N A T U R A L R E S O U R C E S

Geologic Map of the East Half of the Toppenish 1:100,000 Quadrangle, Washington

compiled by
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WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

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Natural Resources
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INTRODUCTION

This map of the east half of the Toppenish 1:100,000-scale quadrangle, Washington, shows the geology of one of 15 complete or partial 1:100,000-scale quadrangles that cover the southeast quadrant of Washington (Fig. 1). Geologic maps of these quadrangles have been compiled by geologists with the Washington Division of Geology and Earth Resources (DGER), Westinghouse Hanford Co., and Washington State University and are the principal data sources for a new 1:250,000-scale geologic map of the southeast quadrant of Washington, which is in preparation. Eleven of these quadrangles are being released as DGER open-file reports (listed p. 4). The map of the Wenatchee quadrangle has been published by the U.S. Geological Survey (Tabor and others, 1982), and the Moses Lake (Gulick, 1990a), Ritzville (Gulick, 1990b), and Rosalia (Waggoner, 1990) quadrangles were released in 1990.

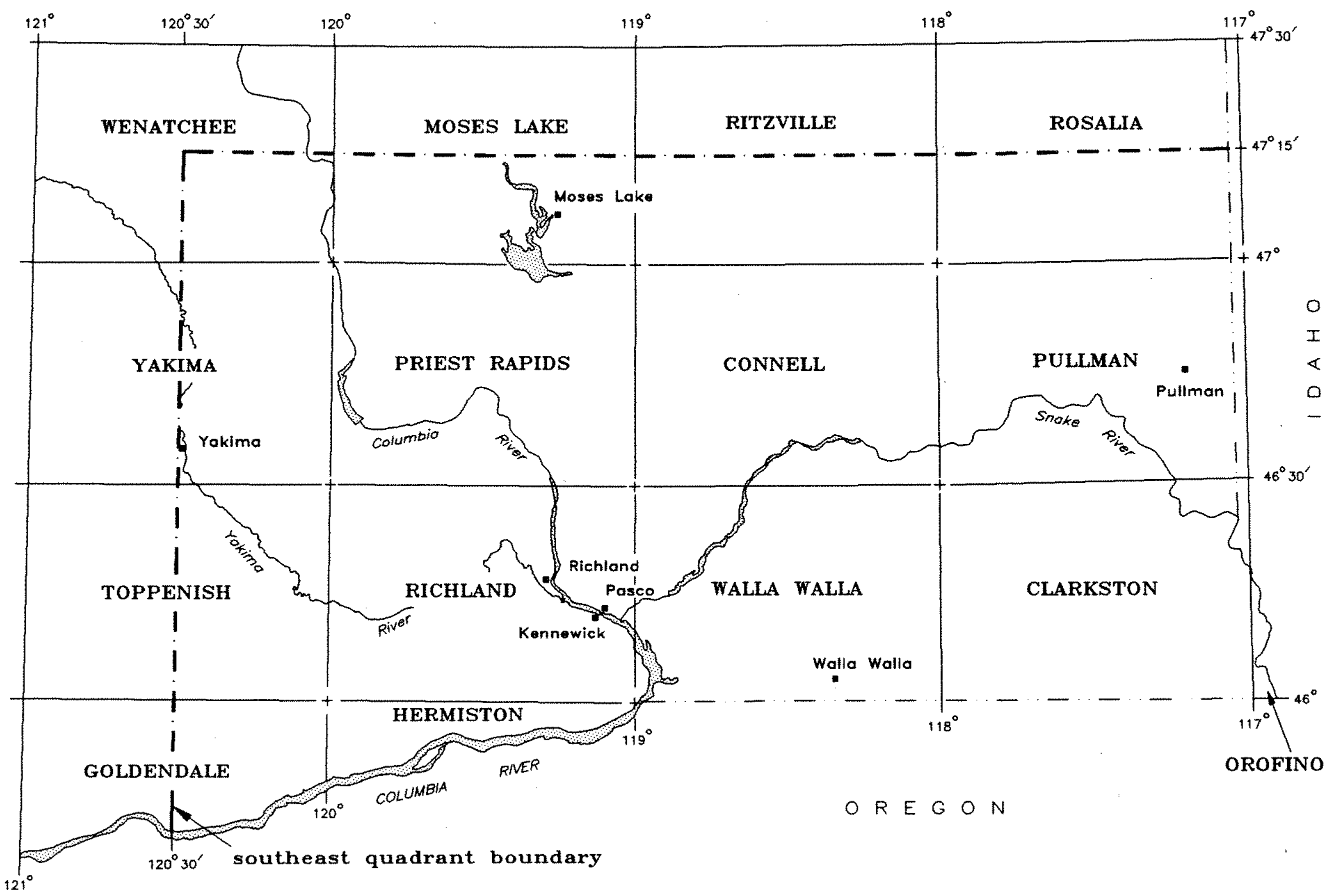

Figure 1. 1:100,000-scale quadrangles in the southeast quadrant of Washington.

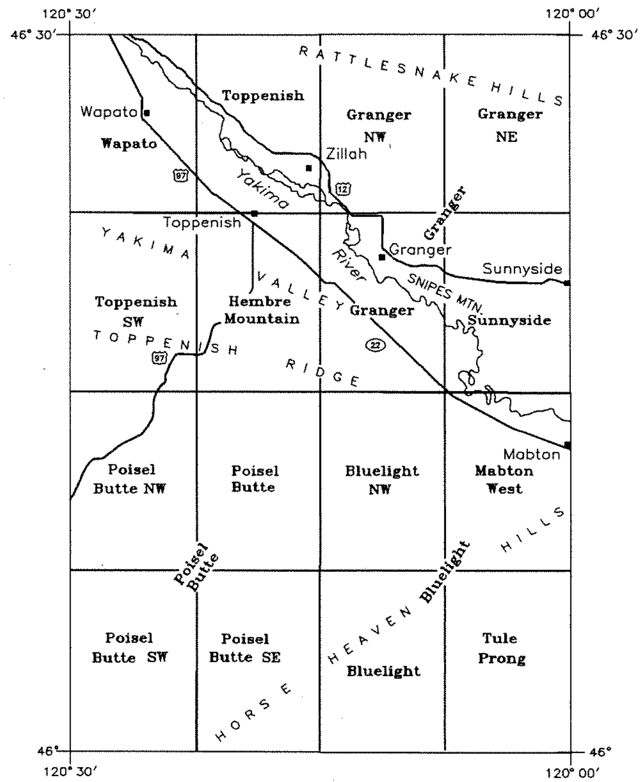

Figure 2. Geographic names and 7.5- and 15-minute quadrangle locations in the east half of the Toppenish 1:100,000 quadrangle.

Figure 2 shows geographic features referred to in this text and the locations of 7.5- and 15-minute quadrangles in the east half of the Toppenish 1:100,000-scale quadrangle.

The geology of the east half of the Toppenish quadrangle has not previously been compiled at 1:100,000 scale. Furthermore, this is the first 1:100,000 or smaller-scale geologic map of the area to incorporate both bedrock and surficial geology.

This map was compiled in 1992-1993, using published geologic maps as sources of data. The areas covered by these sources are shown on Figure 3. Maps produced before 1979 were not used as sources of data for the Columbia River Basalt Group because prior to that year mappers generally did not use geochemistry or magnetic polarity to confirm assignment of basalt flows to stratigraphic units, nor did they employ the stratigraphy that was proposed by Swanson and others (1979b) and, with subsequent modifications, is universally used today. The lack of consistent, reliable identification procedures and standardized nomenclature makes it difficult to use the older maps unless one is personally familiar with the geology. Figure 3 identifies some of the sources of data as primary. Some maps that were not used in compiling the geology of this report are shown on Figure 3 in an attempt to make the sources-of-data listing exhaustive and to inform the reader that these sources were not overlooked.

In a review of late Cenozoic structure and stratigraphy of south-central Washington Reidel and others (1994, table 4) report Holocene movement along the Mill

Highway 97 crosses Toppenish Ridge and the west edge of the map area. For further information, refer to Campbell and Bentley (1981, p. 519-524). Faults in this area are portrayed on the geologic map (Plate 1) as adapted from Bentley and others (1993), not as described by Reidel and others (1994) because Reidel and his co-authors do not provide a geologic map.

Age assignments of geologic units were made following the flow chart in Figure 4. Because all K-Ar ages cited herein (Baksi, 1989; Tolan and others, 1989; McKee and others, 1977; Reidel and Fecht, 1987) were published after 1976, they are assumed to have been calculated using the decay and abundance constants adopted by the International Union of Geological Sciences in 1976 (Dalrymple, 1979). The actual constants used were not reported.

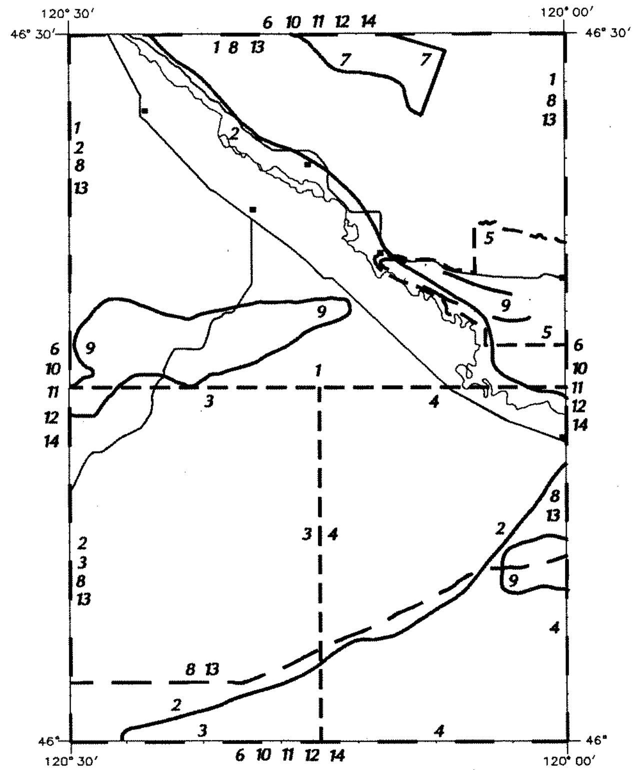

Figure 3. Sources of geologic mapping for the east half of the Toppenish 1:100,000 quadrangle.

1.* Bentley and others, 1993, sheets 3 and 4 (scale 1:31,680).
2. Bentley and others, 1980 (scale 1:84,480).
3.* Bentley and others, 1988a (scale 1:48,000).
4.* Bentley and others, 1988b (scale 1:48,000).
5. Campbell, 1977 (scale 1:24,000).
6. Campbell, 1979 (scale 1:250,000).
7. Kienle and others, 1977, fig. A-8 (scale 1:24,000).
8. Kinnison and Sceva, 1963, plate 1 (scale 1:250,000).
9. Laval, 1956, plates XXIV and XXVII (scale 1:62,500).
10. Myers, Price, and others, 1979, plates II-6 and II-15 (scale 1:250,000).
11. Rigby and others, 1979, plate 9 (scale 1:250,000).
12. Swanson and others, 1979a, plate 6 (scale 1:250,000).
13. U.S. Army Corps of Engineers, 1978, plate 18 (scale 1:250,000).
14. Yeaton, 1923 (scale 1:125,000).

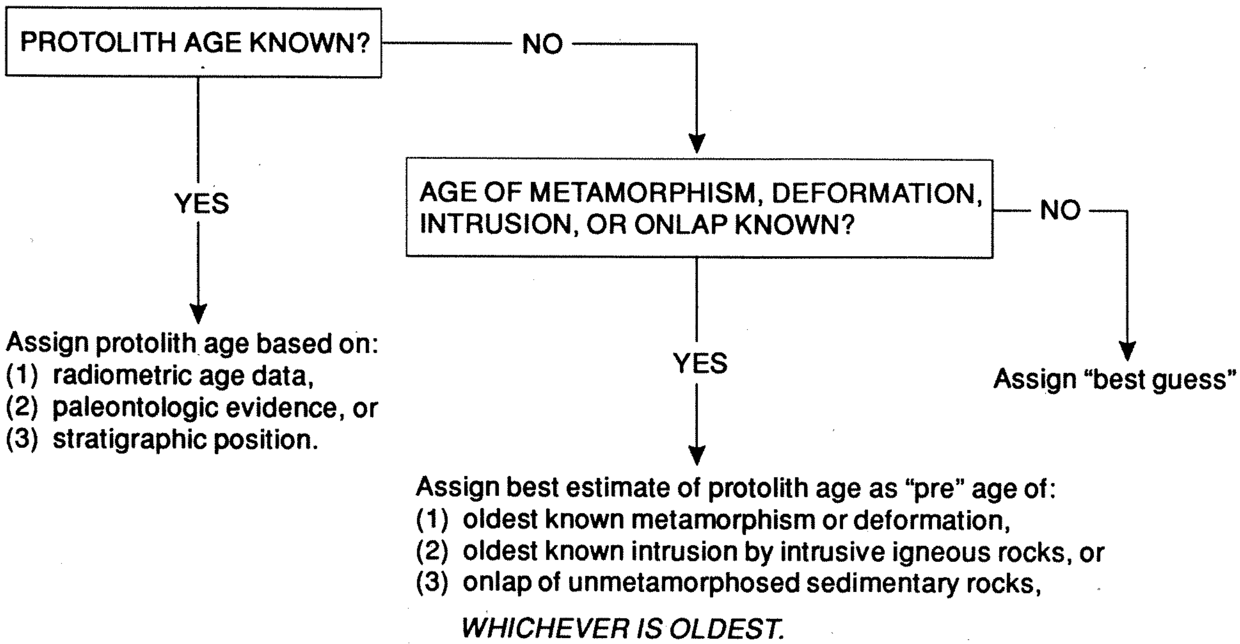

Figure 4. Flow chart for age assignment of geologic units. Protolith age or estimated protlith age may be assigned by correlation with other geologic units. The unit description includes information about how the age of the unit was determined.

The geologic time scale devised for the "Correlation of Stratigraphic Units of North America (COSUNA)" project of the American Association of Petroleum Geologists (Salvador, 1985) is used in this report, with slight modifications: the Oligocene-Eocene boundary is set at 35.7 Ma (Montanari and others, 1985), and the Pleistocene-Pliocene boundary is set at 1.6 Ma (Aguirre and Pasini, 1985).

The current nomenclature and stratigraphic relations of the Columbia River Basalt Group are shown in Figure 5.

DGER Southeast Quadrant Open-File Reports

Gulick, C. W., compiler, 1990a, Geologic map of the Moses Lake 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-1, 9 p., 1 plate.

Gulick, C. W., compiler, 1990b, Geologic map of the Ritzville 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-2, 7 p., 1 plate.

Gulick, C. W., compiler, in press, Geologic map of the Connell 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report.

Gulick, C. W., compiler, 1994, Geologic map of the Pullman 1:100,000 quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 94-6, 23 p., 1 plate.

SERIES		GROUP	FORMATION	MEMBER	ISOTOPIC AGE (Ma)	MAGNETIC POLARITY
MIOCENE	upper	COLUMBIA RIVER BASALT GROUP	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6	N
				ICE HARBOR MEMBER	8.5	
				basalt of Goose Island		N
				basalt of Martindale		R
				basalt of Basin City		N
				BUFORD MEMBER		
	middle			ELEPHANT MOUNTAIN MEMBER	10.5	N,T
				POMONA MEMBER	12	R
				ESQUATZEL MEMBER		N
				WEISSENFELS RIDGE MEMBER		
				basalt of Slippery Creek		N
				basalt of Tenmile Creek		N
				basalt of Lewiston Orchards		N
				basalt of Cloverland		N
				ASOTIN MEMBER	13	
				basalt of Huntzinger		N
				WILBUR CREEK MEMBER		
				basalt of Lapwai		N
				basalt of Wahluke		N
				UMATILLA MEMBER		
				basalt of Sillusi		N
				basalt of Umatilla		N
			WANAPUM BASALT	PRIEST RAPIDS MEMBER	14.5	
				basalt of Lolo		R
				basalt of Rosalia		R
				ROZA MEMBER		T,R
				FRENCHMAN SPRINGS MEMBER		
				basalt of Lyons Ferry		N
				basalt of Sentinel Gap		N
				basalt of Sand Hollow	15.3	N
				basalt of Silver Falls		N,E
				basalt of Ginkgo		E
				basalt of Palouse Falls		E
				ECKLER MOUNTAIN MEMBER		
				basalt of Shumaker Creek		N
				basalt of Dodge		N
				basalt of Robinette Mountain		N
			GRANDE RONDE BASALT	Sentinel Bluffs unit	15.6	N_2
				Slack Canyon unit		
				Fields Spring unit		
				Winter Water unit		
			PRINEVILLE BASALT (interfingers)	Umtanum unit		
				Ortley unit		
				Armstrong Canyon unit		
				Meyer Ridge unit		R_2
				Grouse Creek unit		
				Wapshilla Ridge unit		
				Mt. Horrible unit		
			PICTURE GORGE BASALT (interfingers)	China Creek unit		N_1
				Downey Gulch unit		
				Center Creek unit		R_1
				Rogersburg unit		
				Teepee Butte unit		
				Buckhorn Springs unit	16.9	
	lower		IMNAHA BASALT	See Hooper and others (1984) for Imnaha units	17.0	R_1
						T
						N_0
					17.3	R_0

Figure 5. Generalized nomenclature and stratigraphic relations of the Columbia River Basalt Group. This figure includes units that do not occur in the Toppenish quadrangle. Modified from Reidel and others (1989).

Reidel, S. P.; Fecht, K. R., compilers, in press, Geologic map of the Priest Rapids 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report.

Reidel, S. P.; Fecht, K. R., compilers, 1994, Geologic map of the Richland 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-8, 21 p. 1 plate.

Schuster, J. E., compiler, 1993, Geologic map of the Clarkston 1:100,000 quadrangle, Washington-Idaho, and the Washington portion of the Orofino 1:100,000 quadrangle: Washington Division of Geology and Earth Resources Open File Report 93-4, 43 p., 1 plate.

Schuster, J. E., compiler, 1994, Geologic map of the east half of the Toppenish 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-10, 15 p., 1 plate.

Schuster, J. E., compiler, 1994, Geologic map of the east half of the Washington portion of the Goldendale 1:100,000 quadrangle, and the Washington portion of the Hermiston 1:100,000 quadrangle: Washington Division of Geology and Earth Resources Open File Report 94-9, 17 p., 1 plate.

Schuster, J. E., compiler, in press, Geologic map of the east half of the Yakima 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report.

Schuster, J. E., compiler, 1994, Geologic map of the Walla Walla 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-3, 18 p., 1 plate.

Waggoner, S. Z., compiler, 1990, Geologic map of the Rosalia 1:100,000 quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-7, 20 p., 1 plate.

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N. P. Campbell of Yakima Valley Community College and D. A. Swanson of the U.S. Geological Survey reviewed the map and text and provided many helpful suggestions. C. F. T. Harris and K. G. Ikerd of the DGER cartographic staff and Jari Roloff and K. M. Reed of the DGER editorial staff prepared final copy and provided editorial support.

DESCRIPTIONS OF MAP UNITS

Sedimentary Deposits

Quaternary Sedimentary Deposits

Qa

Alluvium (Holocene to Pleistocene)—Silt, sand, and gravel deposits of diverse composition, locally includes lacustrine, paludal, and eolian deposits in depressions; occurs in valley bottoms throughout the map area; includes a mainstream facies (mainstream facies of Waitt, 1979) deposited directly by the Yakima River in which clasts are of mixed lithologies, and a sidestream facies (sidestream facies of Waitt, 1979) of dominantly basaltic composition deposited by tributaries of the Yakima River; age inferred from geomorphology and ages of parent materials. Description from Bentley and others (1988a, 1988b, 1993).

Qls

Mass-wasting deposits (Holocene to Pleistocene)—Landslide deposits; clay, silt, sand, and gravel, unstratified and poorly sorted; surface commonly hummocky; deposited by rotational-translational slides and debris flows; found at the base of slopes and on lower slopes, commonly along contact of poorly lithified or clay-rich sediments and overlying flows of Wanapum Basalt; age inferred from stratigraphic position, age of parent materials, and geomorphology. Description compiled from Bentley and others (1988a, 1988b, 1993) and Swanson and others (1979a).

Ql

Loess (Holocene to Pleistocene)—Eolian silt and fine sand; locally includes multiple caliche layers and tephra beds; pale orange to brown; uppermost loess locally contains Mazama tephra (Foley, 1982, p. 90), about 7 ka (Kittleman, 1973, p. 2958; Bacon, 1983, p. 105); paleomagnetic measurements show that the oldest loess was deposited during the Matuyama reversed polarity epoch and is at least 790 ka and probably 1 Ma or older (McDonald and Busacca, 1989, p. 338). Includes Palouse Formation. Description from Bentley and others (1988a, 1988b, 1993).

Qaf

Alluvial fans (Holocene to Pleistocene)—Sand and gravel of diverse composition; large clasts dominantly basalt; cone shaped; surface only moderately dissected; little or no caliche development; age inferred from geomorphology, lack of caliche development, and ages of parent materials. Description from Bentley and others (1988a, 1988b, 1993).

Qafo

Older alluvial fans (Holocene to Pleistocene)—Sand and gravel; semiconsolidated fanglomerate of primarily basalt clasts cemented by iron-stained clay; surface commonly dissected and capped by a well-developed caliche layer; age inferred from geomorphology, cementing, and caliche development. Description from Bentley and others (1988a, 1988b, 1993).

Qfs

Outburst flood deposits, silt and sand (Pleistocene)—Silt, minor sand and gravel; rhythmically bedded and graded; locally contains clastic dikes and ice-rafted clasts; includes a thin layer of Mount St. Helens S tephra near the top of the unit in SE1/4 sec. 6, T. 9 N., R. 21 E. near the west edge of the Granger 7.5-minute quadrangle (Bentley and others, 1993); thought to be younger than about 19 ka and older than about 11 ka on the basis of ^{14}C determinations that constrain the ages of advance and retreat of the Columbia ice lobe in southernmost British Columbia (Waitt, 1980, p. 675); additionally, Mount St. Helens set S tephra, with an isotopic age estimate of 13 ka (Mullineaux and others, 1978, p. 178), occurs below the top of the Touchet Beds (Waitt, 1980, p. 667). Deposited by outburst floods from glacial Lake Missoula. Consists of the Touchet Beds. Description from Bentley and others (1988a, 1988b, 1993).

Qt

Terrace deposits (Pleistocene)—Alluvial deposits of silt, sand, and gravel; clasts of diverse compositions; locally includes lacustrine, paludal, and eolian deposits; poorly indurated; slightly to moderately weathered clasts; deposited by the main stem of the Yakima River and largely confined to its valley; includes deposits about 5 m above the modern Yakima River flood plain (lower terrace of Campbell, 1983) and about 10 m above the modern Yakima River flood plain (middle terrace of Campbell, 1983); age inferred from geomorphology. Description from Bentley and others (1993).

Tertiary Sedimentary Deposits

Mc

Continental sedimentary deposits (upper and middle Miocene)—Fluvial sand, silt, and clay; local gravel lenses, diatomite, and lahars; white to reddish brown; derived from basaltic, andesitic, and pumiceous source rocks; weakly to moderately indurated; occurs as interbeds between units of the Columbia River Basalt Group; age determined by K-Ar age estimates of interfingering or interbedded basalt flows; outside the map area overlies the Grande Ronde Basalt (15.6 Ma, Baksi, 1989, p. 109) and underlies the Thorp Gravel which has yielded fission-track ages of 3.64 ± 0.74 and 3.70 ± 0.2 Ma and is thought to lie wholly within the Pliocene (Waitt, 1979, p. 11). Consists of the finer grained facies of the Ellensburg Formation. Description from Bentley and others (1988a, 1988b, 1993).

Mcg

Continental sedimentary deposits, conglomerate (upper Miocene)—Fluvial gravel, silt, and sand; light yellow-tan to reddish orange; weakly to strongly indurated; dominated by well-rounded quartzite pebbles, with significant numbers of granitic, gneissic, and andesitic clasts; deposited by the ancestral Columbia River; interfingers with other fluvial and laharic deposits of the Ellensburg Formation; underlain by the Elephant Mountain Member (isotopically dated at 10.5 Ma by McKee and others, 1977, and at 9.4 ± 0.7 Ma and 10.7 ± 0.8 Ma by Stoffel, 1984) of the Saddle Mountains Basalt and overlain, outside the map area, by Thorp Gravel (see information on age above). Consists of the coarser grained facies of the Ellensburg Formation. Description from Bentley and others (1988a, 1988b, 1993).

Tertiary Volcanic Rocks

Columbia River Basalt Group

The Columbia River Basalt Group in Washington is composed of four formations. From top to bottom they are the Saddle Mountains Basalt, the Wanapum Basalt, the Grande Ronde Basalt, and the Imnaha Basalt. The upper two formations crop out in the east half of the Toppenish 1:100,000-scale quadrangle. Generalized formal and informal stratigraphic units currently recognized in the Columbia River Basalt Group are shown on Figure 5.

The volcanic units of the Columbia River Basalt Group are described as fine, medium, or coarse grained. These terms are rarely quantified in the literature, but it is possible to do so on the basis of average length of plagioclase laths in the matrix. These categories generally correspond with the following plagioclase lengths: fine, ≤0.25 mm; medium, 0.25-0.5 mm; coarse, ≥0.5 mm (V. E. Camp, San Diego State Univ., written commun., 1992).

Saddle Mountains Basalt

Mv$_{sem}$

Elephant Mountain Member (upper Miocene)—Single flow; black to blue-black, gray-weathering; fine-grained; aphyric to sparsely plagioclase-phyric; normal to transitional magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979); occurs widely in upland areas; isotopically dated at 10.5 Ma by McKee and others (1977) and at 9.4 ± 0.7 Ma and 10.7 ± 0.8 Ma by Stoffel (1984). Description from Bentley and others (1988a, 1988b, 1993).

Mv$_{sp}$

Pomona Member (middle Miocene)—Single flow; gray to blue-black, gray-weathering; fine-grained; sparsely to slightly phyric, with abundant white to colorless plagioclase microphenocrysts, sparse plagioclase glomerocrysts, and sparse olivine phenocrysts;

invasive contacts with Ellenburg Formation units common; well-developed entablature and fanning columns; where more than 50 m thick, well-developed 0.5- to 1-m-diameter columns dominant; reversed magnetic polarity (Choiniere and Swanson, 1979); widely distributed in upland areas; isotopically dated at 12 Ma (K-Ar method) by McKee and others (1977) and 12 Ma (^{40}Ar-^{39}Ar method) by S. P. Reidel (Wash. State Univ., unpub. data, 1991). Description from Bentley and others (1988a, 1988b, 1993).

Mv_{su}

Umatilla Member (middle Miocene)—Single flow; black to blue-black, gray- to red-orange-weathering; fine-grained; aphyric to very sparsely plagioclase-phyric; normal magnetic polarity (Rietman, 1966); occurs in the Rattlesnake and Horse Heaven Hills, on Toppenish Ridge, and in deeper stream valleys. Description from Bentley and others (1988a, 1988b, 1993).

Wanapum Basalt

Mv_{wpr}

Priest Rapids Member (middle Miocene)—Basalt flows; gray-black, rusty brown-weathering; medium- to coarse-grained; diktytaxitic; aphyric, with rare plagioclase phenocrysts; one to three flows in map area; well-developed colonnade with 0.5- to 1.5-m-diameter columns; reversed magnetic polarity (Rietman, 1966); occurs in the Rattlesnake Hills in the northeast corner of the map area, on Toppenish Ridge, in the Horse Heaven Hills, and exposed in deeper stream valleys in the southwest and south parts of the map area; isotopic age 14.5 Ma (Tolan and others, 1989). Upper flow is designated the basalt of Lolo and the lower flows the basalt of Rosalia; the Lolo has higher MgO and lower TiO_2 contents than the Rosalia (Swanson and others, 1979b, p. G11, G37). Description from Bentley and others (1988a, 1988b, 1993).

Mv_{wr}

Roza Member (middle Miocene)—One or two basalt flows; gray-black, reddish brown-weathering; fine- to medium-grained; locally diktytaxitic; 0.5-1-cm plagioclase phenocrysts and glomerocrysts, commonly several hundred phenocrysts per square meter of flow surface; well-developed colonnade with columns as much as a meter in diameter; transitional to reversed magnetic polarity (Choiniere and Swanson, 1979); Bentley and others (1988a, 1988b, 1993) report normal magnetic polarity as measured in the field with a fluxgate magnetometer; occurs in the Rattlesnake Hills in the northeast corner of the map area, on Toppenish Ridge, in the Horse Heaven Hills near the east edge of the map area, and in deeper stream valleys near the west edge of the south half of the map area; older than Priest Rapids Member (14.5 Ma, Tolan and others, 1989) and younger than Frenchman Springs Member (15.3 Ma, Tolan and others, 1989). The Roza Member, because of its large and persistent plagioclase phenocrysts and wide distribution, is a key marker unit across much of the Columbia Basin. Description from Bentley and others (1988a, 1988b, 1993).

Mv_{wfs}

Frenchman Springs Member (middle Miocene)—Multiple flows ; generally dark gray to black; fine- to medium-grained; difficult to distinguish from flows of the Grande Ronde Basalt except that they are commonly plagioclase-phyric, especially the lower flows (Swanson and others, 1979a, 1979b); normal to excursional magnetic polarity (Fig. 5); outside the map area rests on Grande Ronde Basalt, commonly with an intervening sedimentary interbed; occurs on Toppenish Ridge, in the Horse Heaven Hills near the east edge of the map area, and exposed in the deeper stream valleys near the west edge of the south half of the map area; isotopic age 15.3 Ma for basalt of Sand Hollow, a flow in the middle of the member (Tolan and others, 1989); Beeson and others (1985) defined the informal Frenchman Springs subunits shown on Figure 5. Includes the Sentinel Gap (Union Gap) flows, Kelley Hollow flow, and Ginkgo flows of Bentley and others (1988a, 1988b, 1993), which are, respectively, the basalt of Sentinel Gap, basalt of Sand Hollow, and basalt of Ginkgo of Beeson and others (1985):

Basalt of Sentinel Gap—Single flow; gray-black; weathers gray to reddish gray; fine- to medium-grained; generally aphyric; an average of about three plagioclase glomerocrysts up to 2 cm in diameter per 10 m^2 of flow surface; colonnade of 1.5- to 2-m-diameter columns; locally pillowed base; some hackly entablatures.

Basalt of Sand Hollow—Single flow; gray-black; weathers reddish gray; fine- to medium-grained; phyric, with scattered (1-100 per square meter) plagioclase phenocrysts and glomerocrysts as large as 2 cm in diameter; thin entablature and well-developed colonnade; columns 0.5-1.5 m in diameter.

Basalt of Ginkgo—One to two flows; gray-black; weathers reddish gray; fine- to medium-grained; phyric, with 100-200 plagioclase glomerocrysts that reach 2 cm in diameter per square meter of surface; thin entablature and well-developed colonnade of columns 0.5-1.5 m in diameter; pillowed base.

Description from Bentley and others (1988a, 1988b, 1993).

REFERENCES CITED

Aguirre, Emiliano; Pasini, Giancarlo, 1985, The Pliocene-Pleistocene boundary: Episodes, v. 8, no. 2, p. 116-120.

Bacon, C. R., 1983, Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal of Volcanology and Geothermal Research, v. 18, no. 1-4, p. 57-115.

Baksi, A. K., 1989, Reevaluation of the timing and duration of extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts, Columbia River Basalt Group. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 105-111.

Beeson, M. H.; Fecht, K. R.; Reidel, S. P.; Tolan, T. L., 1985, Regional correlations within the Frenchman Springs Member of the Columbia River Basalt Group—New insights into the middle Miocene tectonics of northwestern Oregon: Oregon Geology, v. 47, no. 8, p. 87-95.

Bentley, R. D.; Anderson, James Lee; Campbell, N. P.; Swanson, D. A., 1980, Stratigraphy and structure of the Yakima Indian Reservation, with emphasis on the Columbia River Basalt Group: U.S. Geological Survey Open-File Report 80-200, 85 p., 1 plate.

Bentley, R. D.; Campbell, N. P.; Powell, J. E., 1988a, Geologic map of the Bluelight 15-minute quadrangle, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-35, 1 sheet, scale 1:48,000.

Bentley, R. D.; Campbell, N. P.; Powell, J. E., 1988b, Geologic map of the Poisel Butte 15-minute quadrangle, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-36, 1 sheet, scale 1:48,000.

Bentley, R. D.; Campbell, N. P.; Powell, J. E., 1993, Geologic maps of part of the Yakima fold belt, northeastern Yakima County, Washington: Washington Division of Geology and Earth Resources Open File Report 93-3, 13 p., 5 plates.

Campbell, N. P., 1977, Geology of the Snipes Mountain area, Yakima County, Washington: Washington Division of Geology and Earth Resources Open-File Report 77-8, 3 sheets, scale 1:24,000.

Campbell, N. P., 1979, Surficial geologic map of the Yakima quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 79-15, 1 sheet, scale 1:250,000.

Campbell, N. P., 1983, Correlation of late Cenozoic gravel deposits along the Yakima River drainage from Ellensburg to Richland, Washington: Northwest Science, v. 57, no. 3, p. 179-193.

Campbell, N. P.; Bentley, R. D., 1981, Late Quaternary deformation of the Toppenish Ridge uplift in south-central Washington: Geology, v. 9, no. 11, p. 519-524.

Choiniere, S. R.; Swanson, D. A., 1979, Magnetostratigraphy and correlation of Miocene basalts of the northern Oregon coast and Columbia Plateau, southeast Washington: American Journal of Science, v. 279, no. 7, p. 755-777.

Dalrymple, G. B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, no. 11, p. 558-560.

Foley, L. L., 1982, Quaternary chronology of the Palouse loess near Washtucna, eastern Washington: Western Washington University Master of Science thesis, 137 p.

Gulick, C. W., compiler, 1990a, Geologic map of the Moses Lake 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-1, 9 p., 1 plate.

Gulick, C. W., compiler, 1990b, Geologic map of the Ritzville 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-2, 7 p., 1 plate.

Hooper, P. R.; Kleck, W. D.; Knowles, C. R.; Reidel, S. P.; Thiessen, R. L., 1984, Imnaha Basalt, Columbia River Basalt Group: Journal of Petrology, v. 25, part 2, p. 473-500.

Kienle, C. F., Jr.; Bentley, R. D.; Anderson, James Lee, 1977, Geologic reconnaissance of the Cle Elum-Wallula lineament and related structures: Shannon & Wilson [Portland, Ore.], 75 p.

Kinnison, H. B.; Sceva, J. E., 1963, Effects of hydraulic and geologic factors on streamflow of the Yakima River basin, Washington: U.S. Geological Survey Water-Supply Paper 1595, 134 p., 3 plates.

Kittleman, L. R., 1973, Mineralogy, correlation, and grain-size distributions of Mazama tephra and other postglacial pyroclastic layers, Pacific Northwest: Geological Society of America Bulletin, v. 84, no. 9, p. 2957-2980.

Laval, W. N., 1956, Stratigraphy and structural geology of portions of south- central Washington: University of Washington Doctor of Philosophy thesis, 223 p., 11 plates.

McDonald, E. V.; Busacca, A. J., 1989, Record of pre-late Wisconsin floods and of late Wisconsin flood features in the Cheney-Palouse scabland—Trip C. *In* Joseph, N. L.; and others, editors, Geologic guidebook for Washington and adjacent areas: Washington Division of Geology and Earth Resources Information Circular 86, p. 337-346.

McKee, E. H.; Swanson, D. A.; Wright, T. L., 1977, Duration and volume of Columbia River basalt volcanism, Washington, Oregon, and Idaho [abstract]: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 463-464.

Montanari, Alessandro; Drake, Robert; Bice, D. M.; Alvarez, Walter; Curtis, G. H.; Turrin, B. D.; DePaolo, D. J., 1985, Radiometric time scale for the upper Eocene and Oligocene based on K/Ar and Rb/Sr dating of volcanic biotites from the pelagic sequence of Gubbio, Italy: Geology, v. 13, no. 9, p. 596-599.

Mullineaux, D. R.; Wilcox, R. E.; Ebaugh, W. F.; Fryxell, Roald; Rubin, Meyer, 1978, Age of the last major scabland flood of the Columbia Plateau in eastern Washington: Quaternary Research, v. 10, no. 2, p. 171-180.

Myers, C. W.; Price, S. M.; and others, 1979, Geologic studies of the Columbia Plateau—A status report: Rockwell Hanford Operations RHO-BWI-ST-4, 541 p., 53 plates.

Reidel, S. P.; Campbell, N. P.; Fecht, K. R.; Lindsey, K. A., 1994, Late Cenozoic structure and stratigraphy of south-central Washington. *In* Lasmanis, Raymond; Cheney, E. S., convenors, Regional geology of Washington State: Washington Division of Geology and Earth Resources Bulletin 80, p. 159-180.

Reidel, S. P.; Fecht, K. R., 1987, The Huntzinger flow—Evidence of surface mixing of the Columbia River basalt and its petrogenetic implications: Geological Society of America Bulletin, v. 98, no. 6, p. 664-677.

Reidel, S. P.; Tolan, T. L.; Hooper, P. R.; Beeson, M. H.; Fecht, K. R.; Bentley, R. D.; Anderson, James Lee, 1989, The Grande Ronde Basalt, Columbia River Basalt Group; Stratigraphic descriptions and correlations in Washington, Oregon, and Idaho. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 21-53.

Rietman, J. D., 1966, Remanent magnetization of the late Yakima Basalt, Washington State: Stanford University Doctor of Philosophy thesis, 87 p.

Rigby, J. G.; Othberg, K. L.; Campbell, N. P.; Hanson, L. G.; Kiver, E. P.; Stradling, D. F.; Webster, G. D., 1979, Reconnaissance surficial geologic mapping of the late Cenozoic sediments of the Columbia Basin, Washington: Washington Division of Geology and Earth Resources Open-File Report 79-3, 94 p., 7 plates.

Salvador, Amos, 1985, Chronostratigraphic and geochronometric scales in COSUNA stratigraphic correlation charts of the United States: American Association of Petroleum Geologists Bulletin, v. 69, no. 2, p. 181-189.

Shannon & Wilson, Inc., 1973, Geologic studies of Columbia River basalt structures and age of deformation—The Dalles-Umatilla region, Washington and Oregon; Boardman nuclear project: Portland General Electric Company, 1 vol., 2 plates.

Stoffel, K. L., 1984, Geology of the Grande Ronde lignite field, Asotin County, Washington: Washington Division of Geology and Earth Resources Report of Investigations 27, 79 p., 1 plate.

Swanson, D. A.; Anderson, James Lee; Bentley, R. D.; Byerly, G. R.; Camp, V. E.; Gardner, J. N.; 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., 12 plates.

Swanson, D. A.; Wright, T. L.; Hooper, P. R.; Bentley, R. D., 1979b, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p., 1 plate.

Tabor, R. W.; Waitt, R. B.; Frizzell, V. A., Jr.; Swanson, D. A.; Byerly, G. R.; Bentley, R. D., 1982, Geologic map of the Wenatchee 1:100,000 quadrangle, central Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1311, 26 p., 1 plate, scale 1:100,000.

Tolan, T. L.; Reidel, S. P.; Beeson, M. H.; Anderson, James Lee; Fecht, K. R.; Swanson, D. A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

U.S. Army Corps of Engineers, 1978, Yakima Valley regional water management study—Volume I, Summary; Volume II, Water quality; Volume III, Water budget; Volume IV, Geology and ground water: U.S. Army Corps of Engineers [Seattle], 4 v.

Waggoner, S. Z., compiler, 1990, Geologic map of the Rosalia 1:100,000 quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-7, 20 p., 1 plate.

Waitt, R. B., 1979, Late Cenozoic deposits, landforms, stratigraphy, and tectonism in Kittitas Valley, Washington: U.S. Geological Survey Professional Paper 1127, 18 p.

Waitt, R. B., 1980, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653-679.

Yeaton, W. J., 1923, The geology of the Zillah quadrangle: University of Chicago Master of Science thesis, 88 p., 6 plates.