3.0 Hydrogeologic Framework of the Black Rock Model Area

The potential Black Rock dam and reservoir are located within the southwest portion of the Columbia Plateau, in an area known as the Yakima Fold Belt (Figure 3-1). The topography of the Yakima Fold Belt consists of northwest-southeast trending ridges (anticlines) separated by broad, flat valleys (synclines) that were folded and faulted under north-south compression. It is between two of these anticlines, Yakima Ridge on the north and Horsethief Mountain on the south, that the Black Rock dam and reservoir would reside.

The area surrounding the Black Rock Dam and reservoir, extending from the Yakima River on the west and south to the Columbia River on the east, is hereafter referred to as the model domain. Surface elevations within the model domain range from less than 400 feet at the confluence of the Yakima and Columbia Rivers, to more than 3,800 feet at the top of the Umtanum Ridge.

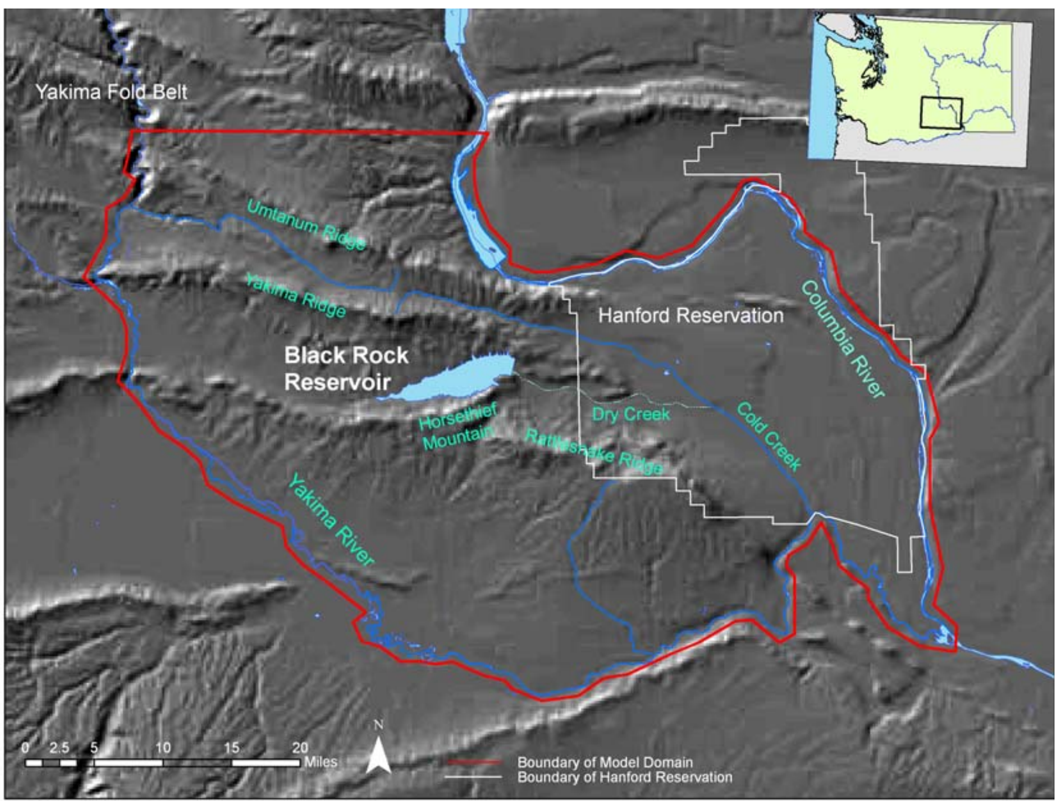

Figure 3-1: Topographic features in the Black Rock model domain.

3.1 Geologic Setting

Over 300 individual basaltic flows erupted from fissures in the eastern part of the Columbia Plateau during the Miocene Epoch (between 6 and 17 million years ago). Individual flows range in thickness from a few feet to more than 100 feet. The Columbia Plateau is the northern part of the Columbia River flood-basalt province and includes the thickest area of basaltic accumulation, on the order of 10,000 feet thick in the Pasco Basin. The flood basalts cover an area of over 63,000 mi^2 in the Pacific Northwest. Within the model domain, in the Yakima Fold Belt sub-province, the basalts overlie Tertiary continental sedimentary rocks. To the east of the fold belt, in the Palouse sub-province, the basalts are much thinner and overlie crystalline bedrock.

3.2 Stratigraphy

Rocks within the model domain are part of the Columbia River Basalt Group (CRBG) and consist of a series of lava flows with intercalated sediments. The basalts have been divided into separate formations based on their physical, geochemical, and paleomagnetic polarity differences. From oldest to youngest the basaltic formations include the Grande Ronde, Wanapum, and Saddle Mountains Basalt. Figure 3-2 is a generalized stratigraphic column that shows the relationship between the basaltic formations, interbedded sediments of the Ellensburg Formation, and the unconsolidated materials overlying the basalt.

The Grande Ronde Basalt is the deepest, most voluminous and areally extensive of the basaltic formations. Individual flows are often only distinguishable by their magnetic polarity (normal or reversed direction). The Grande Ronde is found mainly in the subsurface (from depths of >1,000 feet) and is only exposed at the surface where faulting along the anticlinal ridges (e.g. Umtanum ridge in the northern part of the model domain) has uncovered these rocks. The top of the Grande Ronde is generally defined by a zone of weathering or the presence of a sedimentary interbed (the Vantage sandstone).

The Wanapum Basalt overlies the Grande Ronde and is found throughout the model domain at depth. The uppermost member (Priest Rapids) is exposed in limited, but important outcrops on Horsethief Mountain near the south abutment of the dam (Figure 3-3). The exposures at the east end of Horsethief Mountain have been interpreted to be on the hanging wall of Horsethief Mountain fault (Bentley and Peterson, 2003). The Wanapum Basalt is probably continuous along the ridge to the west at shallow depth and connected to the Wanapum outcrops that are mapped higher on the hill slope. These outcrops are at elevation 1,570 feet and below; therefore, they would be in contact with the reservoir. The upper outcrops are interpreted to be located in the hinge area of the Horsethief Mountain anticline (Bentley and Peterson, 2003) where there may be stress fractures associated with the folding that could enhance horizontal and vertical hydraulic conductivity.

<table>
<tr><th colspan="8">GEOLOGIC FRAMEWORK</th><th>HYDROGEOLOGIC FRAMEWORK</th><th rowspan="2">MODEL LAYERS</th></tr>
<tr><th colspan="7">BASALT STRATIGRAPHY</th><th>SEDIMENT STRATIGRAPHY</th><th>UNIT</th></tr>
<tr><td>Holocene to Miocene</td><td></td><td></td><td></td><td colspan="3"></td><td>Sediments (gaciofluvial, fluvial, lacustrine, eolian, and ash fall materials). Locally includes sediments of the Hanford, Palouse, Latah, Ringold and Ellensburg Formations.</td><td>Overburden sediments</td><td>Layer 1</td></tr>
<tr><td rowspan="4">Miocene</td><td>Upper Miocene</td><td rowspan="4">Columbia River Basalt Group</td><td>Saddle Mountains Basalt</td><td colspan="3">Lower Monumental Member
Ice Harbor Member

Buford Member
Elephant Mountain member

Pomona Member

Esquatzel Member

Weissenfels Ridge Member
Asotin member
Wilbur Creek Member
Umatilla Member</td><td>Intercalated sediments of the Ellensburg Formation

— Levey Interbed

— Rattlesnake Ridge Interbed
— Selah Interbed

— Cold Creek Interbed

— Mabton Interbed</td><td>Saddle Mountains Unit</td><td>Layer 2</td></tr>
<tr><td>Middle Miocene</td><td>Wanapum Basalt</td><td colspan="3">Priest Rapids Member
Roza Member
Frenchman Springs Member
Eckler Mountain Member</td><td>— Vantage Interbed</td><td>Wanapum unit</td><td>Layer 3</td></tr>
<tr><td rowspan="2">Lower Miocene</td><td rowspan="2">Grande Ronde Basalt</td><td rowspan="2"></td><td rowspan="2">Magnetostratigraphic[1] units</td><td rowspan="2">N_2
R_2
N_1
R_1</td><td rowspan="2"></td><td rowspan="2">Grande Ronde Unit</td><td>Layer 4</td></tr>
<tr><td>Layer 5</td></tr>
</table>

[1]Magnetostratigraphic units: N – normal polarity; R- reverse polarity; units numbered sequentially from oldest to youngest.

Figure 3-2: Stratigraphic chart for the Columbia Plateau (Modified from USGS, 1999).

The Wanapum Basalt is a very productive aquifer throughout the Columbia Plateau and is widely used for irrigation and municipal wells. To the west of the Black Rock reservoir site, in the Moxee valley, the Wanapum aquifer is partitioned by geologic structure, and portions of the aquifer have experienced water level declines due to irrigation pumping (Kirk and Mackie, 1993). The Mabton sedimentary interbed overlies the Wanapum Basalt and is a confining bed that separates the underlying Wanapum layer from the overlying Saddle Mountains layer.

The Saddle Mountains Basalt erupted during a period of decreased volcanism and increased folding. It exhibits increased development of sedimentary interbeds between flows and has a volume of less than 1 percent of the total volume of the CRBG, yet is the most chemically diverse of any of the basaltic formations in the group (Swanson and Wright, 1978). The thickness and extent of the Saddle Mountains Basalt also vary more than other basaltic units. Of the ten Saddle Mountains members identified throughout the Columbia Plateau, only half are found in the model domain and some cover only a small area. Basaltic exposures at the surface are principally those of the Saddle Mountains unit (Figure 3-4).

Three members of the Saddle Mountains Basalt, the Pomona, Esquatzel, and Umatilla, are found in the Black Rock valley and in the adjacent anticlinal ridges. The Elephant Mountain member, encountered in two test holes drilled within the Black Rock valley, is probably limited in aerial extent because it is confined by an ancient erosional channel that filled in this area. The Elephant Mountain flow is more extensive in the eastern part of the model domain. Outcrops of the Elephant Mountain flow are mapped along the Dry Creek valley, southeast of the damsite (Figure 3-3).

The interbedded sediments between basaltic flows are stratigraphically assigned to the Ellensburg Formation and are mainly found between flows of the Saddle Mountains Basalt. Towards the end of the volcanism period, there were longer intervals of time between subsequent flows for deposition to occur. The interbeds are relatively thin, compared to the thick sequence of basalts, and are generally fine-grained, weakly consolidated and have low permeability. However, in some areas the interbeds are coarse-grained and serve as aquifers. The interbed materials were derived chiefly from volcanic activity and erosion from the Cascade Range and from the anticlinal ridges.

The Ellensburg Formation comprises most of the unconsolidated sediments overlying the basalts in synclinal basins in the western part of the model domain. Basin-fill deposits also include alluvium, wind-blown silt (loess), alluvial fan deposits, and flood gravels. These deposits were recently mapped in the Yakima River Basin by the U.S. Geological Survey for a separate groundwater study (USGS, 2006b). Thickness of the basin-fill sediments varies from 0 (absent) to more than 500 feet.

The Ringold Formation overlies basalts in the eastern part of the model domain (Figure 3-4). The Ringold Formation consists of fluvial sediments derived from ancestral rivers that flowed into and through the Pasco Basin during the Pliocene Epoch. These deposits vary in texture, consolidation, and saturation. The mapped thickness of the Ringold sediments and overlying glaciofluvial deposits (informally called the Hanford formation) within the Hanford Reservation were obtained from Pacific Northwest National Laboratory (PNNL, 2006).

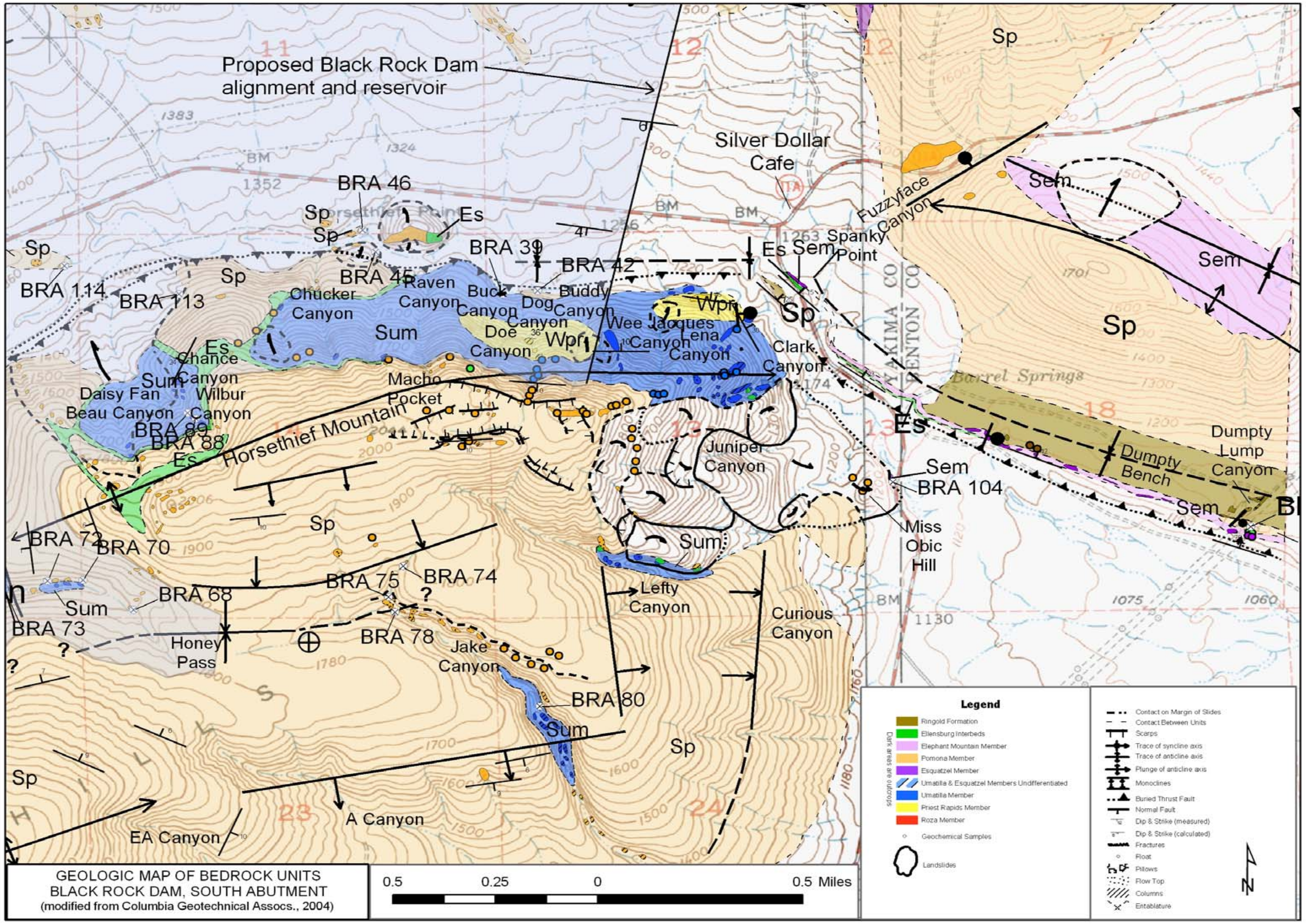

Figure 3-3: Geologic map of bedrock units underlying Black Rock dam right abutment.

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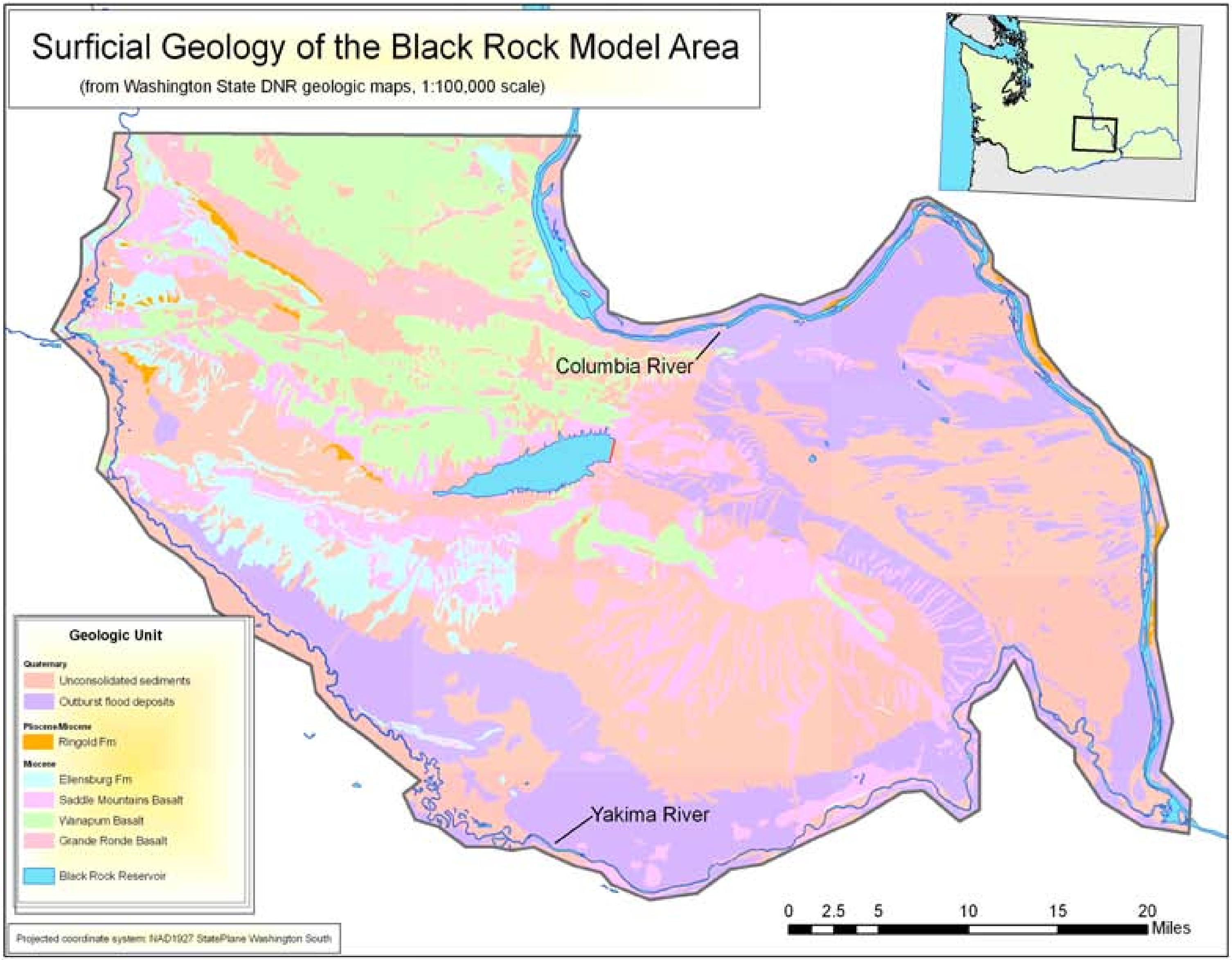

Surficial Geology of the Black Rock Model Area
(from Washington State DNR geologic maps, 1:100,000 scale)
Columbia River
Yakima River
Geologic Unit
Quaternary
Unconsolidated sediments
Outburst flood deposits
Pliocene/Miocene
Ringold Fm
Miocene
Ellensburg Fm
Saddle Mountains Basalt
Wanapum Basalt
Grande Ronde Basalt
Black Rock Reservoir
0 2.5 5 10 15 20
Miles
Projected coordinate system: NAD1927 StatePlane Washington South

3.3 Geologic Structure

The uplift of the Yakima Fold Belt started during the eruption and emplacement of the underlying basalts; most of the structural relief has developed in the last 10 million years and continues to the present. The anticlines are often complexly folded and faulted with en echelon thrust faults extending along the base of the northern limb. Most of the anticlines in the Yakima Fold Belt are asymmetric in shape with a steeply dipping north limb and a shallow dipping south limb. The folds are often segmented by cross-structures. To the west, the Hog Ranch anticline separates the Black Rock Valley to the east from the Moxee Valley to the west. In addition, large-scale deformation zones have displaced and deformed parts of the Yakima Fold Belt. For more detail on the structural geology of the region, refer to Reidel and others (2003), Bentley and Peterson (2003), and Campbell (1998).

The potential Black Rock damsite is located at the east end of the Black Rock Valley where the Yakima Ridge anticline turns southeast and Horsethief Mountain anticline extends northeastward from the Rattlesnake Hills. Bentley and Peterson (2003) described this as a “convergence zone” where the structures appear to intersect in a north-trending cross structure that they name the Cairn Hope Peak Axis (CHPA). Along the axis, the ridges change from simple, large amplitude folds to a diffuse series of smaller folds that may be more complexly faulted and folded. On their tectonic map (Figure 3-5) they show an east-west trending, south dipping thrust fault at the northern base of Horsethief Mountain and an intersecting northwest trending thrust fault that dips to the north. This fault, named the Barrel Springs fault, extends to the southeast from the damsite, along the Dry Creek Valley. It is uncertain whether the fault zone in the Dry Creek drainage represents a more intensely fractured, high permeability zone. There is anecdotal evidence however that historic “Barrel Springs”, mapped along the east side of the fault, stopped flowing when irrigation wells located on the west side of the fault began pumping from the Wanapum Basalt aquifer (personal communication Brett Lenz, Columbia Geotechnical Associates, 2004).

3.4 Hydrogeology

The occurrence and flow of groundwater within the Black Rock model domain are controlled primarily by the physical characteristics of the rock units, geometry and relationship between rock units, and geologic structure. The physical characteristics of the basaltic flows (density and texture, fractures, and internal structures) are important in determining their hydraulic properties. Internal structures found in the flows may influence both the ease of water movement and direction through the formation. Individual basaltic flows typically exhibit features that are formed from the emplacement and cooling of the flow. These features may include a vesicular flow top, dense flow interior, and vesicular or brecciated flow bottom. If the basalt flowed into a body of water or encountered saturated sediments, a pillow-shaped structure is formed and the space between the pillows is usually composed of palagonite (hydrated basaltic glass). The dense interior portions of the flows have predominately vertical cooling joints and exhibit a high level of anisotropy, with preferred vertical flow and very low lateral permeability. The combination of flow top with the adjacent flow bottom of the overlying flow is called an “interflow” and this zone generally has high lateral permeability. The basaltic flows and interflow zones are often laterally continuous for tens of miles.

The thickness and extent of flows and the occurrence or absence of fine-grained sedimentary interbeds also influence groundwater movement. At the distal ends of the basaltic flows or where erosion has interrupted the continuity of flows, interbedded sediments are able to co-mingle and may serve as a vertical conduit between previously separated flow systems. Often, the dense flow interiors and fine-grained interbeds serve as confining layers between the more permeable interflow zones.

Folding, faulting, and other large-scale geologic deformation can affect regional groundwater flow direction, influence hydraulic gradients, and create flow conduits or barriers. At least some of the faults in the model domain are proven hydraulic barriers. Others appear to be conductive and may connect deep basaltic formations with shallower formations and surface springs. Folding increases the occurrence of fractures on the anticlinal ridges and tends to enhance aquifer hydraulic conductivity.

3.5 Aquifer Recharge and Discharge

Local, intermediate, and regional scale groundwater flow systems within the model domain are recharged by various mechanisms. On a regional scale, basaltic units are recharged along the western margin of the Columbia Plateau where the basalts interfinger with pre-basaltic rocks and sediments at higher elevations in the Cascade Range. Intermediate and local flow systems are recharged through basalts that are exposed to precipitation at the ground surface on the anticlinal ridges, and through groundwater exchange with other basins and formations.

The lower arid portion of the Yakima River basin and the Hanford Reservation generally receives about 6 to 10 inches of precipitation annually. The ridges at higher elevations receive between 10 and 20 inches. In addition, crop irrigation on surficial sediments has increased recharge to the groundwater system of the Yakima Basin. Almost half of the applied irrigation water eventually returns to the surface via tile drains. Irrigation return flows to the lower Yakima River account for about 75 percent of the streamflow below the streamflow gaging station near Parker (USGS, 2006a).

Aquifer discharge occurs principally to major surface drainage systems (i.e. Yakima and Columbia Rivers) and through irrigation well pumping. Annual pumpage in the

Yakima River basin increased almost 270 percent from 1960 to 2000 (USGS, 2006a). About 430 ft^3/s were pumped in 2000, with 60 percent of the pumpage for irrigation and another 12 percent for municipal water supply.

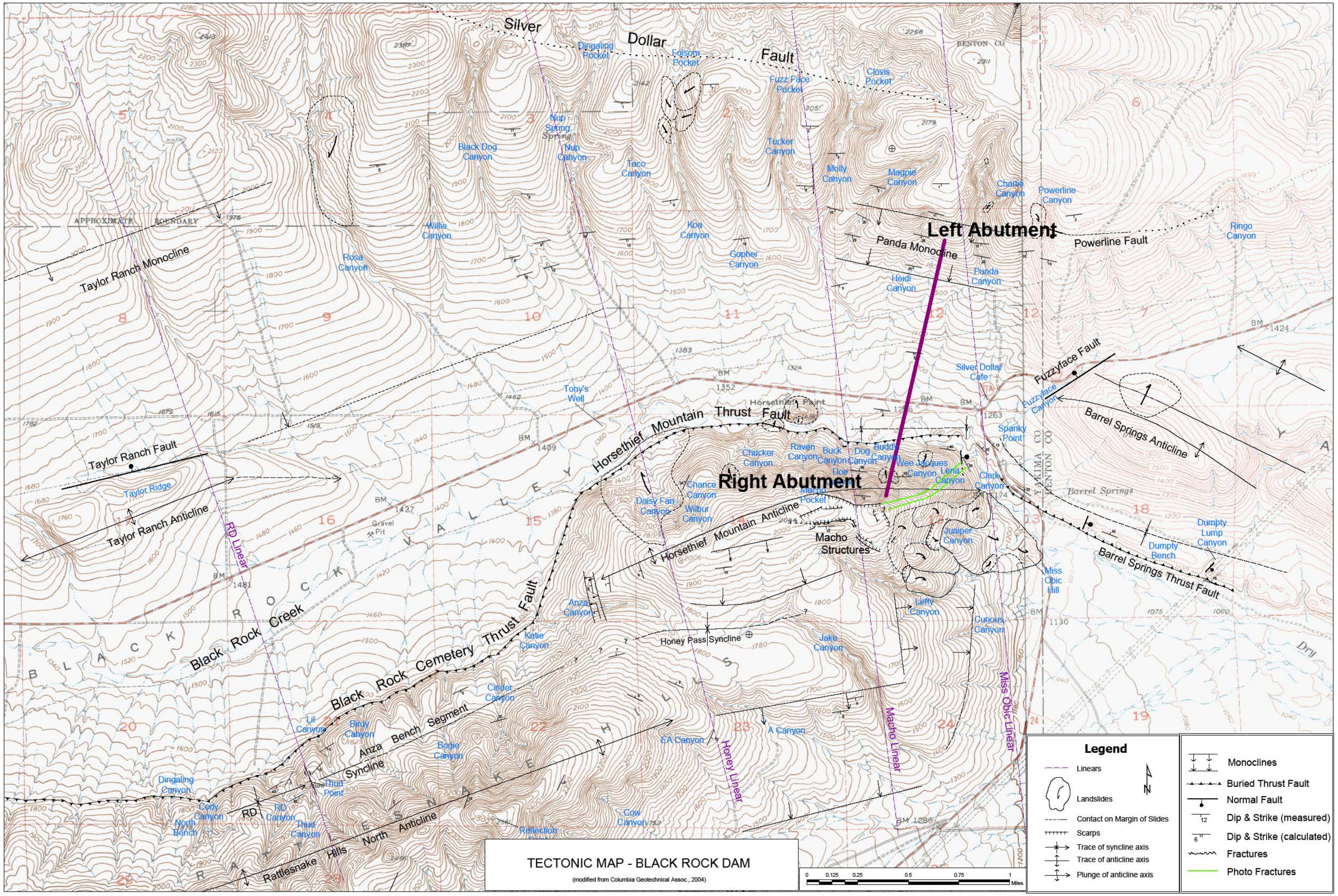

Figure 3-5: Tectonic map of the Black Rock damsite.

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