Kahle, S.C., Olsen, T.D., and Morgan, D.S., 2009, Geologic setting and hydrogeologic units of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho

Introduction

The Columbia Plateau Regional Aquifer System (CPRAS) covers approximately 44,000 square miles of northeastern Oregon, southeastern Washington, and western Idaho (fig. 1). The area supports a $6 billion per year agricultural industry, leading the Nation in production of apples and nine other commodities (State of Washington Office of Financial Management, 2007; U.S. Department of Agriculture, 2007). Groundwater availability in the aquifers of the area is a critical water-resource management issue because the water demand for agriculture, economic development, and ecological needs is high.

The primary aquifers of the CPRAS are basalts of the Columbia River Basalt Group (CRBG) and overlying basin-fill sediments. Water-resources issues that have implications for future groundwater availability in the region include (1) widespread water-level declines associated with development of groundwater resources program for irrigation and other uses, (2) reduction in base flow to rivers and associated effects on temperature and water quality, and (3) current and anticipated effects of global climate change on recharge, base flow, and ultimately, groundwater availability.

The U.S. Geological Survey Groundwater Resources program began a study of the CPRAS in 2007 with the broad goals of (1) characterizing the hydrologic status of the system, (2) identifying trends in groundwater storage and use, and (3) quantifying groundwater availability.

The study approach includes documenting changes in the status of the system, quantifying the hydrologic budget for the system, updating the regional hydrogeologic framework, and developing a groundwater-flow simulation model for the system. The simulation model will be used to evaluate and test the conceptual model of the system and later to evaluate groundwater availability under alternative development and climate scenarios.

The objectives of this study were to update the hydrogeologic framework for the CPRAS using the available geologic mapping and well information and to develop a digital, three-dimensional hydrogeologic model that could be used as the basis of a groundwater-flow model. This report describes the principal geologic and hydrogeologic units of the CPRAS and geologic map and well data that were compiled as part of the study. The report also describes simplified regional hydrogeologic sections and unit extent maps that were used to conceptualize the framework prior to development of the digital 3-dimensional framework model.

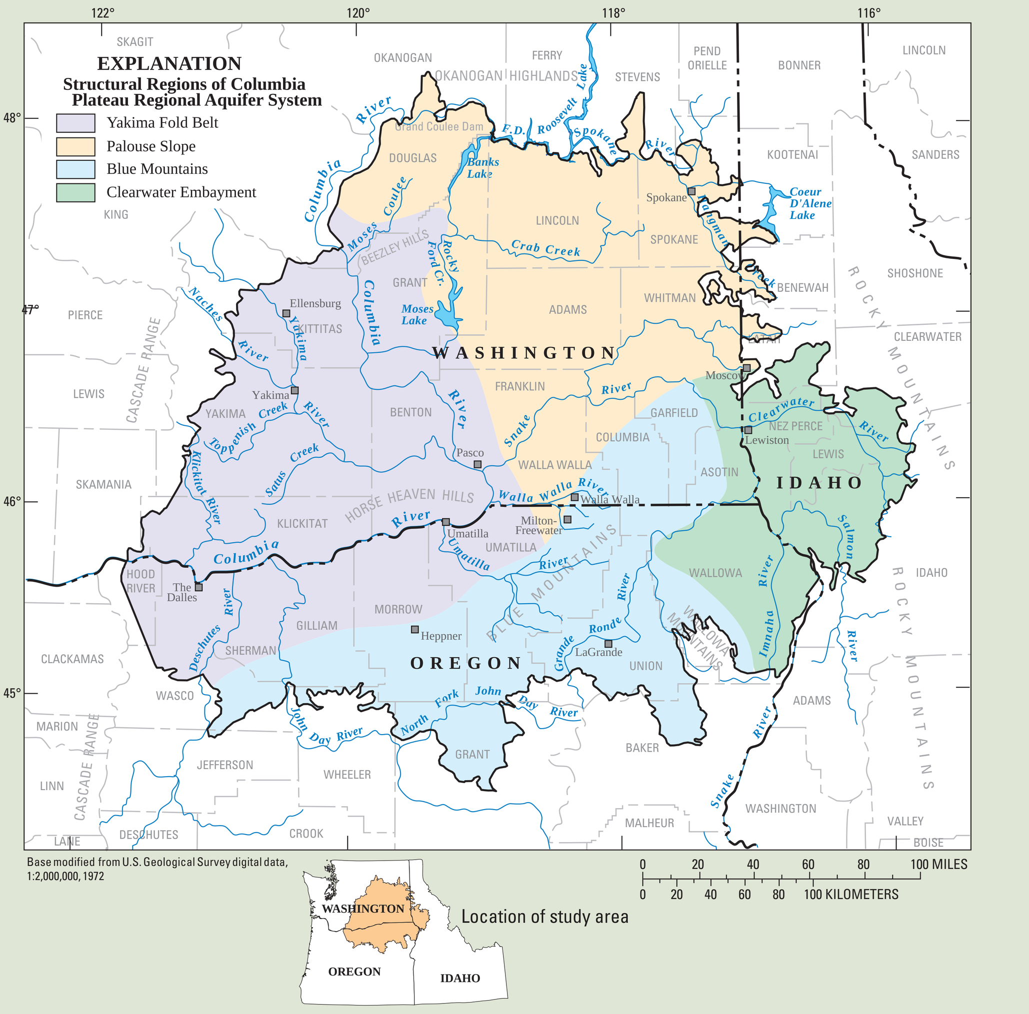

Figure 1. Columbia Plateau Regional Aquifer System study area and structural regions (modified from Reidel and others, 2002), Washington, Oregon, and Idaho.

Methods of Investigation

A surficial geologic map of the Columbia Plateau (fig. 2) was compiled and simplified from digital geologic map databases for Idaho (Zientek and others, 2005), Oregon (Jenks and others, 2006), and Washington (Washington Division of Geology and Earth Resources, 2005). Simplified geologic units are described in table 1, and their distribution is shown in figure 2. Due to incomplete digital coverage in a small part of the study area, the Oregon part of The Dalles 1° × 2° Quadrangle (Bela, 1982) was simplified and then digitized to complete the geologic map. Geologic units across State boundaries were reconciled to the extent possible and were straightforward, with the exception of a veneer of Quaternary sediment along part of the Washington-Idaho boundary, where the digital coverage for Washington indicated a separate unit above the CRBG or pre-CRBG rocks, whereas the Idaho digital coverage did not (fig. 2). Major geologic structures (faults and folds) shown on figure 2 were compiled from two sources: Washington Division of Geology and Earth Resources (2005) for Washington; and Ludington and others (2007) for Oregon and Idaho.

A dataset of 2,523 wells was compiled for this investigation to provide regional coverage of the study area; only wells with data already in the USGS National Water Information System (NWIS) database were used. An initial set of 2,463 wells located in Washington and Oregon—originally used for the Columbia Plateau Regional Aquifer-System Analysis (RASA) (Lane, 1988)—was updated to include deepenings, and in some cases, more refined locations. Drillers' logs for wells that were deepened from 1985 to present (2008) were retrieved from the Washington on-line well-log database for the Washington part of the study area (http://apps.ecy.wa.gov/welllog/; accessed March 10–28, 2008). Using location, well depth, and owners' names, 59 of the Washington RASA wells were matched to deepening logs. Only one well from the original RASA dataset in Oregon could be correlated to a reported deepening (T. Jacklin, U.S. Geological Survey, written commun., June 16, 2008). The new depths and stratigraphic data for these wells and any other construction changes were entered into the USGS NWIS database.

The updated well dataset was augmented with 43 wells located in Oregon and Washington that are included in the U.S. Geological Survey Columbia River Basalt Stratigraphy in the Pacific Northwest website (Conlon, 2006). Wells located in Idaho were added to the project well dataset to provide coverage in the eastern extent of the study area that was not included in the RASA study. The dataset for Idaho includes 17 wells that meet the following conditions: wells were in the Idaho NWIS as of March 20, 2008; well depths are greater than 300 feet; wells are located in Latah, Lewis, or Nez Perce Counties, Idaho; and drillers' logs of the wells are readily available in the Idaho Department of Water Resources on-line well-log database (http://www.idwr.idaho.gov/apps/appswell/searchWC.asp; accessed April 21, 2008).

Unit information for the project wells was simplified from more detailed hydrogeologic units in Lane (1988) and stratigraphic units in Conlon (2006) using hydrogeologic unit designations in Drost and others (1990) and Jones and Vaccaro (2008). These data were used in the construction of the surficial hydrogeologic unit extent map (fig. 3) and the generalized hydrogeologic sections (fig. 4).

In order to illustrate the distribution of the hydrogeologic units at or near land surface, approximate extents of the basalt hydrogeologic units were drawn based on information from (1) the simplified geologic map (fig. 2), (2) the project well data (locations shown in fig. 3), and (3) previously constructed hydrogeologic unit contours for the Columbia Plateau Aquifer System (Drost and others, 1990; J.J. Vaccaro, U.S. Geological Survey, oral commun., May 12, 2008).

Although much of the study area is covered by relatively thin and discontinuous Quaternary sediment (fig. 2), the extent of the Overburden hydrogeologic unit (fig. 3) was drawn to include generally large areas where unit thicknesses, based on the project well data, were greater than 100 feet. These areas include much of the western and central parts of the Columbia Plateau and generally small areas near the Washington-Idaho State line and southeast of the Blue Mountains (fig. 3).

In order to illustrate the distribution of the hydrogeologic units below land surface, regional hydrogeologic sections were constructed. Hydrogeologic units primarily were correlated based on stratigraphic position and mapped extents of the hydrogeologic units. Where data were sparse or unavailable, stratigraphic contacts between hydrogeologic units were inferred. The base of the CPRAS was inferred based on limited deep drilling information in the project well dataset and a thickness map of the CRBG (Reidel and others, 2002). Six hydrogeologic units are shown on the generalized sections: Overburden, and the Saddle Mountain, Wanapum, and Grande Ronde basalt units and the Mabton and Vantage interbed units (fig. 4).

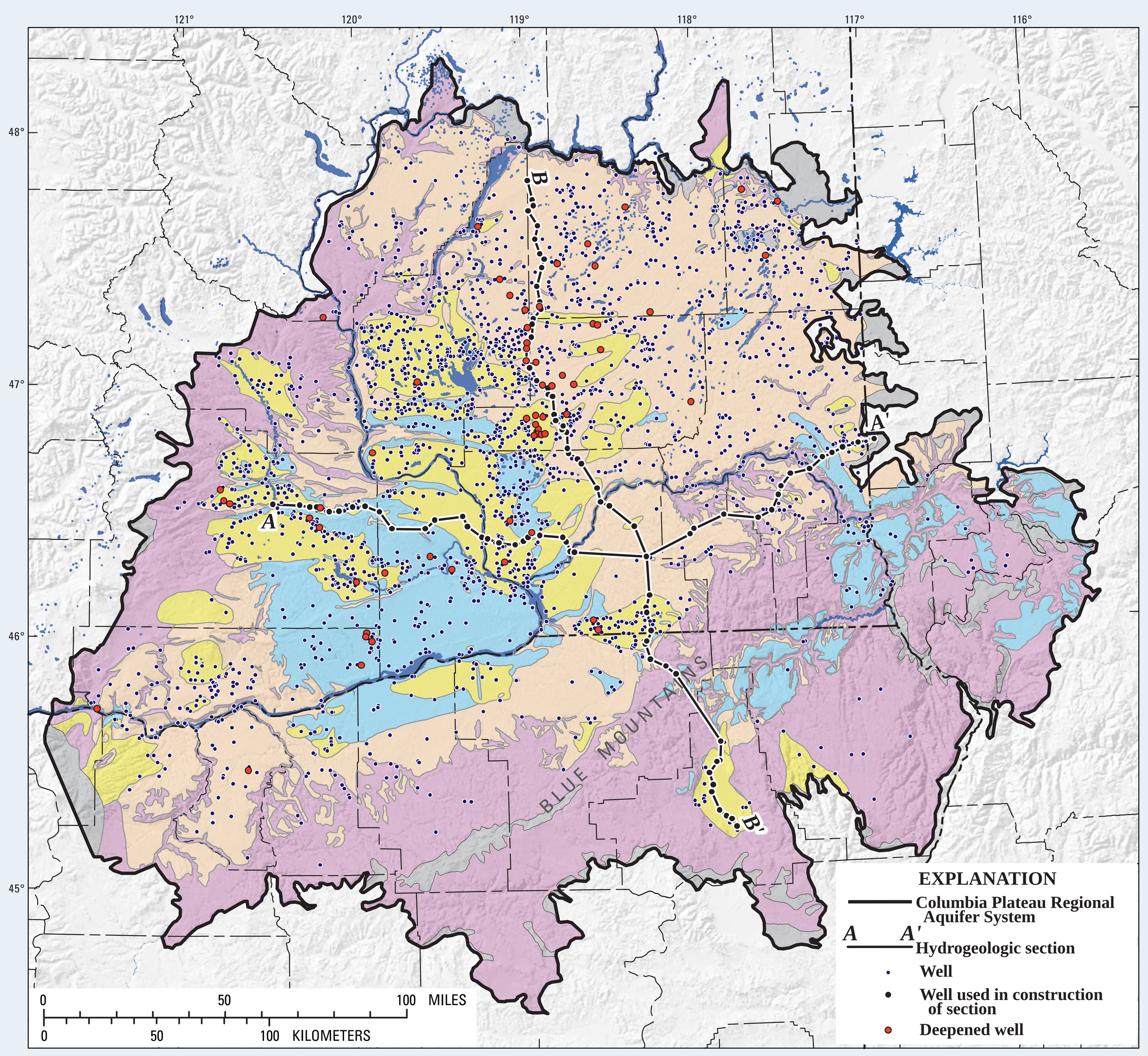

Figure 3. Locations of wells, surficial distribution of generalized hydrogeologic units, and locations of hydrogeologic sections. Explanation of surficial hydrogeologic unit is shown in table 2.

Table 2. Correlation chart showing relation between generalized stratigraphy and hydrogeologic units of the Columbia Plateau Regional Aquifer System, Idaho, Oregon, and Washington.

<table>
<tr><th>Hydrogeologic Unit</th><th>ERA</th><th>PERIOD</th><th>EPOCH</th><th>General Sediment Stratigraphy</th><th colspan="3">General Basalt Stratigraphy</th></tr>
<tr><td rowspan="3">Overburden</td><td rowspan="10">Cenozoic</td><td rowspan="2">Quaternary</td><td>Holocene</td><td rowspan="2">Alluvial, colluvial, eolian, glacial, glacial outburst flood, lacustrine, landslide, terrace, and peat deposits; ash, debris-avalanche and debris-flow deposits, talus; Touchet Beds, Palouse Formation</td><td colspan="3" rowspan="3">Quaternary and Pliocene Basalts</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td rowspan="8">Tertiary</td><td>Pliocene</td><td>Alluvial fan deposits; Alkali Canyon, Chenoweth, Deschutes, Madras and Ringold Formations; Dalles Group; Thorpe Gravel; and unknown continental sedimentary deposits</td></tr>
<tr><td>Saddle Mountains</td><td rowspan="7">Miocene</td><td rowspan="7">Ellensburg, Deschutes, Latah, Madras, Payette, and Ringold Formations; Dalles Group; Snipes Mountain deposits; Deer Creek Beds; and unknown continental sedimentary deposits</td><td rowspan="7">Columbia River Basalt Group</td><td colspan="2">Saddle Mountains Basalt flow members and interbeds</td></tr>
<tr><td>Mabton Interbed</td><td colspan="2">Mabton interbed (Mabton Member of the Ellensburg Formation)</td></tr>
<tr><td>Wanapum</td><td colspan="2">Wanapum Basalt flow members and interbeds</td></tr>
<tr><td>Vantage Interbed</td><td colspan="2">Vantage interbed (Vantage Member of the Ellensburg Formation)</td></tr>
<tr><td rowspan="3">Grande Ronde</td><td>Prineville Basalt</td><td rowspan="2">Grande Ronde Basalt flow members and interbeds</td></tr>
<tr><td>Picture Gorge Basalt</td></tr>
<tr><td colspan="2">Imnaha Basalt</td></tr>
<tr><td>Older Bedrock</td><td colspan="7">pre-Columbia River Basalt Group rocks, undivided</td></tr>
</table>

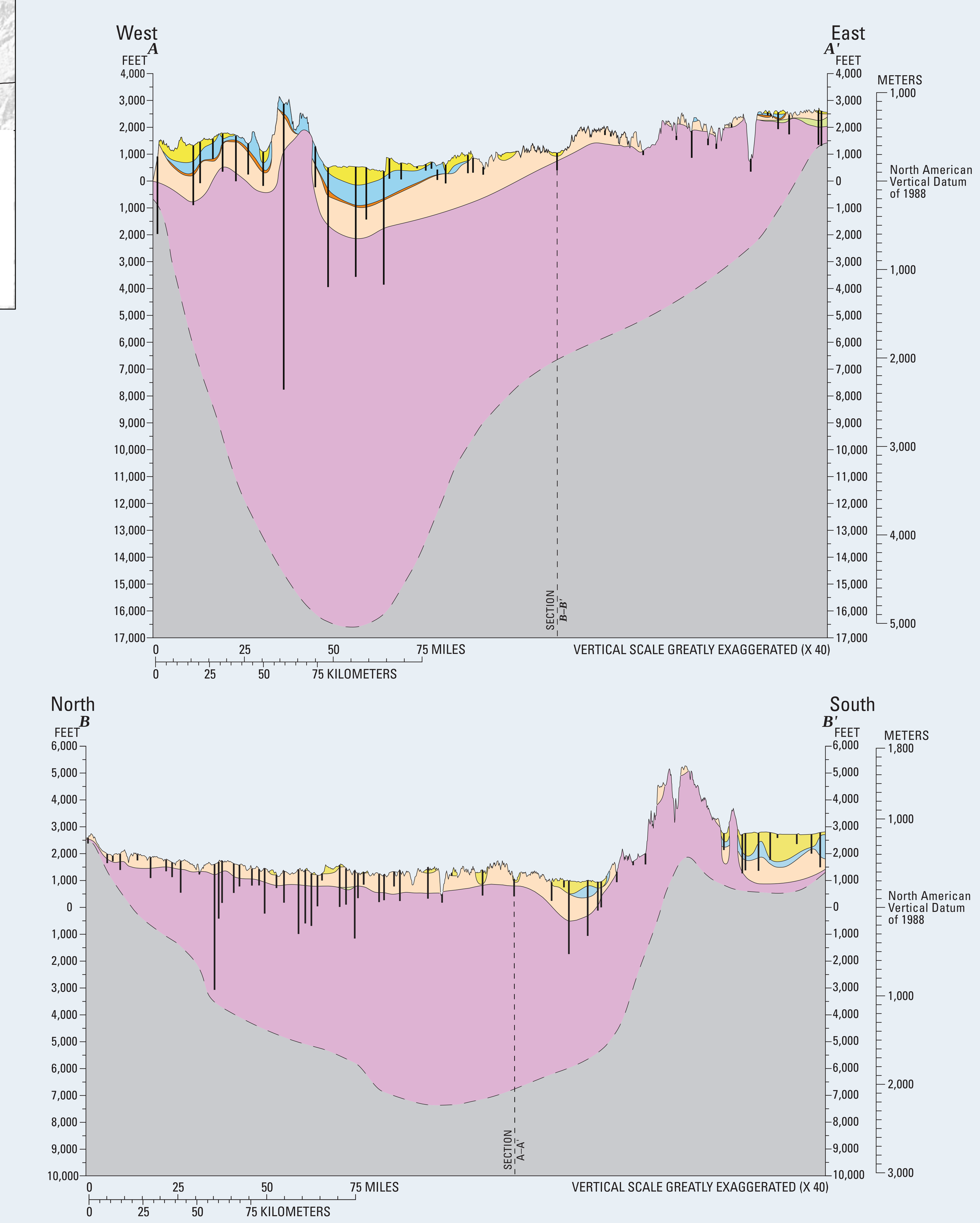

Figure 4. Generalized hydrogeologic sections. Explanation of hydrogeologic units is shown in table 2.

Geologic Setting

The Columbia Plateau is an intermontane basin between the Rocky Mountains and the Cascade Range filled mostly with Cenozoic basalt and sediment. The CRBG consists of a series of flows that erupted during various stages of the Miocene Age, 17 million to 6 million years ago. The basalt lava flowed from fissures and vents in eastern Washington, northeastern Oregon, and western Idaho. The number, extent, and thickness of flows vary depending on many factors, including proximity to and volume of eruption, lava viscosity, cooling process, erosion, and topography over which the lava flowed (Swanson and others, 1979; Conlon, 2006). More than 300 flows have been identified and individual flows range in thickness from 10 to more than 300 feet (Tolan and others, 1989; Drost and others, 1990). Total thickness of the series of flows may be greater than 15,000 feet near Pasco, Washington (Reidel and others, 2002). Typically, lava erupted quickly and advanced away from the fissure or vent as a single, uniform sheet of lava. When the hiatus between flows was sufficiently long, soil developed or sediments were deposited on the surface of a flow. If these sediments were preserved, a sedimentary interbed occurs between flows.

The CPRAS occurs in an area of several structural regions: The Yakima Fold Belt and the Palouse Slope occupy the Columbia River basin (fig. 1). The Yakima Fold Belt includes the western and central parts of the Columbia River basin and consists of a series of anticlinal ridges and synclinal valleys (Reidel and others, 2002). The Palouse Slope, in the eastern part of the basin, is much less deformed and has a gently westward dipping slope. The Blue Mountains, a composite anticlinal structure, forms the southeastern extent of the Columbia River basin. The Clearwater Embayment marks the eastward extent of the CPRAS along the foothills of the Rocky Mountains (fig. 1).

Stratigraphy

The simplified stratigraphy that comprises the CPRAS is summarized in table 1. The majority of rocks exposed in the region are the CRBG, intercalated sedimentary rocks of the Ellensburg Formation, younger sedimentary rocks and deposits, Pleistocene cataclysmic flood deposits, eolian deposits, terrace gravels of modern rivers, and other localized deposits.

Sediment Stratigraphy

Within the Yakima Fold Belt, Miocene sedimentary deposits of the Ellensburg Formation underlie, intercalate, and overlie the CRBG and compose most of the thickness of the unconsolidated deposits in the basinal areas (Jones and others, 2006). These continental sedimentary deposits include fluvial sands and gravels, overbank deposits, lacustrine deposits, alluvial-fan deposits, sandstone, conglomerate, and interbedded volcaniclastic sediments. In eastern Washington and west-central Idaho, sediment of the Latah Formation underlies, intercalates, and overlies the CRBG (Leek, 2006). The Latah Formation consists mostly of clay, silt, and sand deposited in drainages blocked by encroaching basalt flows. Pleistocene to Holocene sediments overlying the CRBG include flood gravels and slackwater sediments, terrace gravels of modern rivers, and eolian deposits including the Palouse Formation.

Basalt Stratigraphy

The thickest, most extensive, and hydrologically most important geologic unit in the CPRAS is the CRBG (Whiteman and others, 1994). The CRBG has been divided into six geologic formations (table 1): Imnaha Basalt, Picture Gorge Basalt, Prineville Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt by Swanson and others (1979). These formations are divided into members and further subdivided into flow units based on field mapping, well logs, aeromagnetic surveys, geochemistry, and magnetic polarity (Conlon, 2006).

Flows belonging to the Imnaha Basalt, the oldest known in the CRBG, are found in western Idaho, eastern Washington, and Oregon (fig. 2). The Picture Gorge and Prineville Basalt Formations are limited to areas in central Oregon defining the southern extent of CRBG (fig. 2). The Imnaha Basalt and Grande Ronde Basalt (including Prineville and Picture Gorge) constitute 90 percent of the volume of the CRBG (Bjornstad and others, 2007). The remaining 10 percent includes the Wanapum and Saddle Mountains Basalts. Flows of the Wanapum Basalt commonly overlie the Grande Ronde Basalt in most areas. Flows of the Saddle Mountains Basalt are less widely distributed (fig. 2). During the Pleistocene, the surface expression of the basalt units was modified greatly during repeated catastrophic outburst flooding, which caused erosion of vast channels and ancient waterfalls in places, as well as removal and or deposition of overlying sediment.

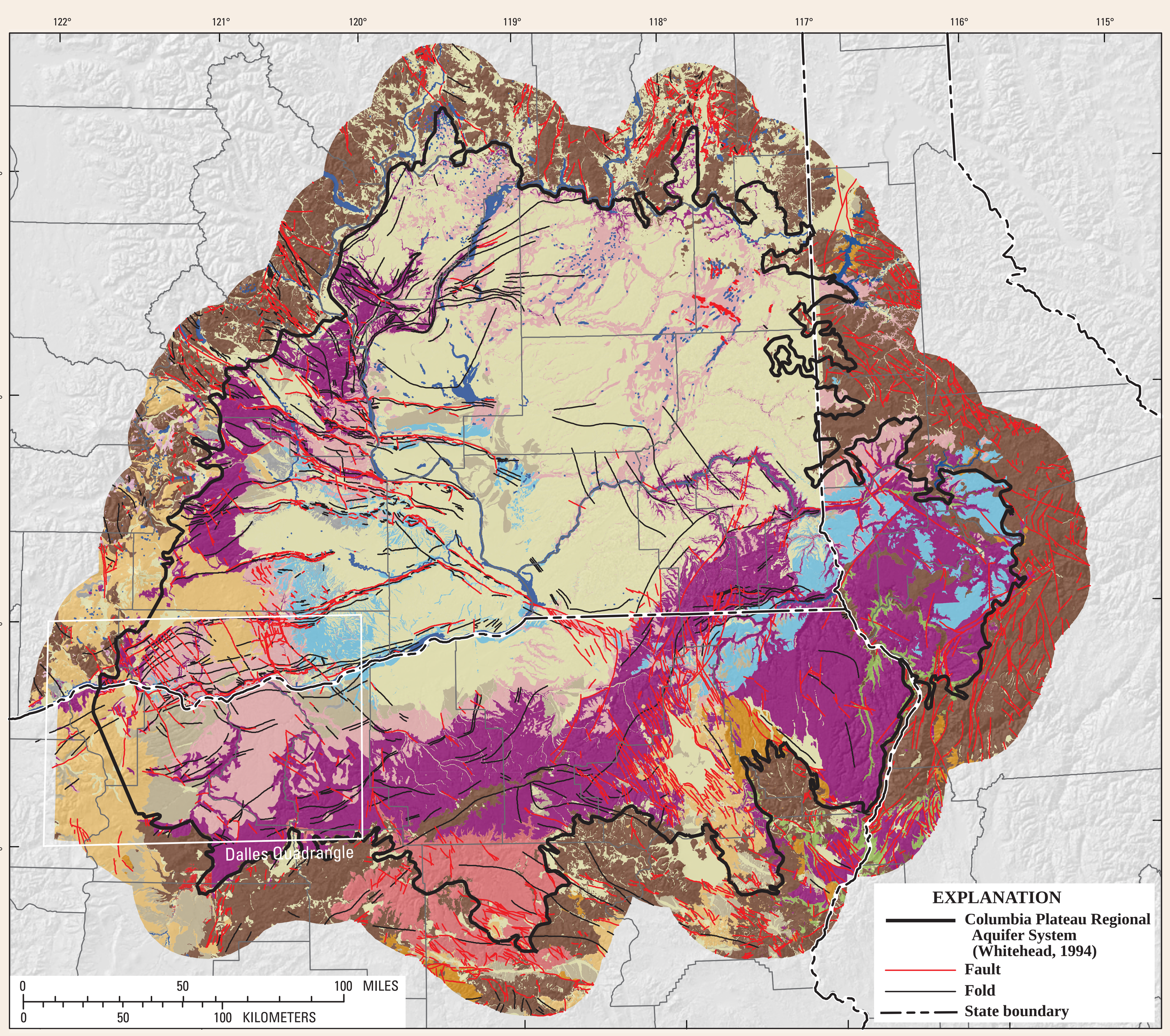

Figure 2. Simplified geologic units and major geologic structures. Explanation of simplified geologic units is shown in table 1.

Table 1. Names, descriptions, and ages of simplified geologic units of the Columbia Plateau, Idaho, Oregon, and Washington

[CPRAS, Columbia Plateau River Aquifer System. CRBG, Columbia River Basalt Group. Notes, summarized from State digital compilations (number of original map units; unit type)]

Geologic unit symbol and color	Age	CPRAS simplified geologic map unit	Idaho [310; MU_SYMBOL]	Oregon [729; MAP_UNIT_NAME]	Washington [746; GUNIT_TXT]
Qs	Quaternary	Sediment	Alluvial, eolian, glacial, glacial outburst flood, glaciolacustrine, landslide, and peat deposits	Alluvial, colluvial, eolian, glacial, glacial outburst flood, lacustrine, landslide, terrace, and peat deposits; artificial fill, ash, debris-avalanche and debris-flow deposits, mine tailings, talus; sedimentary deposits or rocks	Alluvial, eolian, glacial, glacial outburst flood, glaciolacustrine, lacustrine, landslide, and peat deposits; talus; artificial fill
QTi	Quaternary-Tertiary	Intrusives	Not a map unit in Idaho	Not a map unit in Oregon	Mostly Mount Rainier/Adams intrusives
QTsdr	Quaternary-Tertiary	Sedimentary deposits or rocks	Alluvial gravel, terrace; Conglomerate near Round Mountain; consolidated alluvial and(or) glacial deposits	Alkali Canyon, Dalles, Deschutes, Ellensburg, Madras, McKay, Rattlesnake, and Simtustus Formations; alluvial, fluvial, lacustrine, and terrace deposits; sedimentary rocks; tuffaceous sedimentary deposits and rocks; volcaniclastic deposits	Continental sedimentary deposits or rocks, alluvium, landslides
QTv	Quaternary-Tertiary	Non-CRBG volcanics	Basalt of Cuddy Mountain	Numerous non-CRBG volcanics	Mostly Mount Rainier/Adams flows, lahars, intrusives, volcaniclastic deposits or rocks
Msdr	Miocene	Sedimentary deposits or rocks	Alluvial gravel, Latah Formation, Deer Creek Beds, Payette Formation	Not a map unit in Oregon	Continental sedimentary deposits or rocks, landslide deposits
Mv(SMB)	Miocene	Saddle Mountains Basalt	Includes Asotin, Grangeville, Onaway, Wilbur Creek, and Weissenfels Ridge Members; and basalt of Cragmont, Lapwai, and Weippe	Buford, Elephant Mountain, and Umatilla members; basalt of Eden, Ferguson Spring, and Umatilla; Pomona basalt	Includes Asotin, Buford, Elephant Mountain, Esquatzel,Grangeville, Ice Harbor, Lower Monumental, Onaway, Pomona, Umatilla, Wilbur Creek, and Weissenfels Ridge Members
Mv(WB)	Miocene	Wanapum Basalt	Includes Eckler Mountain, Priest Rapids, and Roza Members; and basalt of Ferry Creek	Frenchman Springs and Roza members; Basalt of Ginkgo, Lookingglass, Lyons Ferry, Palouse Falls, Powatka, Robinette Mountain, Sand Hollow, and Sentinel Gap	Includes Eckler Mountain, Frenchman Springs, Priest Rapids, and Roza Members
Mv(GRB)	Miocene	Grande Ronde Basalt	Includes upper and lower flows of normal magnetic polarity (N2 and N1) and upper and lower flows of reverse magnetic polarity (R2, R1)	Includes upper and lower flows of normal magnetic polarity (N2 and N1) and upper and lower flows of reverse magnetic polarity (R2, R1)	Includes upper and lower flows of normal magnetic polarity (N2 and N1) and upper and lower flows of reverse magnetic polarity (R2, R1)
Mv(PB)	Miocene	Prineville Basalt	Not a map unit in Idaho	CRBG, Prineville chemical type	Not a map unit in Washington
Mv(PGB)	Miocene	Picture Gorge Basalt	Not a map unit in Idaho	Basalt intrusives and flows (normal and reversed magnetic polarity); Dayville, Monument Mountain, and Twickenham Basalt	Not a map unit in Washington
Mv(IB)	Miocene	Imnaha Basalt	Basalt	Basalt with minor tuff breccia	Basalt
Mv(CRBG)	Miocene	CRBG, undivided	CRBG, undivided	CRBG, undivided; basalt and dikes	Not a map unit in Washington
preM	preMiocene	Pre-CRBG rocks, undivided	Intrusive, metamorphosed intrusive, sedimentary, and metamorphosed sedimentary rocks	Volcanic, metavolcanic, intrusive, sedimentary, and metamorphosed sedimentary rocks; sedimentary deposits (pre-CRBG)	Intrusive, metamorphosed intrusive, sedimentary, metamorphosed sedimentary, and volcanic rocks (pre-CRBG)

Hydrogeologic Units

Generalized hydrogeologic units recognized in this investigation include Overburden, Saddle Mountains, Mabton Interbed, Wanapum, Vantage Interbed, Grande Ronde, and Older Bedrock (table 2). Figure 3 shows the approximate surficial distribution of the overburden and the three basalt units in the study area; figure 4 illustrates the general subsurface distribution of the units. The interbed units are fairly extensive laterally, but are thin when compared with the thickness of the basalt units. Basalt and interbed units are described in detail in Drost and others (1990), Whiteman and others (1994), and Jones and Vaccaro (2008).

Overburden Unit

The Overburden hydrogeologic unit consists predominantly of undivided unconsolidated to semi-consolidated sedimentary deposits ranging from Miocene to Holocene in age (Drost and others, 1990). Several formations of local and or regional extent and numerous types of sedimentary deposits in the Overburden unit are grouped including alluvial, colluvial, eolian, glacial, glacial outburst flood, lacustrine, landslide, terrace and peat deposits; talus; and other unknown continental sedimentary deposits (table 2). Minor basalt and andesite of limited extent, generally in the western part of the study area, is included in this unit. Thickness of the Overburden unit, based on 1,714 wells that fully penetrate this unit, ranges from 0 to 1,300 feet. The distribution of the Overburden unit where thickness is estimated to be more than 100 feet is shown in figure 3.

Saddle Mountains Unit

The Saddle Mountains hydrogeologic unit consists mostly of the Saddle Mountains Basalt and interbed members; it is the least extensive and youngest formation of the CRBG. Most of the unit is in the west-central part of the study area, with less continuous occurrences in the Blue Mountains and eastward into Idaho (fig. 3). The unit has an estimated areal extent of about 8,000 square miles. The top of the Saddle Mountains unit ranges from an altitude of about 4,000 to -280 feet. Thickness of the Saddle Mountains unit, based on 351 wells that fully penetrate this unit, ranged from about 0 to 990 feet.

Mabton Interbed Unit

The Mabton hydrogeologic unit is the sedimentary interbed between the overlying Saddle Mountains unit and the underlying Wanapum unit. The Mabton unit consists of the Mabton Member of the Ellensburg Formation and is mostly in the west-central part of the study area. Limited surficial outcrops of the Mabton unit are present in the study area and the extent is assumed to be within the extent of the Saddle Mountains unit. The Mabton unit generally consists of clay, shale, claystone, clay with basalt, clay with sand, and sandstone. Thickness of the Mabton unit, based on 242 wells that fully penetrate this unit range from about 0 to 520 feet.

Wanapum Unit

The Wanapum hydrogeologic unit, composed mostly of basalt and interbed members of the Wanapum basalt, is in most of the north-central part of the study area (fig. 3) and has an estimated areal extent of about 25,000 square miles. Much of the unit lies beneath the Overburden and Saddle Mountain units. The top of the Wanapum unit ranges from an altitude of about 3,400 to –1,000 feet. Thickness of the Wanapum unit, based on 738 wells that fully penetrate this unit, ranges from about 0 to 1,200 feet.

Vantage Interbed Unit

The Vantage hydrogeologic unit is the sedimentary interbed between the overlying Wanapum unit and the underlying Grande Ronde. Over most of the study area, this unit consists of the Vantage Member of the Ellensburg Formation; however, this unit includes sediment of the Latah Formation in the northeastern part of the study area. Limited surficial outcrops of this unit are present in the study area and the extent is assumed to be within the extent of the Wanapum unit. The Vantage unit consists of clay, shale, sandstone, tuff with claystone, and clay with basalt, but also may contain small amounts of sand and sand-and-gravel. A few well-record interpretations also indicate that the Vantage unit is not present in the southeastern part of the Yakima River basin and near the Cold Creek Syncline and Rattlesnake Hills Structure (Jones and Vaccaro, 2008). Thickness of the Vantage unit, based on 444 wells that fully penetrate this unit, ranges from about 0 to 320 feet.

Grande Ronde Unit

The Grande Ronde hydrogeologic unit is the oldest and most extensive of the basalt units. This unit underlies most of the study area, except for an area along the southern boundary of the CPRAS in Oregon and along the eastern edge of the aquifer system in Idaho (fig. 3). The estimated areal extent of the Grande Ronde unit is about 42,000 square miles. The Grande Ronde unit contains the basalt and interbed members associated with the Grande Ronde basalt as well as the less extensive Prineville, Picture Gorge, and Imnaha Basalts. Sedimentary interbeds within the Grande Ronde basalt generally are rare and where present are only a few feet thick. The top of the Grande Ronde unit ranges from 4,300 to –2,100 feet based on well log data. Thickness of the unit is largely unknown, but as shown on the sections (fig. 4), the thickness may be greater than 15,000 feet near the central part of the basin.

Older Bedrock Unit

The Older Bedrock hydrogeologic unit that borders and underlies the CPRAS is composed of various rock types older than the CRBG (table 1). In Washington and Idaho, the rocks bordering the CPRAS consist mostly of sedimentary and granitic rocks. In Oregon, the CPRAS is bordered by sedimentary, volcaniclastic, volcanic, plutonic and metamorphic rocks (Drost and others, 1990).

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Geologic Setting and Hydrogeologic Units of the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho

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