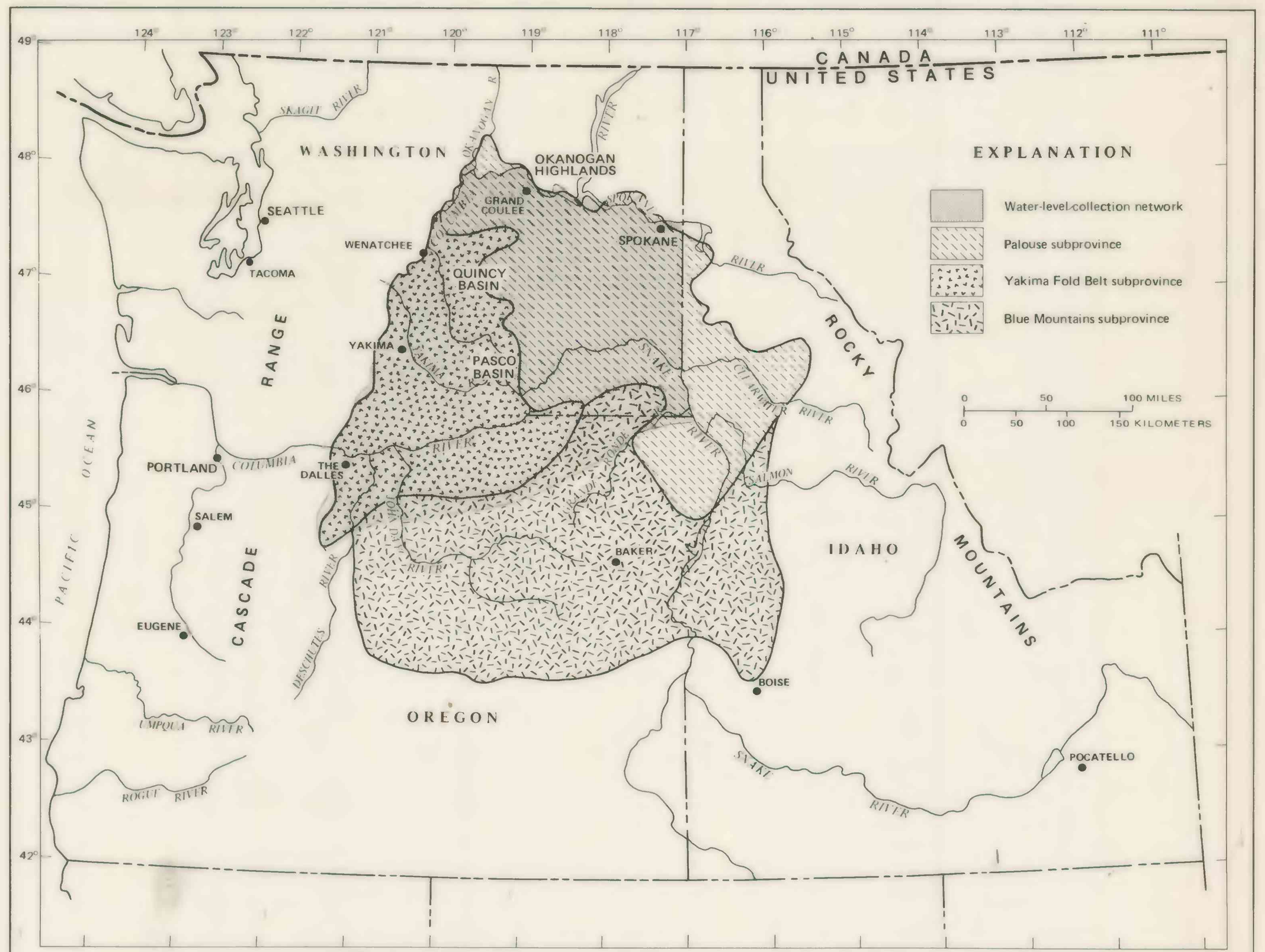

Figure 1. – Location of study area and geologic subprovinces of the Columbia Plateau.

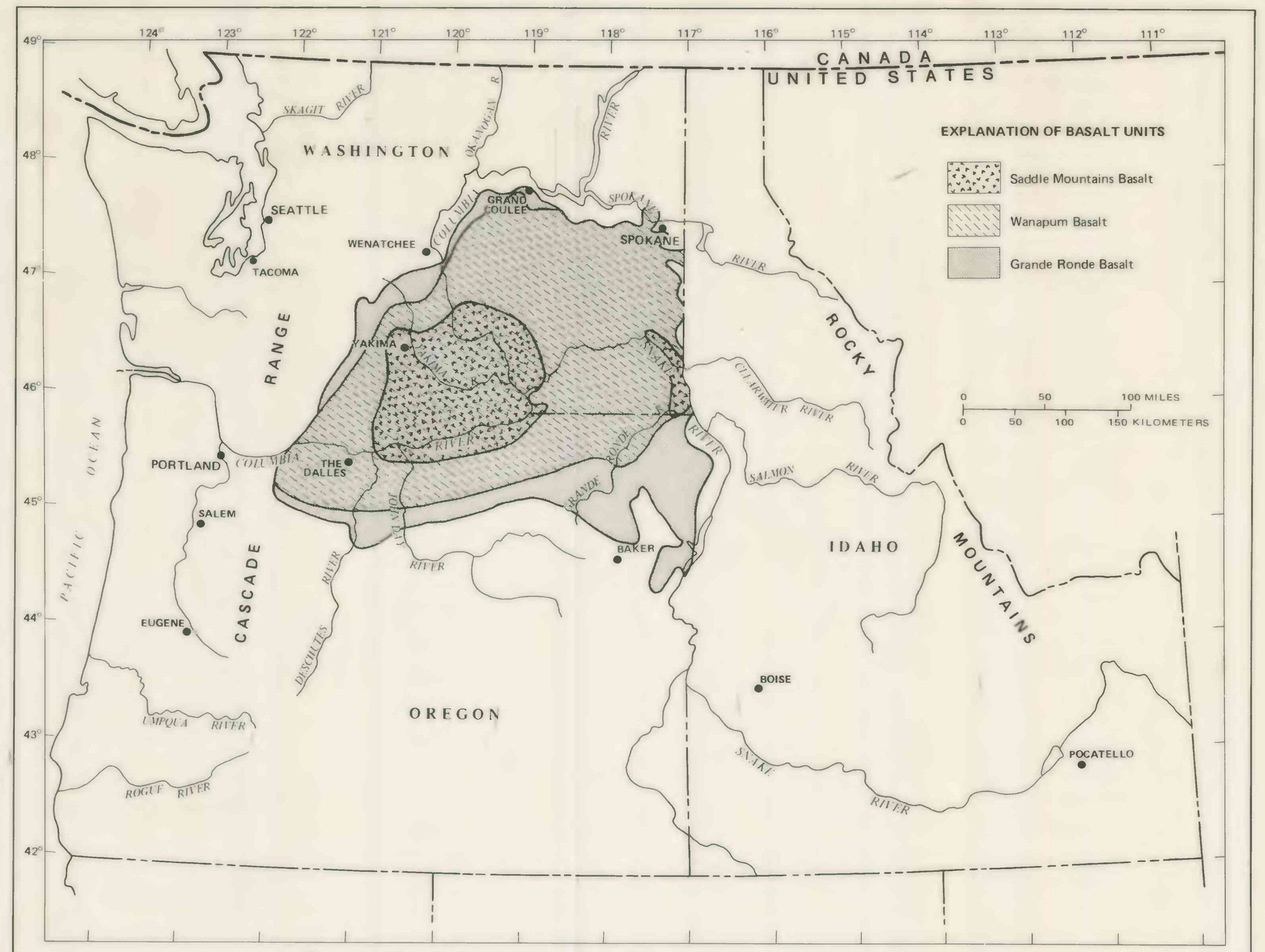

Figure 3. – Generalized extents of occurrence of the three basalt units underlying the project area.

ABSTRACT

Ground-water-level contour maps for three basalt units of the Columbia River Basalt Group were constructed for the Columbia Plateau in Washington and Oregon using water levels measured at about 1,500 wells during spring 1984 and ground-water flow information developed for spring 1983 in the Washington part of the study area. The dominant pattern of ground-water movement in all three units indicates flow from higher elevations toward major surface drainage features. Variations in flow direction from one unit to the next appear to be related to depth of burial below overlying units. Upgradient flexures of water-level contours north of Connell and south of Umatilla show effects of prolonged irrigation pumpage, and downgradient flexures in an area south of Potholes Reservoir in the vicinity of the East Low Irrigation Canal show the effects of increased man-induced recharge.

INTRODUCTION

The Columbia Plateau Regional Aquifer System is one of the regional aquifers chosen for study under the U.S. Geological Survey's RASA (Regional Aquifer-System Analysis) program. The study was begun in the fall of 1982 as a 4-year project to define and analyze the regional hydrology of the Columbia Plateau ground-water system.

This report is one of several that will describe geologic, hydrologic, and geochemical characteristics of the Columbia River basalts. Its purpose is to describe the spring 1984 ground-water-level configuration for the three major basalt units that constitute the basalt aquifer system, and includes a brief overview of the project area and the geology of the Columbia Plateau. The report comprises the following four sheets.

Sheet No.	Title
1	Introduction and text
2	Generalized altitude of ground-water levels in the Saddle Mountains unit, spring 1984, Washington and Oregon.
3	Generalized altitude of ground-water levels in the Wanapum unit, spring 1984, Washington and Oregon.
4	Generalized altitude of ground-water levels in the Grande Ronde unit, spring 1984, Washington and Oregon.

Aquifers in the basalts are the principal source of water for irrigation, stock, domestic, and municipal use in much of the study area. Because the economy of the entire Columbia Plateau depends largely on irrigated agriculture, the water-level configurations presented in this report are of major importance in the understanding of ground-water movement and availability in the basalts. These maps also are essential in the planned development of a ground-water model to simulate flow in the Columbia Plateau ground-water system. Such a computer model is one of the goals of the current RASA program and will establish a regional framework for more detailed local ground-water investigations.

ACKNOWLEDGMENTS

The cooperation of the well owners, tenants, and well drillers who supplied information and allowed access to wells is gratefully acknowledged. Special thanks are extended to the Washington State Department of Ecology, U.S. Bureau of Reclamation, and Rockwell Hanford Operations for collecting and supplying water-level data for this project.

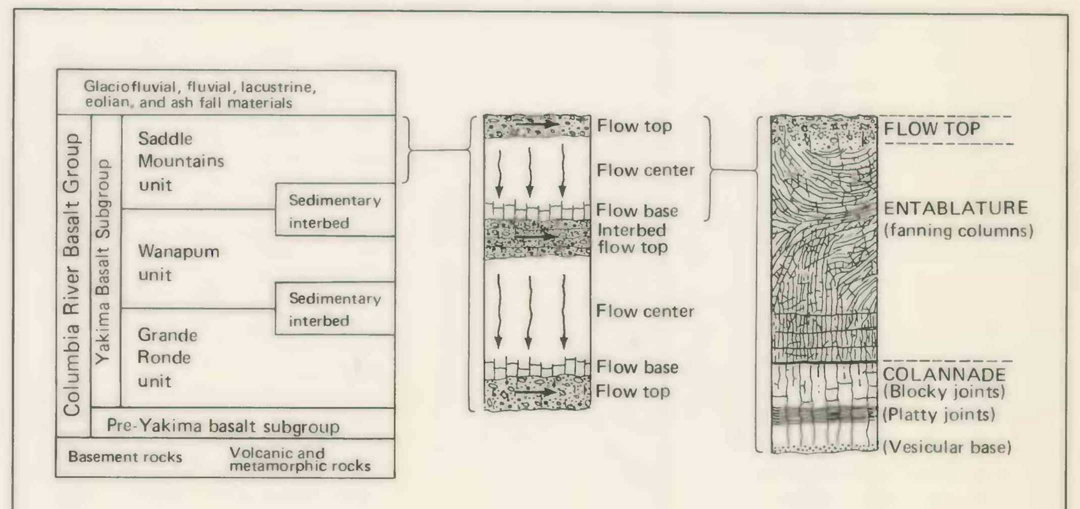

Figure 2.– Generalized lithologic column for the study area with idealized basalt interflow structure and conceptualized ground-water movement (thickness of arrows indicates relative magnitude of flow).

REGIONAL SETTING

The Columbia Plateau occupies an area of approximately 70,000 square miles in parts of Washington, Oregon, and Idaho (fig. 1). The region is drained by the Columbia River and its major tributaries, the Snake, Spokane, Yakima, Deschutes, John Day, and Umatilla Rivers.

The Columbia Plateau is an intermontane area bounded by the Cascade Range on the west, the Okanogan Highlands to the north, the Rocky Mountains to the east, and the Blue Mountains to the south and southeast. In the north, the plateau exhibits geomorphic features which are characteristic of the channeled scablands, such as extensive exposure of Columbia River basalt, deep coulees, and paleochannels. In contrast, the Palouse Hills in the eastern plateau are characterized by a well-dissected, thick layer of windblown silts that overlie the basalt. In north-central Oregon the plateau is a moderately dissected basalt plateau which rises steeply from the north to the south and abuts the Blue Mountains; the Yakima Fold Belt section in the west is characterized by a series of east-west trending anticlinal ridges and intervening synclinal valleys. In the center of the plateau is a major downwarp containing two structural basins, the Quincy basin and Pasco basin. In glacial times, these basins functioned as sinks for outwash sediments carried by floodwaters from the northeast, and consequently the basalts in the central plateau are buried by a thick sequence of glaciofluvial and lacustrine sediments.

The average annual precipitation ranges from less than 10 inches in the central, low-lying part of the Columbia Plateau to over 25 inches on the surrounding mountain slopes. Most of the annual precipitation falls between October and March; the summers are generally quite dry.

GEOLOGIC FRAMEWORK

The following overview of the geology of the Columbia Plateau relies heavily on work done in recent years by other researchers. Swanson and others (1979c) described stratigraphic relationships and nomenclature for the Columbia River Basalt Group; Swanson and others (1979a and 1980), surficial geology and structural features; Swanson and others (1979b) and Myers and Price (1979 and 1981), altitudes of the tops of the Wanapum and Grande Ronde Basalts; and Drost and Whiteman (1986), surficial geology, structure, and thickness of basalt geohydrologic units in the Washington part of the Columbia Plateau.

To avoid confusion in the discussions that follow, the formal geologic names will be used when referring to the geologic unit and the term "unit" will be added when referring to the hydrogeologic unit. For example, the term Saddle Mountains Basalt refers to only the basalt flows in the Saddle Mountains Basalt, whereas the term Saddle Mountains unit is used in a hydrogeologic sense to refer to the Saddle Mountains Basalt as well as to the enclosed sedimentary interbeds. The water-level information presented on sheets 2-4 represents both the basalt flows and the interbeds for each basalt unit.

The part of the Columbia Plateau underlain by the Columbia River basalts is both a structural and topographic basin with its lowest point near Pasco, Washington. The rocks of the plateau are primarily Miocene basalts with minor amounts of interbedded sediments of Miocene age and overlying sediments of Pliocene to Holocene age. The basalt was extruded from a system of northwest-trending linear vents in southeast Washington and northeast Oregon over a period of about 16.5 to 6.0×10^6 years before present (B.P.). Most of the flows extruded over a short period centered around 15×10^6 years B.P.; and less frequent eruptions from 14 to 6.0×10^6 years B.P. allowed time for erosion and deformation between subsequent eruptions. Subsidence occurred concurrently with volcanism, producing lava flows that thin progressively outward from the basin axis. Along the borders of the plateau, the basalts are underlain by "basement" rocks, mostly volcanic and metamorphic rocks of Precambrian to early Tertiary age. In the interior of the plateau the nature of the rocks underlying the basalts is not known.

Two distinctive features of the basalts are layering and jointing. Layering resulted from the accumulation of successive flows of highly fluid lava. These flows generally occur as distinct stratigraphic units, separated from the flows above and below by a difference in jointing, texture, color, interbedded sedimentary materials, or other horizontal characteristics that alter the vertical continuity of these massive basalt flows. The jointing is a result of lava cooling processes, and the degree and configuration differs from flow to flow. Usually, joints are most abundant at the top of a flow and decrease in number toward the flow center. The thicker flows exhibit a characteristic jointing that forms well-developed prismatic columns at right angles to the upper and lower surfaces of the flow layers.

Individual basalt flows range in thickness from a few inches to as much as about 300 feet. The structure of an individual flow, from bottom to top, generally consists of three sections: the colonnade, the entablature, and the flow top (fig. 2). The basal colonnade, commonly 20 percent of the flow thickness, consists of nearly vertical three- to eight-sided columns formed by vertical jointing during the slow cooling and contraction of the flow interior. The individual columns average about 3 feet in diameter and 25 feet in length, and are commonly crosscut by horizontal joints. Porous pillow structures, caused by underwater cooling, are often present at the base of the colonnade, and a vesicular zone may be present above the pillows. The entablature, generally 70 percent of the flow thickness, consists of small-diameter (averaging less than a foot) columns in fan-shaped arrangements. The presence of irregular cross-jointing produces a hackly or friable structure. In places the upper part of the entablature is vesicular. The flow top, sometimes called the interflow, generally consists of vesicular basalt and clinker, and averages about 10 percent of the total thickness of a single flow. The most permeable water-bearing zone is generally the flow top, while the central part, particularly the entablature, is generally less permeable. The layered and jointed structure, extent, and permeability distribution induce primarily lateral ground-water movement in the flow top and vertical movement through the fractures of the colonnade and entablature.

The Columbia River Basalt Group is composed primarily of the Grande Ronde, Wanapum, and Saddle Mountains Basalts. Figure 3 shows the generalized occurrence and extent of these three basalts. The Grande Ronde Basalt underlies virtually all of the study area and is exposed along the plateau margins and in the canyons of the Columbia and Snake Rivers. Its thickness ranges from a few feet along the northern margin, where it pinches out against the older rock, to 4,000 feet and perhaps as much as 9,000 feet in the central and southwest parts of the study area. The Grande Ronde Basalt is composed of at least 30 and perhaps as many as several hundred individual flows. Sedimentary interbeds are rare in the Grande Ronde Basalt and are generally only a few feet thick. These interbeds, as is common with virtually all the interbeds in the Columbia River basalts, range in composition from clay to sand and gravel. A sedimentary interbed is present between the Grande Ronde Basalt and the overlying Wanapum Basalt in much of the study area. It averages 25 feet in thickness and ranges from nearly 0 to 100 feet or more.

The Wanapum Basalt is present in most of the study area and is either exposed or is covered by a veneer of sedimentary or colluvial material throughout most of the northern half of the study area. In the southern half, it is generally covered by thick sequences of sediments and (or) by the Saddle Mountains Basalt. The Wanapum Basalt averages 600 feet in thickness, ranging from a few feet, where it pinches out against exposures of the Grande Ronde Basalt, to more than 1,600 feet in the southwest part of the study area. The Wanapum Basalt contains as many as 10 flows. Sedimentary interbeds are more common in the Wanapum Basalt than in the Grande Ronde Basalt, but are still relatively rare and only a few feet thick. A sedimentary interbed ranging in thickness from 0 to more than 150 feet and averaging 50 feet occurs between the Wanapum Basalt and the overlying Saddle Mountains Basalt in the southwest part of the study area.

The Saddle Mountains Basalt occurs only in the southwest part of the study area, where it is either exposed at the land-surface or is covered by sediments. This basalt unit averages 600 feet in thickness in the south-central part of the study area, with maximum thicknesses of over 800 feet near Pasco, Washington. Sedimentary interbeds are common and relatively thick in the Saddle Mountains Basalt (usually 50 feet or more). One such interbed, located in the western part of Oregon, is important stratigraphically and hydrologically due to its large areal extent and to thicknesses in excess of 200 feet.

Myers and Price (1979) have subdivided the Columbia Plateau into three geologic subprovinces: the Yakima Fold Belt subprovince, the Palouse subprovince, and the Blue Mountains subprovince (fig. 1). The Yakima Fold Belt subprovince is characterized by long, narrow, tightly folded anticlines and broad intervening synclines trending in an easterly to southeasterly direction from the western margin of the plateau to its center. The folds are generally asymmetric, with the steeper limb to the north. Most of the major faults associated with anticlinal fold axes are thrust or reverse faults and are probably contemporaneous with the folding. Northwest- to northeast-trending shear zones and minor folds commonly transect the major folds. The Palouse subprovince is characterized by a regional southwest dip of less than 5 degrees and by a small number of broader, gentler folds of northeast and northwest orientation. The Blue Mountain subprovince is a broad, east- to northeast-trending anticline which extends from central Oregon into southeastern Washington. The anticline is cut by a series of north- to northwest-trending faults that are nearly vertical. Beneath the basalts, the core of the anticline is composed of folded, faulted, and metamorphosed rocks of late Paleozoic and Mesozoic age.

Land-surface features tend to reflect the underlying geologic structure in the project area. The mountains are generally anticlines and the valleys synclines, and in the Palouse subprovince north of the Snake River the land surface parallels the gradual southwesterly dip slope of the basalts toward the south center of the project area.

METHOD OF ANALYSIS

The basalts, sedimentary interbeds, and overburden compose the regional aquifer system of the Columbia Plateau. This system has been conceptualized as consisting of four major aquifers, corresponding to the three basalt units and the sedimentary overburden materials. In general, changes of hydraulic head occur with depth for any given location. The water-level contours drawn for a basalt unit represent the vertically averaged areal hydraulic head distribution for that unit insofar as the data permit. The overburden is in direct hydraulic connection with the immediately underlying basalts and, where thick enough, comprises a water-table aquifer. The ground-water-level configuration for the overburden has not been included in this report, but is described in a report by Bauer, Vaccaro, and Lane (1985). The ground-water level surfaces for the three basalt units are shown on sheets 2 through 4.

Ground-water level contours for each unit were based on water-level data obtained from 1,500 wells in spring 1984 when water levels were at their seasonal high prior to summer pumping. Water-level configurations drawn for spring 1983 in the Washington part of the Columbia Plateau (Bauer, Vaccaro, and Lane, 1985) provided a useful framework for analysis of the 1984 water-level data. Information was also obtained from other U.S. Geological Survey studies in the area (F. Packard, Horse Heaven Hills area; J. Gonthier and A. Davies-Smith, Umatilla Basin).

The contours drawn for this study are highly generalized because of the large-scale, regional nature of this RASA project. In many areas where 1984 data were sparse or lacking, water-level configurations shown have been inferred. Water-level data were interpreted according to whether a well was partially penetrating, fully penetrating, or penetrating more than one basalt unit.

GROUND-WATER-LEVEL CONFIGURATION

Ground water in basalt aquifers occurs in joints, vesicles, fractures, and other localized features that create permeable zones. The highest permeabilities occur in flow tops, and relatively high permeabilities are found where the colonnades have vesicular bases. The entablature and much of the colonnade have lower permeabilities because they are more dense and coherent. Permeability can be increased by the presence of associated joints and fractures where basalt flows are folded or faulted. Interbeds serve as aquifers in those areas where their lithologies facilitate the storage and transmission of water.

The ground-water surface in the Saddle Mountains unit appears to roughly parallel land surface where there is little or no overburden. This is particularly noticeable at the higher elevations, where there is more precipitation and probably more recharge. Typically, water levels in shallow wells in these areas are only a few tens of feet below land surface. The lateral ground-water flow in this basalt unit is generally toward major surface-drainage features, but numerous small and intermediate-sized streams also abstract base flow from the unit. This occurs in the Wanapum and Grande Ronde units also, where they are not overlain by the younger basalts or by a great thickness of overburden. Otherwise, flow in the Wanapum and Grande Ronde units is controlled less by local surface-drainage patterns and more by the major rivers, streams, and coulees. In the Palouse subprovince north of the Snake River the regional ground-water flow in both the Wanapum and Grande Ronde units roughly parallels the southwest regional dip slope of the basalts. Regional discharge is to the Columbia and Snake Rivers. The dominant pattern in the Yakima Fold Belt is ground-water movement downward from the anticline axes toward the streams and rivers lying in the intervening synclines.

The relation between surface-water bodies and the ground-water flow system is shown on sheet 3. Downgradient flexures of the water-level contours near lakes and streams indicate recharge to the aquifer; upgradient flexures indicate ground-water discharge to lakes and streams. Both phenomena are found in the north-central and northeast parts of the study area, which contains numerous lakes. The streams and lakes in the northeast part of the study area appear, for the most part, to be draining ground water to the Wanapum unit. Water-level contours near Crab Creek valley, the Palouse Canyon, the Columbia Gorge, the Snake River valley, and Grand Coulee indicate major ground-water drains.

Water levels in the deeply buried parts of the Wanapum and Grande Ronde units show significant differences from those in overlying units, even though there are much less data to establish water-level contours. Where data do exist, as in the south-central part of the plateau, water-level contours appear to be less influenced by the surface-drainage features and consequently have a smoother form. The smoothing is due, in part, to the fact that recharge to and discharge from the deeply buried basalts occurs more through vertical leakage over broad areas to and from the overlying basalts than by direct physical contact with surface-water bodies or drainage features. An example of this can be seen in the Quincy Basin (located in the northern part of the Yakima Fold Belt subprovince) on sheets 3 and 4. There, ground-water movement in the Wanapum unit, which is at or near land surface, is toward Moses Lake and Potholes Reservoir. Ground-water movement in the underlying Grande Ronde unit, however, is generally unaffected by these land-surface features, and flow is to the south toward the Columbia River.

In most of the study area, water-table conditions exist in the uppermost basalt flows, but owing to the wide difference between the horizontal and vertical hydraulic conductivities, the deeper basalt aquifers are generally semiconfined. Fine-grained, tight interbeds and flow-center rock units compose the semiconfining beds of the underlying flows. The hydraulic connection between flows is sufficient to allow some continuous vertical movement of water between them. From the water-level data, it appears that, over most of the plateau, the vertical component of flow is downward except near discharge areas. The few exceptions to this pattern are probably due to unknown geologic structures and heavy pumpage in some areas. Newcomb (1961) cites lateral flow impediments resulting in upward flow caused by faulting in the basalts near Walla Walla and in the Cold Creek syncline east of Yakima in Washington and southwest of The Dalles in Oregon. More recent work by the Geological Survey (Frank A. Packard, written commun., 1984) investigated an area of the Horse Heaven Hills in Washington, where the wells tapping the Wanapum unit are artesian, but where, approximately 2 miles downgradient to the southeast, the water levels are about 340 feet lower. The vertical head gradient is upward northwest of the impediment and downward southeast of the impediment.

Steep water-level gradients are depicted on the flanks of the Blue Mountains, Horse Heaven Hills, Frenchman Hills, Rattlesnake Hills, and Saddle Mountains anticlines. Water-level data from locations on the flanks of anticlines and from other areas where the basalts are steeply dipping show lateral water-level gradients to be approximately equal to or slightly less than the structural gradients. This phenomenon was assumed to hold in similar areas where data were not available, and water-level contours were drawn accordingly.

In recent years, ground-water pumping for irrigation has altered the regional flow pattern. The effects of pumping on ground-water-level contours can be seen in the area of Connell, north toward the Odessa-Lind area (sheet 3). This area shows a large upgradient bending or flexure of the contours, typical of lowered water levels. A similar upgradient contour flexure attributed to pumping is evident in the Umatilla River basin in Oregon.

The effects of man-induced recharge on the water-level configuration are shown by the downgradient contour flexure just below Potholes Reservoir, between the 1,100- and 800-foot contours. The large East Low Irrigation Canal, which is part of the Columbia Basin Irrigation Project, runs along the downgradient flexures.

In summary, the dominant pattern of ground-water movement in all three basalt units indicates flow from higher elevations toward surface-drainage features. Variations in flow direction from one unit to the next are generally related to depth of burial below overlying units. Depth of burial affects the occurrence, extent, and composition of interbeds; the degree of confinement of the ground water; overall permeability; and amounts of recharge to each unit. Ground-water flow patterns described in this report also indicate the impact of man-induced recharge and prolonged irrigation pumpage.

CONVERSION FACTORS

Multiply inch-pound units	By	To obtain metric (SI) units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

degree Fahrenheit (°F) to degree Celsius (°C): °C = 5/9 (°F -32)

SELECTED REFERENCES

Bauer, H. H., Vaccaro, J. J., and Lane, R. C., 1985, Ground-water levels in the Columbia River Basalt Group and the overlying materials, spring 1983, southeastern Washington State: U.S. Geological Survey Water-Resources Investigations Report 84-4360, 4 sheets.

Drost, B. W., and Whiteman, K. J., 1985, Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4326, 10 sheets.

Myers, C. W., and Price, S. M., 1979, Geologic studies of the Columbia Plateau, a status report: Rockwell International, Rockwell Hanford Operations, RHO-BWI-ST-4.

----1981, Subsurface geology of the Cold Creek syncline: Rockwell International, Rockwell Hanford Operations, RHO-BWI-ST-14.

Newcomb, R. C., 1961, Storage of ground water behind subsurface dams in the Columbia River Basalt, Washington, Oregon, and Idaho: U.S. Geological Survey Professional Paper 383-A, 15 p.

Swanson, D. A., Anderson, J. L., Bentley, R. D., Byerly, G. R., Camp, B. E., Gardner, J. N., and Wright, T. L., 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1363, 26 p., scale 1:250,000, 12 sheets.

Swanson, D. A., Brown, J. C., Anderson, J. L., Bentley, R. D., Byerly, G. R., Gardner, J. N., and Wright, T. L., 1979b, Preliminary structure contour maps on the top of the Grande Ronde and Wanapum Basalts, eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1364, scale 1:500,000, 2 sheets.

Swanson, D. A., Wright, T. L., Hooper, P. R., and Bentley, R. D., 1979c, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Swanson, D. A., Wright, T. L., Camp, V. E., Gardner, J. N., Helz, R. T., Price, S. M., Reidel, S. P., and Ross, M. E., 1980, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1139, scale 1:250,000, 2 sheets.

GROUND-WATER LEVELS IN THREE BASALT HYDROLOGIC UNITS UNDERLYING THE COLUMBIA PLATEAU WASHINGTON AND OREGON SPRING 1984

By
K. J. Whiteman
1986