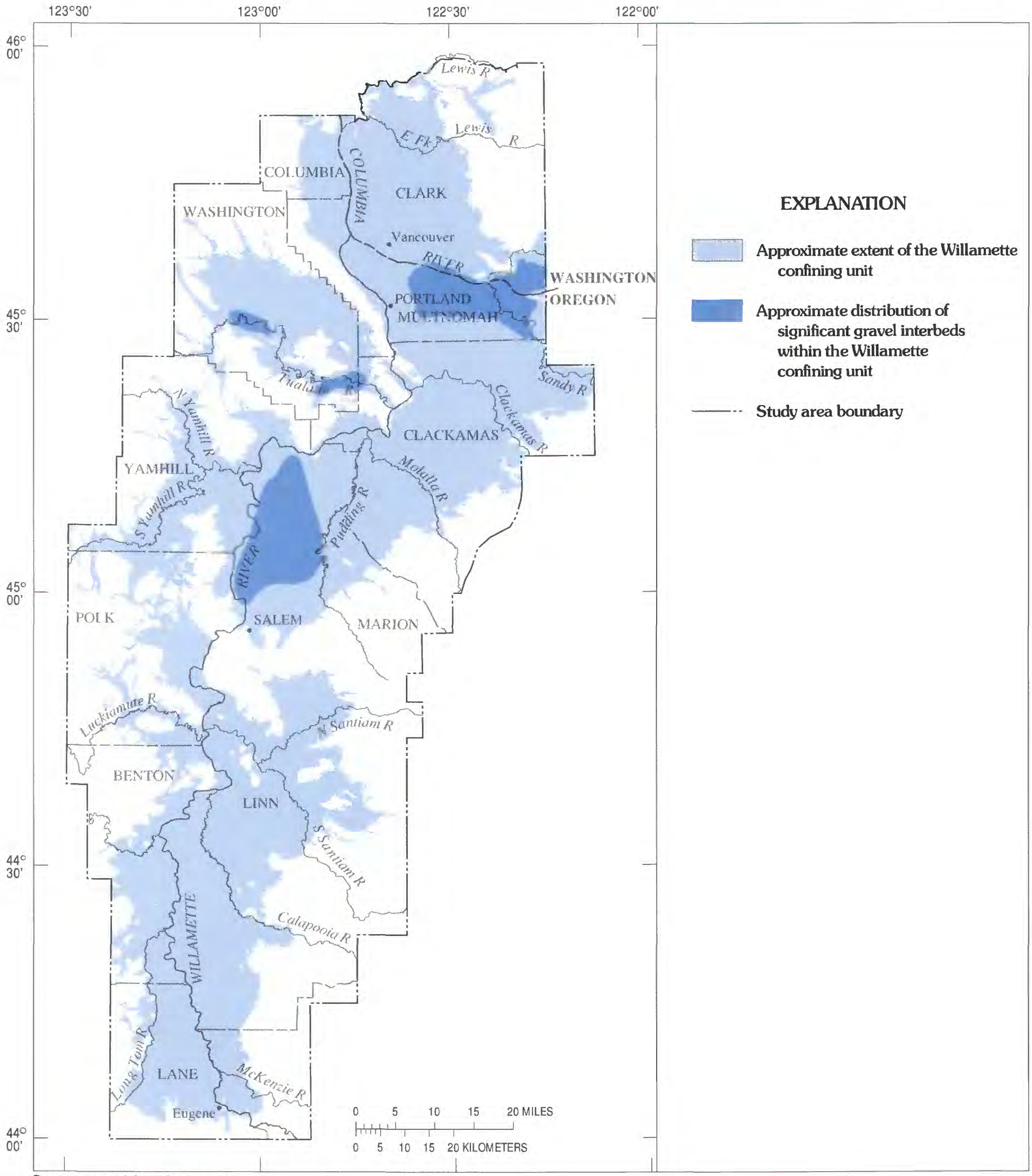
The Willamette confining unit ranges in thickness from less than 100 ft to more than 1,600 ft (pl. 5). In general, the unit is thickest in the northern part of the central Willamette Valley, and centers of the Tualatin and Portland Basins. The unit is thinner, averaging 100 ft to 300 ft thick, in the southern Willamette Valley and along the periphery of the Willamette Lowland. Thickness contours of the Willamette confining unit (pl. 5) strongly resemble elevation contours of the top of the basement confining unit and Columbia River Basalt Group (pl. 2). This is because the amount of relief on the top of the basement confining unit and Columbia River basalt aquifer is larger than the relief on the top of the Willamette confining unit. The Willamette confining unit covers approximately 3,100 mi^2.

Although the fine-grained sediment of the Willamette confining unit generally yields only small amounts of water to wells (Price, 1967a; Swanson and others, 1993), the unit locally contains sand or gravel interbeds which serve as aquifers. These interbeds are typically thin and discontinuous. In most cases, well data were insufficient to accurately map or describe these interbeds. However, potentially productive sand and gravel interbeds are known to occur within the Willamette confining unit in a few areas (fig. 12). Where the Columbia River debouches into the Portland Basin, sediment in the upper part of the Willamette confining unit grades laterally into a sequence of silty to gravelly sand named the sand and gravel aquifer (Hartford and McFarland, 1989; Swanson and others, 1993). This sand and gravel facies underlies an area of about 120 mi^2, averages 50 ft thick, and locally is more than 200 ft thick. It appears to be the thickest near the present channel of the Columbia River. A layer of vitric sand and quartzite-bearing basaltic conglomerate, averaging 100 to 200 ft thick, occurs in the upper part of the Willamette confining unit in the southern part of the Portland Basin (fig. 12). This unit, named the Troutdale sandstone aquifer, thins toward the west and northwest, and grades into fine-grained sediments near the center of the basin (Swanson and others, 1993). Thin discontinuous sand and gravel layers occur at various depths in places within the Tualatin Basin (fig. 12). In the central Willamette Valley, a tongue of sand and gravel about 10 to 30 ft thick and situated at about 80 to 100 ft below sea level within the Willamette confining unit extends several miles north from the Salem area (fig. 12). This gravel interbed is an important aquifer in the French Prairie area.

WILLAMETTE AQUIFER

The Willamette aquifer is the principal aquifer in the Willamette Lowland. The unit occurs over 2,700 mi^2 and ranges from less than 20 ft to more than 600 ft thick. The Willamette aquifer consists primarily of layers of sand and gravel that are a few tens of feet to several tens of feet thick. Interbeds of sand, silt, and clay commonly occur, but generally are thinner and fewer in number than their coarse-grained counterparts. The sand and gravel layers exhibit a wide range of sorting and cementation. Many layers are described as mixtures of clay, sand, and gravel. The Willamette aquifer does not occur in the Tualatin Basin.

In the Portland Basin, the Willamette aquifer essentially includes all basin-filling deposits above the Willamette confining unit, and generally corresponds to the upper sedimentary subsystem of Swanson and others (1993), which consists of their Troutdale gravel aquifer and unconsolidated sedimentary aquifer. The Troutdale gravel aquifer primarily consists of poorly to moderately cemented gravel in a matrix of micaceous arkosic and lithic sand, as well as conglomerate and sandstone (Swanson and others, 1993), and was deposited by the Columbia River and streams from the Cascade Range.



Basemap source information on page v.

FIGURE 12.—Approximate distribution of significant gravel interbeds within fine-grained sediments of the Willamette confining unit.

The unconsolidated sedimentary aquifer consists of silt, sand, and gravel of glacial-outburst flood origin; Holocene alluvial deposits; terrace deposits along present drainages; and glacial outwash in small basins in northern Clark County, Washington. Because the Willamette aquifer includes the uppermost basin-fill units in the Portland Basin, the top of the unit (pl. 6) corresponds to land surface in that area. The Willamette aquifer ranges in thickness from 100 ft to 400 ft, locally exceeding 600 ft, in the Portland Basin.

Alluvial fan morphology is not apparent in the Willamette aquifer in the Portland Basin. This is possibly because streams flowing into the Portland Basin from the Cascade Range are incised into the surrounding Boring Lava plateau, and because of the overwhelming ability of the Columbia River to redistribute sediment in the basin.

Swanson and others (1993) include the Boring Lava in the Troutdale gravel aquifer; however, the lava was not included in the Willamette aquifer nor any regional hydrogeologic unit in this study. Where the Boring Lava is most extensive in the study area, on the plateau between the Portland Basin and the central Willamette Valley, it overlies fine-grained sediment of the Willamette confining unit. The contact between these two units lies above the regional ground-water flow system, and the Willamette confining unit hydrologically separates the two basins. The largest part of the Boring Lava is situated on top of this barrier and is not considered an important element of the regional ground-water system.

In the central and southern Willamette Valley, the Willamette aquifer consists largely of a series of partially buried alluvial fans separated by thinner, locally discontinuous braided stream deposits. These deposits correspond in part to the Troutdale Formation of Price (1967a) and Hampton (1972), and the upper part of the older alluvium of Frank (1973, 1974, 1976). The top of the unit (pl. 6) lies beneath late-Pleistocene glacial-outburst flood deposits as thick as 130 ft, and is essentially the pre-flood land surface. The geometry of this surface shows the alluvial fans emanating from the Cascade Range in the central and southern Willamette Valley. Alluvial fans are also strikingly apparent on plate 7, which shows the thickness of the Willamette aquifer.

The geometry of the top of the Willamette confining unit (pl. 4) shows that the thickness of the Willamette aquifer that is coincident with the alluvial fans is not due entirely to the geometry of the upper surface of the fans. The fans also are seen as "depressions" in the upper surface of the Willamette confining unit. These were never actual physical depressions, because the contact between the Willamette aquifer and Willamette confining unit is generally not an erosional surface in the vicinity of the fans; the contact is more commonly a facies boundary in these areas. The relation between the two units is shown schematically in figure 13, and can be seen in sections through alluvial fans in the southern and central Willamette Valley (pl. 3, sections D-D′, E-E′, and F-F′). The Willamette aquifer grades laterally into, and interfingers with, the Willamette confining unit. The two units are, in part, time-stratigraphic equivalents, and represent proximal and distal alluvial-fan facies, respectively. In some places, particularly where the sides of fans are parallel with terrace deposits, the contact between the two units may be erosional.

In the central Willamette Valley, three major fans occur within the Willamette aquifer: the Salem fan, the Molalla fan and the Canby fan (pls. 6 and 7). The largest of these fans, the Salem fan, occurs in the southern part of the central valley. The morphology of this fan indicates a primary sediment source that once fed through the Turner gap. This source was undoubtedly the ancestral North Santiam River. The Salem fan is 6 to 8 mi wide, and forms a gravel deposit at least 200 ft thick (pl. 7). In the southern part of the Salem fan, gravel of the Willamette aquifer rests directly on the underlying Columbia River Basalt Group (pl. 3, section C-C′), and fine-grained sediment of Willamette confining unit does not occur in the section. Immediately southwest of Mount Angel, the northeastern part of the Salem fan merges with a thick section of gravel that was probably deposited by Abiqua Creek.

The Mount Angel fault has had a major influence on the geometry of the Salem fan (pl. 7). The coarse sediment of the Willamette aquifer is much thicker on the downdropped, south side of this structure, and thins abruptly to the north across the fault zone. More rapid subsidence of the basin on the south side of this structure probably localized drainages in that area during basin development. The effects of the Mount Angel fault are not apparent on the west side of the valley. A major tongue of gravel extends from the Salem fan north across the projected trace of the fault with no obvious offset (fig. 12 and pl. 3).

A large fan is also present where the Molalla River debouches into the valley. This fan, named the Molalla fan, is 4 to 6 mi wide and forms gravel deposits in excess of 120 ft. The Molalla fan overlies several hundred feet of fine-grained sediment of the Willamette confining unit.

The third fan, known as the Canby fan, occurs just south of the Oregon City gap (pl. 7). It is approximately 2 mi wide and forms a gravel deposit up to 100 ft thick.

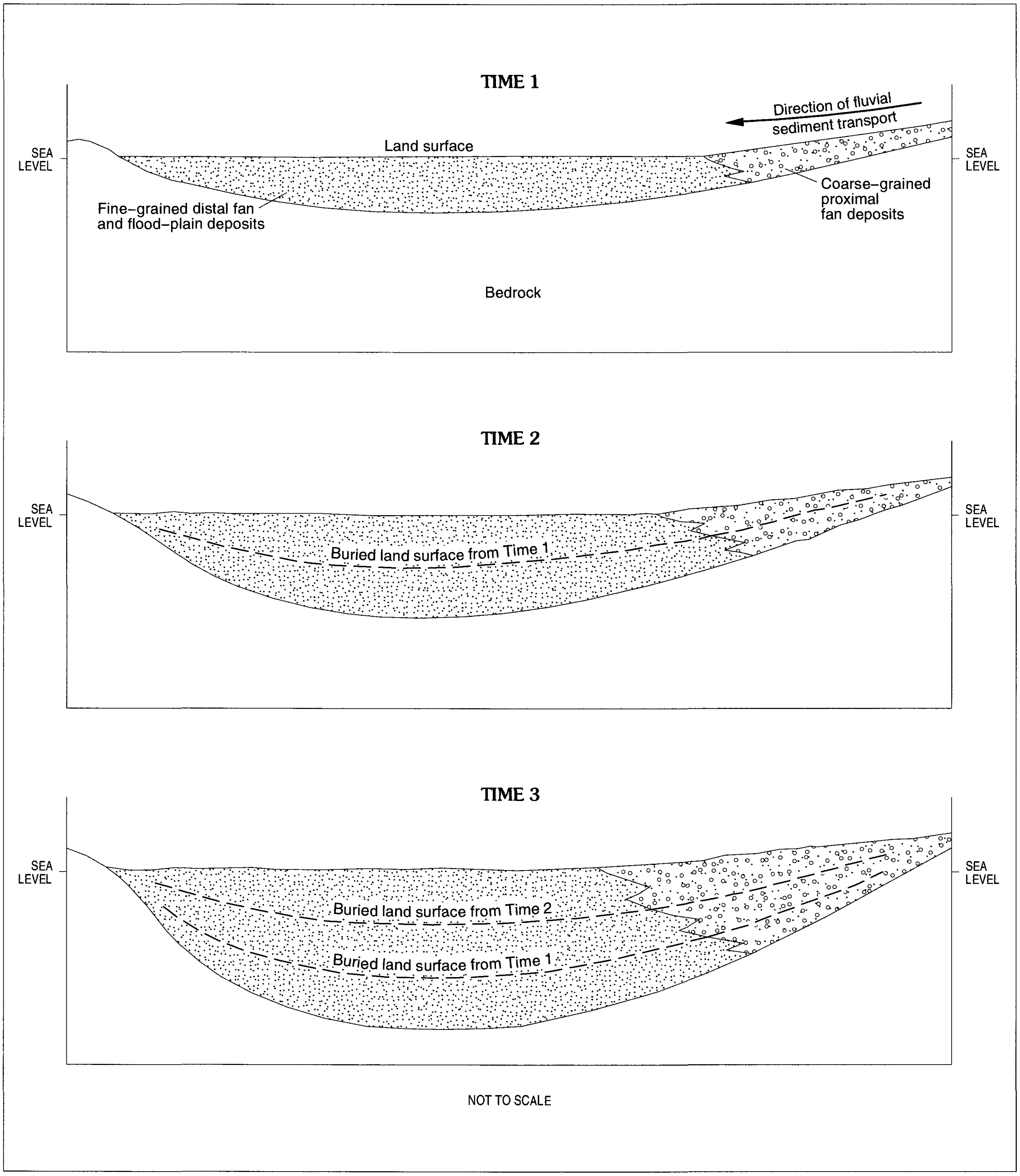


FIGURE 13.—Schematic section showing the development of fan deposits and the relation between coarse- and fine-grained facies in the Willamette Lowland during basin subsidence.

It is different from other gravel fans in the central and southern Willamette Valley in that it was deposited by Pleistocene glacial-outburst floods. Floodwater entering the central valley from the Portland Basin had sufficient velocity to transport gravel. As the water entered the central valley, its velocity decreased causing deposition of the gravel. Flood sediment elsewhere in the valley consists primarily of silt and fine sand.

The Willamette aquifer was not mapped in the northwestern part of the central Willamette Valley because the gravel deposits are thin, discontinuous, occur at various elevations, and do not represent a hydraulically continuous unit. The geometry of the Willamette aquifer is particularly complex northeast of the Mount Angel fault and south of the Molalla fan. This may be due to the effects of the fault, or the presence of a numerous small drainages that enter the valley in that area.

In the southern Willamette Valley, the Willamette aquifer includes gravel deposits of three large fans: the Springfield fan, the Lebanon fan, and the Stayton fan (pls. 6 and 7). The coarse-grained deposits of these fans generally overlie silt and clay of the Willamette confining unit. At the heads of these fans in the river valleys of the Cascade foothills, the fans grade into valley train gravel deposits, locally in excess of 200 ft thick, which lie directly on bedrock.

The Springfield fan, which is the southernmost of the three, was deposited by the ancestral Willamette and McKenzie Rivers. It forms a deposit of predominantly sand and gravel at least 240 ft thick and 8 to 9 mi wide.

The Lebanon fan, which occurs in the northern part of the southern Willamette Valley, consists of coarse sediment deposited primarily by the South Santiam River. This fan is about 8 to 10 mi wide, and includes deposits of predominantly sand and gravel up to 140 ft thick.

The Stayton fan occupies the partly enclosed Stayton Subbasin in the northeast part of the southern Willamette Valley (pl. 6). The North Santiam River enters the eastern part of the basin creating an alluvial fan that abuts the western side of the basin formed by the Salem Hills. In the past, the North Santiam River has flowed out of the Stayton Subbasin through either of two outlets on opposite sides of the fan. The river presently flows out of the wide southwestern outlet, where it joins the South Santiam River. In times past, however, the North Santiam River flowed northwestward out of the relatively narrow Turner gap now occupied by Mill Creek and into the central Willamette Valley near Salem, depositing gravels of the Salem fan (pl. 7). The large volume of the Salem fan suggests that this may have been the preferred course for long periods in the past.

The Willamette aquifer is much thinner (averaging only about 20 to 40 ft thick) and locally discontinuous between the alluvial fans of the southern Willamette Valley (pl. 7). This relatively thin gravel that occurs between the fans is considered part of the Linn gravel, and is generally at or near the top of the pre-flood basin-fill section.

Most of the sediment of the Willamette aquifer came from the Cascade Range, and only a small amount of coarse-grained sediment appears to have come out of the Coast Range (pl. 7). Most of the sediment from the Coast Range is derived from erosion of marine sedimentary rock and is fine grained. The small amount of gravel from the Coast Range usually consists of Eocene basalt clasts. A thin gravel deposit occurs in the Yamhill River Valley north and west of the Eola Hills (pls. 6 and 7). Gravel deposits also are associated with the Long Tom River southwest of Fern Ridge Reservoir and Rickreall Creek west of Dallas.

Holocene alluvial deposits along the Willamette River flood plain are locally included within the Willamette aquifer. Analysis of well data for the southern and central Willamette Valley indicates that the Holocene alluvium along the modern flood plain is thin (a few tens of feet at most). Sections through parts of the southern and central valley (pl. 3, sections B-B′, D-D′, and E-E′) show that the modern flood plain is cut into the adjacent basin-fill deposits. The flood plain beds are predominantly sand and gravel lithologically similar to, laterally continuous with, and in large part derived from sand and gravel deposits within the Willamette aquifer.

WILLAMETTE SILT UNIT

The Willamette Silt hydrogeologic unit corresponds in large part to the Willamette Silt geologic unit. The Willamette Silt, which was deposited by glacial outburst floods, has a relatively uniform lithology over the entire lowland outside of the Portland Basin. In the central and southern Willamette Valley, where the silt overlies the Willamette aquifer, there is significant lithologic difference between the two units and the Willamette Silt is considered a distinct regional hydrogeologic unit. In the Tualatin Basin, however, where the Willamette aquifer is absent, lithology of the Willamette Silt and the underlying Willamette confining unit is too similar to warrant dividing them into separate regional hydrogeologic units. Therefore, the Willamette Silt in the Tualatin Basin is considered part of the Willamette confining unit. The Willamette Silt unit includes essentially all fine-grained deposits above the Willamette aquifer.

Therefore, the unit as mapped may in places include some pre-flood sand and silt of local fluvial origin in addition to the flood-deposited sediment.

The Willamette Silt unit covers approximately 1,200 mi^2 and forms a wedge-shaped deposit which thins toward the south. The unit is as much as 130 ft thick in the northern part of the central Willamette Valley and thins to about 10 ft thick in the southern valley near Harrisburg (pl. 8). Above an elevation of about 350 ft on the valley floor, the Willamette Silt cannot be distinguished from other fine-grained surficial deposits and recent alluvium on the modern Willamette flood plain using water well logs.

The Willamette Silt unit is partly saturated in most places on the valley floor, and the water table resides within the unit over much of its extent. The Willamette Silt unit generally is not used as a source of water; however, a few wells, some of which are old hand-dug wells, reportedly produced adequate water for domestic use (Hampton, 1972; Price, 1967a,b). The Willamette Silt unit generally is a semiconfining unit of regional extent.

SUMMARY

The Willamette Lowland consists of a series of structural and erosional basins between the Coast Range and the western Cascade Range in western Oregon and part of southwestern Washington. It includes four separate basins: the southern Willamette Valley, the central Willamette Valley, the Tualatin Basin, and the Portland Basin.

Much of the Willamette Lowland is underlain by lava flows of the Columbia River Basalt Group. These lavas are locally exposed in uplands adjacent to the central Willamette Valley, the Tualatin Basin, and the Portland Basin. The southern Willamette Valley is underlain primarily by marine sediments similar to those exposed in the Coast Range. Epiclastic and pyroclastic volcanic debris and lava flows, similar to those exposed in the western Cascade Range, locally underlie the eastern part of the Willamette Lowland, primarily in the southern Willamette Valley. More than 1,600 feet of post-middle Miocene to Holocene continental sediment have been deposited locally in the basins that make up the Willamette Lowland.

Five regional hydrogeologic units have been delineated and mapped in the Willamette Lowland. These units are the basement confining unit, the Columbia River basalt aquifer, the Willamette confining unit, the Willamette aquifer, and the Willamette Silt unit.

The basement confining unit is primarily composed of the marine sedimentary rocks and the volcanic rocks of the western Cascade Range that underlie the Willamette Lowland. This unit also locally includes Eocene volcanic rocks and Oligocene intrusive rocks. These units generally have low permeability, and, locally, the water they contain may be unsuited for some uses.

The Columbia River basalt aquifer lies above the basement confining unit and below the basin-fill sediment in much of the Willamette Lowland. The accordantly layered flows of the Columbia River Basalt Group have relatively high lateral permeability and low vertical permeability. Because of its high lateral permeability, the Columbia River basalt aquifer is capable of providing water to wells at a high rate. However, the low vertical permeability limits recharge to the unit and movement of water between individual water-bearing zones.

The Willamette confining unit comprises the fine-grained sediment that dominates the lower part of the basin-fill section in most of the Willamette Lowland. It primarily consists of clay, silt, and sand with minor interbedded sand and gravel, and is considered a regional confining unit. In the Portland Basin, the upper part of the sand and gravel aquifer of Hartford and McFarland (1989) and Swanson and others (1993) is an important gravel facies of this unit. All of the basin-fill sediments in the Tualatin Basin are included in this unit.

The Willamette aquifer is the principal aquifer unit in the Willamette Lowland. The aquifer primarily consists of sand and gravel with minor interbedded silt and clay, and dominates the upper part of the basin-fill sequence in most of the Willamette Lowland. The coarse sediment of this unit was deposited primarily on alluvial fans formed by streams entering the valley from the Cascade Range. Major alluvial fans are associated with the ancestral Willamette, McKenzie, South Santiam, North Santiam, and Molalla Rivers. During the Pleistocene, these fans prograded out onto the valley floor, and their coarse-grained proximal facies deposits coalesced to blanket much of the Willamette Lowland. In the Portland Basin, the Willamette aquifer was deposited primarily by the ancestral Columbia and Clackamas Rivers, and includes coarse-grained Pleistocene glacial-outburst flood deposits. The Willamette aquifer does not occur in the Tualatin Basin.

In the southern and central Willamette Valley, the Willamette aquifer is overlain by the Willamette Silt unit. This unit, which is composed of silt and fine sand, forms a wedge-shaped deposit approximately 130 ft thick in the north part of the central Willamette Valley that thins to about 10 ft thick in the southern Willamette Valley near Harrisburg. The silt locally acts as a semiconfining unit for the Willamette aquifer.

The Willamette Silt unit is not differentiated from the Willamette confining unit in the Tualatin Basin because the Willamette aquifer does not occur to separate the two units, which have similar lithologic characteristics.

This study is the first attempt to describe and map in three dimensions the regional hydrogeologic units in the Willamette Lowland. The delineation of hydrogeologic units in the Willamette Lowland aquifer system and accompanying maps presented in this report provide the geologic framework for the quantitative analysis of regional ground-water flow in the region.

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