NATURAL RESOURCES

Geologic Map of the Connell 1:100,000 Quadrangle, Washington

compiled by
Charles W. Gulick

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

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WASHINGTON STATE DEPARTMENT OF
Natural Resources
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INTRODUCTION

This map of the Connell 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 Company, and Washington State University and are the principal data sources for a 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 on p. 6). 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.

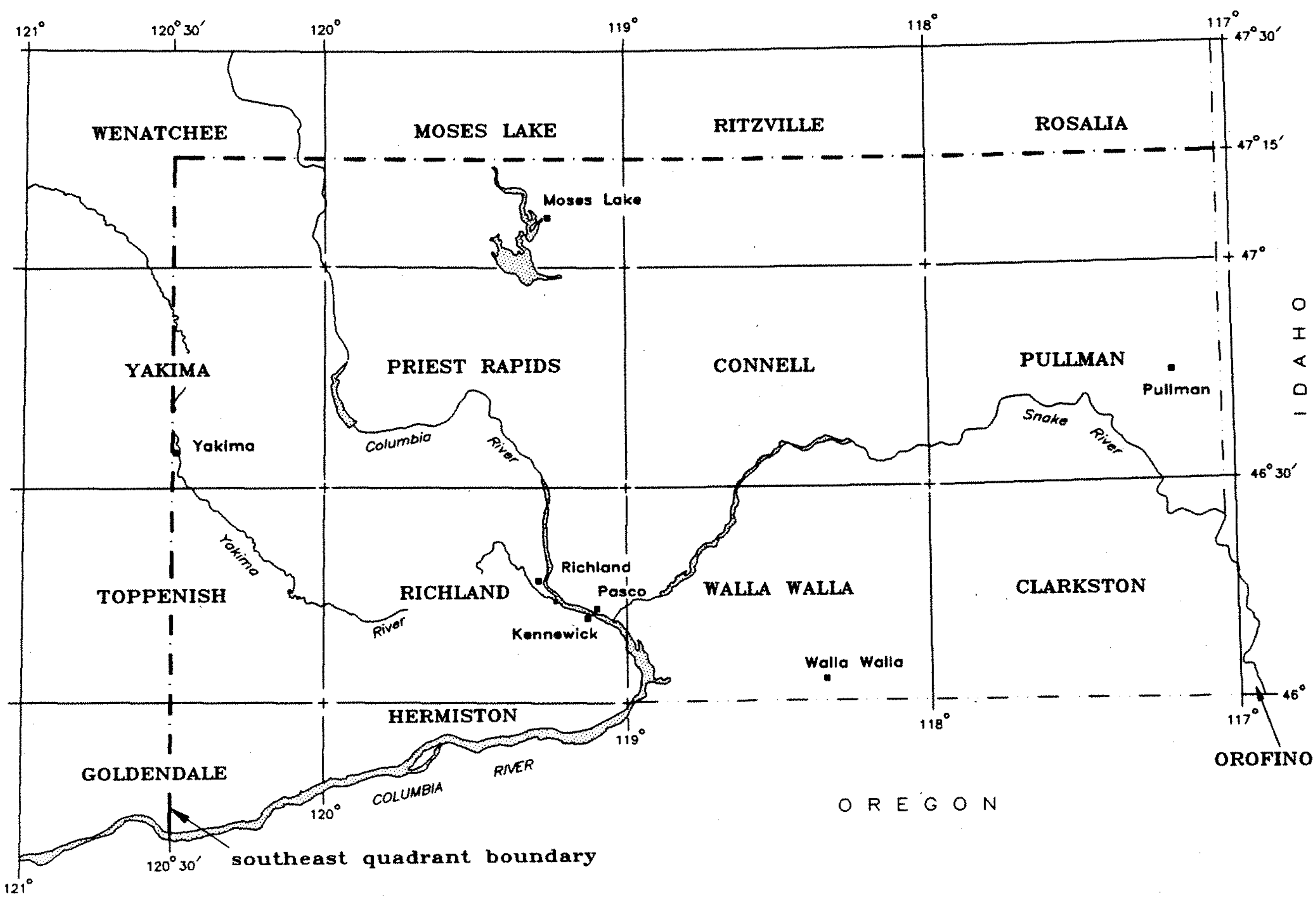

Figure 1. 1:100,000-scale quadrangles in the southeast quadrant of Washington.

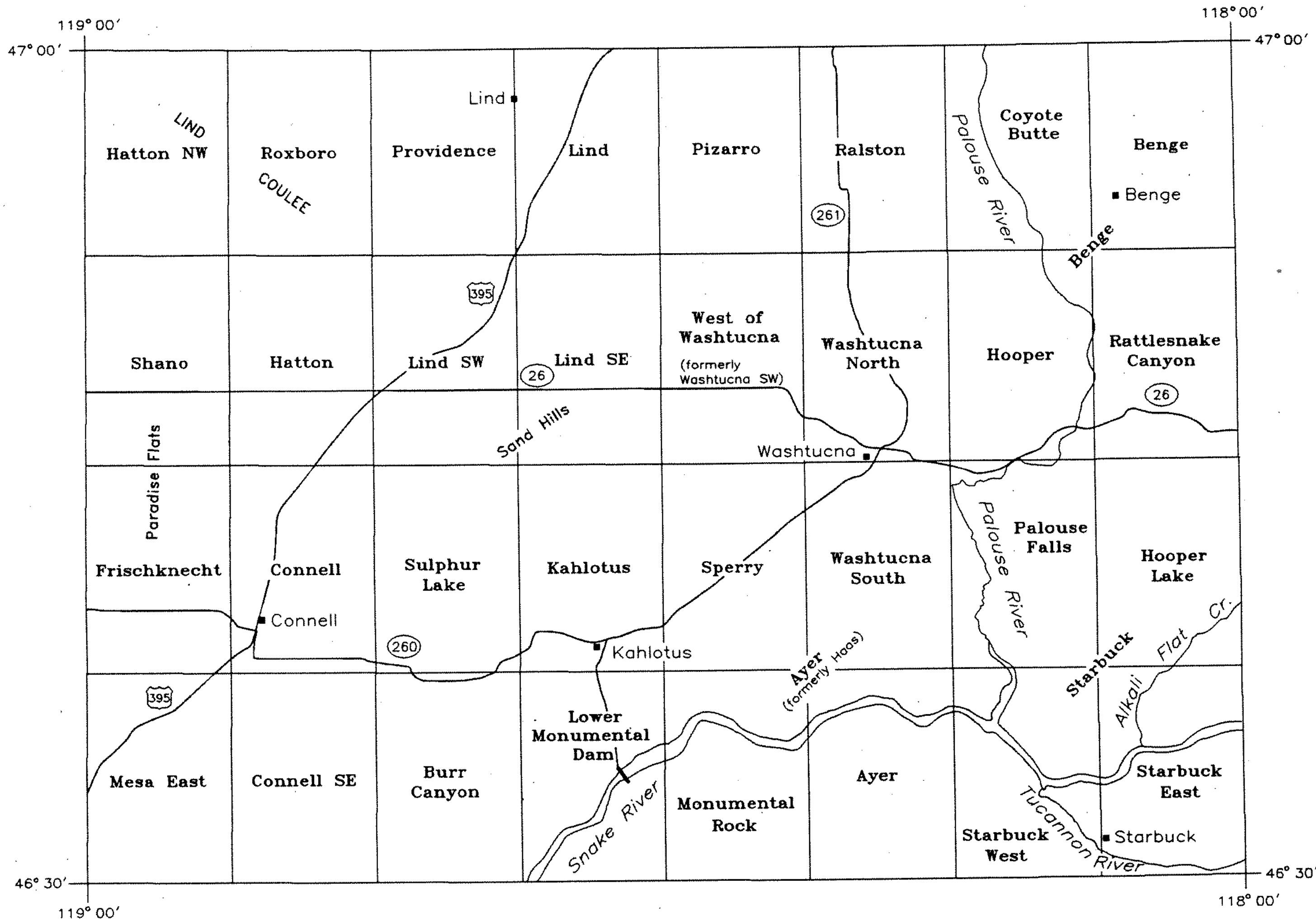

Figure 2. Selected geographic features and 7.5- and 15-minute quadrangles in the Connell 1:100,000 quadrangle.

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

The geology of the Connell 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This map was compiled in 1992-1994, using published and unpublished geologic maps as sources of data. The areas covered by these sources are shown on Figure 3. Except for Swanson and others (1980), Foundation Sciences, Inc. (1973), and Geomatrix Consultants, Inc. (1990), source maps with scales smaller than 1:125,000 were not used for geologic data. 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 (1979) and, with subsequent modifications, is universally used today. Figure 3 includes maps that were not used in compiling the geology shown in this report so as to make the source-of-data listing exhaustive and to inform the reader that these sources of data were not overlooked.

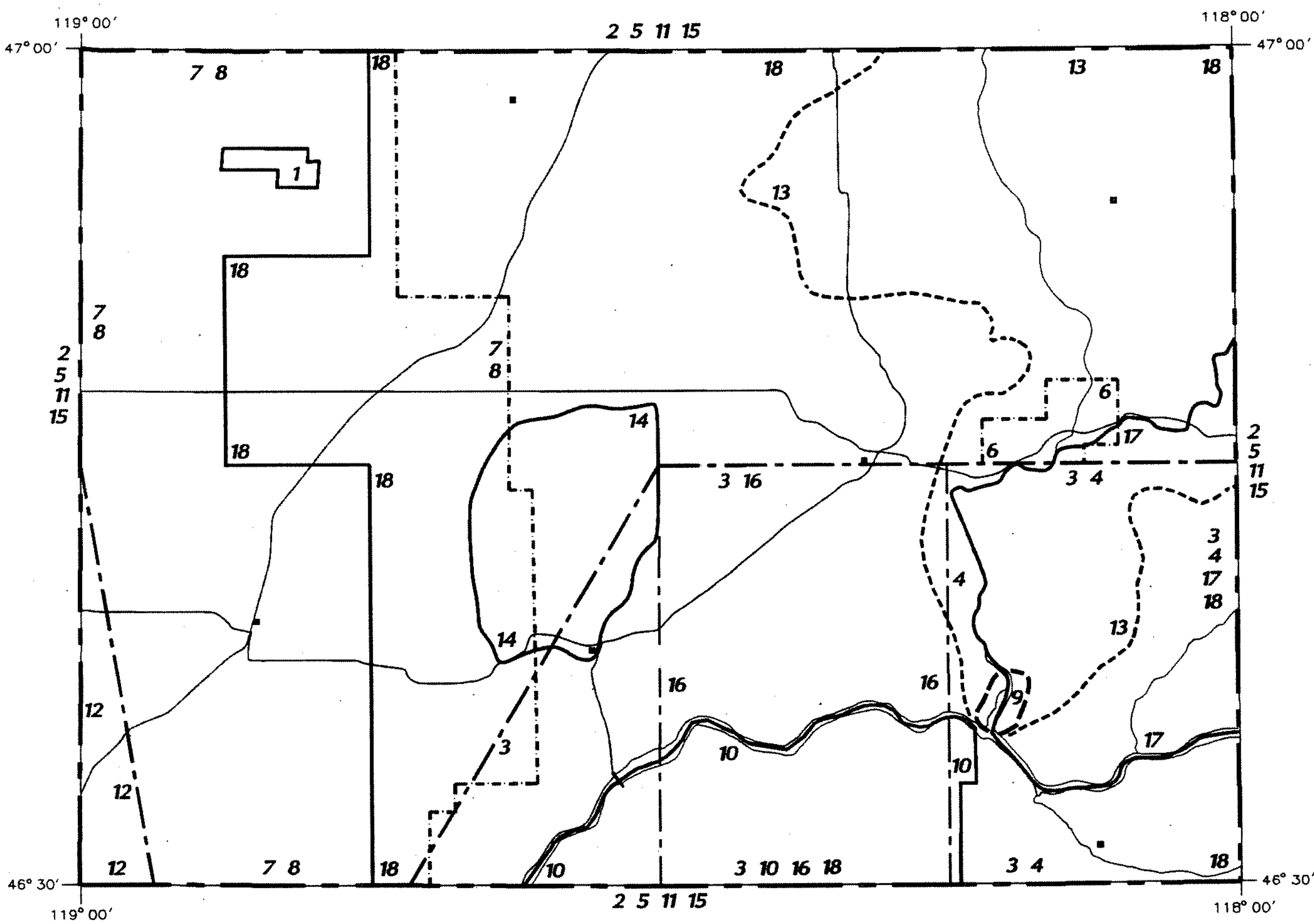

Figure 3. Sources of geologic map data for the Connell 1:100,000 quadrangle, Washington; *, sources of geologic data (outcrop/polygon pattern, contacts) used in this compilation; $, sources of structural feature data (folds, faults) used in this compilation.

1.* Burlington Environmental, Inc., 1990, fig. 3-1, scale 1:18,000.
2. Campbell and others, 1979, scale 1:250,000.
3.$ Foundation Sciences, Inc., 1980, plate 2, scale 1:170,000.
4.* Gard and Waldron, 1954, scale 1:62,500.
5.$ Geomatrix Consultants, Inc., 1990, fig. 2, scale 1:250,000.
6.* Golder Associates, Inc., 1992, fig. 4-2, scale about 1:24,370.
7. Grolier and Bingham, 1965, 7 sheets, scale 1:62,500.
8.* Grolier and Bingham, 1971, sheets 4 and 5, scale 1:62,500.
9.* Marshall, 1971, scale 1:6,600.
10. Molenaar, 1968, scale 1:127,000.
11. Myers, Price, and others, 1979, plate II-16, scale 1:250,000.
12. Myers, Price, and others, 1979, plate III-1, scale 1:62,500.
13. Nassar and Walters, 1975, scale 1:250,000.
14. Pardee, 1928, fig. 4, scale 1:125,000.
15.*$ Swanson and others, 1980, 2 sheets, scale 1:250,000.
16. Trimble, 1954, scale 1:62,500.
17. Walters and Glancy, 1969, plate 3, scale 1:84,480.
18.* G. D. Webster, Wash. State Univ., unpub. maps, 1978, 13 sheets, scale 1:24,000; 3 sheets, scale 1:62,500.

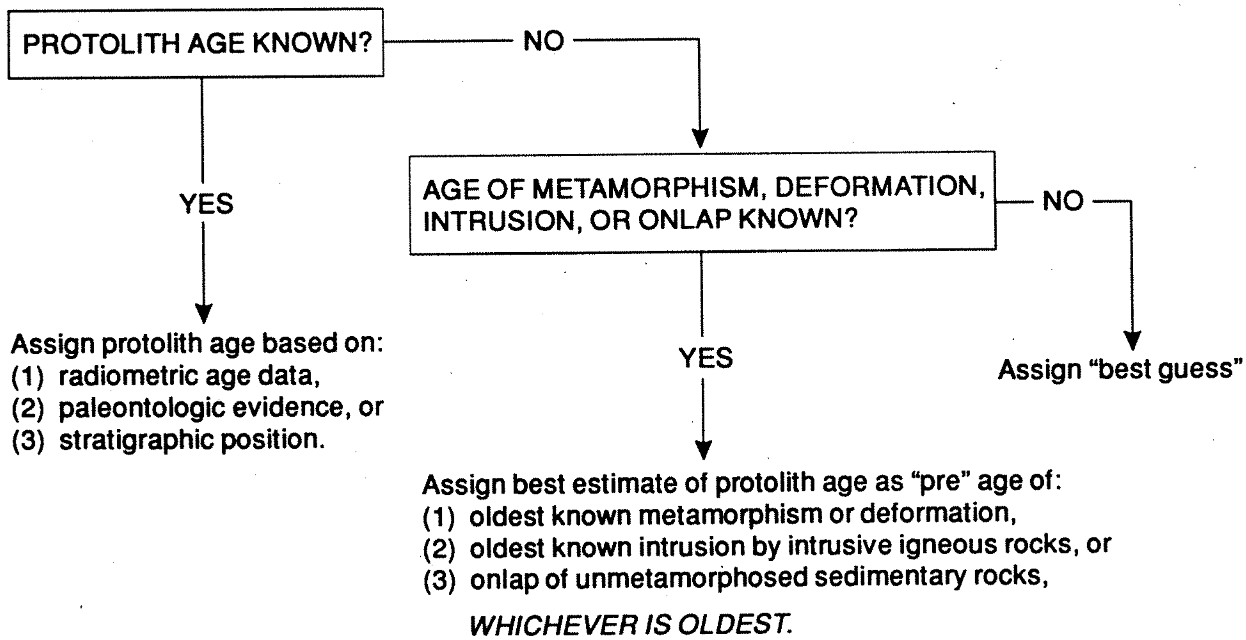

Figure 4. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description includes information about how the age of the unit was determined.

One group of unpublished documents was used as a source of geologic map data: G. D. Webster's 7.5-minute and 15-minute geologic maps of post-basalt geologic units for most of the Connell 1:100,000-scale quadrangle. These maps are cited as G. D. Webster, Wash. State Univ., unpub. maps, 1978.

Figure 3 identifies (with asterisks) six primary sources of data that were used to compile the outcrop patterns of bedrock and Quaternary units. The mapping of Swanson and others (1980) was also used to differentiate units of the Columbia River Basalt Group by superimposing their interpretation of the distribution of these members on undivided basalt outcrop patterns that were derived from Gard and Waldron (1954) or G. D. Webster (Wash. State Univ., unpub. maps, 1978). Swanson and others (1980), Foundation Sciences, Inc. (1980), and Geomatrix Consultants, Inc. (1990) were the only sources used for compiling structural features (faults and folds).

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 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 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 generalized stratigraphic relations of the Columbia River Basalt Group are shown in Figure 5.

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		
				Umtanum unit		
				Ortley unit		
				Armstrong Canyon unit		
			PRINEVILLE BASALT	Meyer Ridge unit		R_2
				Grouse Creek unit		
				Wapshilla Ridge unit		
				Mt. Horrible unit		
			PICTURE GORGE BASALT	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 Columbia River Basalt Group units. This figure includes units that do not occur in the Connell quadrangle. Modified from Reidel and others (1989).

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, 1994, Geologic map of the Connell 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-14, 18 p., 1 plate.

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, 22 p., 1 plate.

Reidel, S. P.; Fecht, K. R., compilers, 1994, Geologic map of the Priest Rapids 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-13, 22 p., 1 plate.

Reidel, S. P.; Fecht, K. R., 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, 1994, Geologic map of the east half of the Yakima 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-12, 22 p., 1 plate.

Schuster, J. E., compiler, 1994, Geologic map of the Walla Walla 1:100,000 quadrangle: 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

Acknowledgments

G. D. Webster of Washington State University provided unpublished geologic maps. P. R. Hooper of Washington State University, D. A. Swanson of the U.S. Geological Survey, and Webster reviewed the map and text in detail and provided excellent suggestions. N. A. Eberle, C. F. T. Harris and K. G. Ikerd of the DGER cartographic staff and K. M. Reed and J. M. Roloff of the DGER editorial staff prepared final copy and provided editorial support. P. Weyant color-edited the map. J. E. Schuster coordinated the project and attended to many of the details required to release this report.

DESCRIPTIONS OF MAP UNITS

Sedimentary Deposits

Quaternary and Older Sedimentary Deposits

Qd

Dune sand (Holocene)—Eolian medium to fine sand and silt; grains typically composed of quartz, basalt, or feldspar; volcanic ash is present locally; dunes comprise the Sand Hills in the center of the map area. Description from Grolier and Bingham (1971).

Qla

Lacustrine and fluvial deposits (Holocene)—Clay, silt, and sand in interior drainage basins; occurs at three localities in the channeled scabland tract in the northeast part of the map area. Description from Rigby and others (1979).

Qa

Alluvium (Holocene to Pleistocene)—Clay, silt, sand, and gravel deposits of varied thickness, sorting and composition, commonly including reworked loess and basalt; includes Mazama tephra at numerous places; occurs in valley bottoms throughout the map area; age inferred from geomorphology, ages of parent materials, and the presence of Mazama tephra (about 7 ka; Kittleman, 1973, p. 2958; or 6,845 $\pm$ 50 ka; Bacon, 1983). Description from Myers, Price, and others (1979).

Qaf

Alluvial fans (Holocene to Pleistocene)—Fluvial deposits of silt, sand, and gravel of various lithologies including nearly pure reworked loess, or mixtures of loess with angular to rounded clasts of basalt; typically occurs where tributaries enter major drainage canyons; commonly cone-shaped; overlain in places by loess; age inferred from geomorphic form and ages of parent materials. Description compiled from: Myers, Price, and others (1979); Rigby and others (1979).

Ql

Loess (Holocene to Pleistocene)—Homogeneous, unconsolidated eolian silt and fine sand; buff, tan, gray-tan, light-brown, and pale-orange; massive; locally contains thin, discontinuous caliche layers, tephra beds, and paleosols; a maximum of about 250 ft thick; predominantly composed of angular quartz grains with lesser amounts of feldspar, mica, and hornblende; uppermost loess locally contains Mazama tephra (Foley, 1982, p. 90), about 7 ka (Kittleman, 1973, p. 2958; Bacon, 1983); locally contains Mount St. Helens set S tephra dated at 13 ka (Mullineaux and others, 1978); paleomagnetic polarity measurements indicate 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); typical geomorphic expression of loess throughout the region is a complex of dunes; dune formation by southwesterly winds is indicated by long, gentle southwest sides and steep northeast sides, by strong northeast alignment of dune long axes, and by uniformly decreasing grain size to the northeast; includes the Palouse Formation. Description compiled from: Grolier and Bingham (1971); Myers, Price, and others (1979); Rigby and others (1979); Schuster (1994).

Qls

Mass-wasting deposits (Holocene to Pleistocene)—Talus, predominantly basalt, landslide deposits, and colluvium; found at the base of slopes and on lower parts of slopes; age inferred from geomorphology, stratigraphic position, and ages of parent materials; occurrences along the Palouse River (T. 14 N., R. 36-37 E.; T. 13 N., R. 37 E.) are basalt talus. Description compiled from: Grolier and Bingham (1971); Myers, Price, and others (1979); Rigby and others (1979).

Qfs

Outburst flood deposits, silt and sand (Pleistocene)—Silt and fine sand, predominantly quartz and feldspar, with stringers of coarse sand and gravel; rhythmically bedded; deposited by relatively low energy slack waters of catastrophic floods and/or surges of catastrophic floods released by glacial Lake Missoula; locally contains ice-rafted cobbles, clastic dikes, tephra beds, and ice-melt structures; commonly cross-bedded; equivalent to the Touchet Beds of the Walla Walla area; 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); outburst flood deposits (unit Qfg) overlie 14-15 ka Bonneville flood deposits in T. 13 N., R. 35 E. (also see Qfg description below) and to the east of the map area on the adjacent Pullman quadrangle (Gulick, 1994); at two locations along the Snake River known to be underlain by outburst flood deposits, gravel (unit Qfg): (1) the bar in parts of secs. 3, 9, and 10, T. 12 N., R. 34 E.; and (2) the bar in parts of secs. 8 and 9, T. 12 N., R. 34 E.; 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 unit (Waitt, 1980, p. 667). Periodic, colossal jökulhlaups have been proposed as the origin of some rhythmic strata in the flood-affected regions of southeastern Washington (Waitt, 1980, 1984, 1985; Atwater, 1986). Others question the jökulhlaups origin because some rhythmites occur where stream velocity and erosional power would have been high during a cataclysmic flood (Baker and others, 1991). Description compiled from: Grolier and Bingham (1971); Myers, Price, and others (1979); Rigby and others (1979); Schuster (1994).

Qfg

Outburst flood deposits, gravel (Pleistocene)—Angular to subrounded pebbles, cobbles, and boulders in a matrix of gravel and sand; poorly sorted; local foreset bedding; clasts of diverse rock types but dominantly basaltic; some fragments as much as several feet across; generally less than 15 m thick; locally contains tephra and locally overlain by loess; known to be underlain by Bonneville flood deposits (unit Qf_b) at the bar along the Snake River in parts of secs. 21, 22, 26, 27, and 28, T. 13 N., R. 35 E.; deposited by high-energy floodwaters associated with the repeated failure of an ice dam(s) that impounded Lake Missoula; same age as finer outburst flood deposits (unit Qfs above). Description from Rigby and others (1979).

Qfbg

Outburst flood deposits, backwater gravel (Pleistocene)—Gravel of diverse size and composition, dominantly basalt, that was deposited by Lake Missoula flood waters that moved up drainages that drain into the scabland tract from the south and southeast, specifically the Tucannon River and a portion of the Snake River in the southeast corner of the map. Description from Rigby and others (1979).

Qf_b

Bonneville flood deposits (Pleistocene)—Gravel and sandy gravel deposits; dominantly basaltic sediments with lesser amounts of granitic and greenschist-facies volcaniclastic constituents. Currently accepted age estimates based on radiocarbon dates from wood collected in Lake Bonneville paleodeltas are 14-15 ka (Scott and others, 1982). This unit occurs in a small area in sec. 31, T. 13 N., R. 38 E. and along the north bank of the Snake River in secs. 21, 22, and 26-28, T. 13 N., R. 35 E. where it is overlain by unit Qfg. The latter is the farthest downstream occurrence of Bonneville flood sediments identified along the Snake River. Description from Hooper and Webster (1982).

QMg

Gravel (Pleistocene to Miocene?)—Pebble to cobble gravel composed of approximately 30 percent basalt and 70 percent metavolcaniclastic, porphyritic, and metamorphic rocks, and lesser granitic rocks; as much as 60 m thick; occurs in large bars along the Snake River and referred to as older Snake River gravels by Rigby and others (1979); virtually all outcrops are overlain by thin to thick veneers of slackwater Missoula flood sediments (unit Qfs); differentiated from Missoula flood deposits (units Qfg and Qfs) and Bonneville flood deposits (unit Qf_b) on the adjacent Pullman geologic map to the east (Gulick, 1994) by composition of clasts, which are overwhelmingly basaltic in the Missoula flood deposits (95%+) and predominantly basaltic in the Bonneville flood deposits (>50%); older than Missoula outburst flood deposits (about 19 ka) and/or Bonneville flood deposits and possibly as old as Miocene? (younger than intracanyon basalt flow of the Lower Monumental Member); may be derived from a flooding event(s) associated with the ancestral Salmon River (Webster and others, 1982). Description from G. D. Webster (Wash. State Univ., unpub. maps, 1978).

Tertiary Sedimentary Deposits

Ringold Formation

The Ringold Formation consists of fine and coarse, semi-indurated, fluvial and lacustrine deposits in and near the Pasco Basin (Lindsey, 1991). In the Connell 1:100,000 quadrangle the fine facies of this unit crops out extensively along the west edge of the map on Paradise Flats and in four exposures in Lind Coulee west of Paradise. The formation is as thick as 185 m in the deepest part of the Cold Creek syncline at the Hanford Site, which is southwest of the map area (Lindsey, 1991). Extensive research at Hanford has revealed that the unit is overlain by unconsolidated Pliocene and Pleistocene deposits and underlain by the Ice Harbor Member of the Saddle Mountains Basalt (Fecht and others, 1985; Lindsey, 1991), which was dated at 8.5 Ma by McKee and others (1977). At the White Bluffs north of Pasco, the lower 20 m of the Ringold has normal magnetic polarity, and the upper 100 m has reversed polarity (Rigby and others, 1979, p. 16). Microtine (rodent) fossils and magnetic polarity data indicate that the unit is older than 3.4 Ma (Fecht and others, 1985, p. 37). The conglomerate facies of the Ringold Formation is not present on the Connell quadrangle.

$P_L Mc$

Continental sedimentary deposits (Pliocene to upper Miocene)—Interbedded sand, silt, and clay beds with local pebble lenses and stringers; white, gray, green, red, or tan; silty clay units horizontally laminated and generally lacking current-generated sedimentary structures; silt and sand units display horizontal, ripple, and cross bedding; sand chiefly quartz and feldspar; commonly capped by caliche; contains diatomite beds, ash beds, and fossils. Consists of the finer facies of the Ringold Formation. Description compiled from: Myers, Price, and others (1979); Rigby and others (1979); Schuster (1994).

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 three formations crop out in the Connell 1:100,000-scale quadrangle. Formal and informal stratigraphic units currently recognized in the Columbia River Basalt Group are shown on Figure 5.

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

Saddle Mountains Basalt

Mv_{slm}

Lower Monumental Member (upper Miocene)—Single flow; nearly aphyric; microphenocrysts of olivine in opaque glass; flow partly filled an ancestral Snake River canyon; normal magnetic polarity (Choiniere and Swanson, 1979); average thickness about 25 m, with maximum preserved thickness of 60 m; the single flow is also the youngest of the Columbia River Basalt Group; K-Ar age approximately 6 Ma (McKee and others, 1977). An underlying sequence of fluvial sand and gravel (considered to be part of this member) is locally present. Description from Swanson and others (1980).

Mv_{sem}

Elephant Mountain Member (upper Miocene)—Two nearly aphyric basalt flows (Swanson and others, 1980); normal to transitional magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979); average total thickness of about 30 m; occurs as remnants of intracanyon flow(s) along an ancestral Snake River canyon; 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).

Upper flow—Black; weathers reddish-brown; fine- to coarse-grained, locally diktytaxitic, and generally coarser grained than lower flow; abundant microphenocrysts of plagioclase; vesicular flow top; thin entablature; well-developed colonnade with columns as much as

2 m in diameter; vesicle sheets that cause platy jointing; locally pillowed base (Myers, Price, and others, 1979).

Lower flow—Black to dark gray; weathers reddish-gray; fine-grained to glassy, locally diktytaxitic; felty texture caused by abundant plagioclase microphenocrysts; thick, locally tiered entablature caused by horizontal vesicle sheets; well-developed colonnade with 1.0- to 2.0-m-diameter columns; local pillows and vesicle cylinders (Myers, Price, and others, 1979).

~~M~~v_s

Saddle Mountains Basalt, undivided (middle Miocene)—Two or more intracanyon flows; plagioclase-phyric basalt (phenocrysts as large as 10 mm across); major-element composition similar to that of the Frenchman Springs chemical type (Wright and others, 1973) but differs in both trace-element content and Sr-isotope ratios; approximately 60 m thick. Occurs at two localities (sec. 17, T. 13 N., R. 35 E., and secs. 21-22, T. 13 N., R. 34 E.). Description from Swanson and others (1980).

~~M~~v_{sp}

Pomona Member (middle Miocene)—One or more flows; medium-grained; medium-gray; small phenocrysts of plagioclase (generally less than 5 mm long and commonly wedge shaped), clinopyroxene, and olivine; locally contains large clots (as much as 100 mm or more across) of plagioclase, pyroxene (including very rare hypersthene), and olivine, which are thought by Swanson and others (1980) to have formed during crystallization after eruption; average thickness in the map area about 30 m; reversed magnetic polarity (Choiniere and Swanson, 1979); occurs as remnants of intracanyon flow(s) along an ancestral Snake River canyon; isotopically dated at 12 Ma (K-Ar method) by McKee and others (1977) and 12 Ma (^{40}Ar-^{39}Ar method) (S. P. Reidel, Wash. State Univ., unpub. data, 1991). Description from Swanson and others (1980).

Myers, Price, and others (1979) describe two flows:

Upper flow—Black to gray-black; weathers gray; fine- to medium-grained; phyric with plagioclase and olivine phenocrysts as much as 5 mm across; locally microvesicular to diktytaxitic; well-developed entablature, generally with fanning columns; poorly to well-developed colonnade of 1-m-diameter columns.

Lower flow—Blue-black; weathers black-gray; fine- to medium-grained; plagioclase phenocrysts as much as 1 cm across; sparse olivine phenocrysts as much as 0.5 mm across; glomerocrysts of plagioclase and pyroxene as much as 2 cm across; well-developed entablature; hackly jointing and fanning columns.

~~M~~v_{se}

Esquatzel Member (middle Miocene)—Single flow; phyric; irregularly distributed phenocrysts of plagioclase and clinopyroxene less than 5 mm in diameter; locally contains hyaloclastite; occurs as remnants of an intracanyon flow(s) along an ancestral Snake River canyon; normal magnetic polarity (Choiniere and Swanson, 1979). Description from Swanson and others (1980).

Mv_{sa}

Asotin Member (middle Miocene)—Single flow; contains microphenocrysts of plagioclase and olivine with subophitic augite in coarser grained zones; typically forms small columns; normal magnetic polarity (Camp, 1976; Swanson and others, 1977, 1979); isotopically dated (K-Ar method) at 13 Ma by Reidel and Fecht (1987); the Asotin flow filled the Lewiston Basin east of the map area, where it is particularly thick, then followed Union Flat Creek on the adjacent Pullman quadrangle (Gulick, 1994) and ultimately reached the north side of the Saddle Mountains west of the map area (Swanson and others, 1980); exposures of the Asotin flow in the Connell quadrangle occur north of the Palouse River channel where they are well exposed in the southern half of T. 16 N., R. 36 E. along a series of dry falls (secs. 26-29) in the Cheney-Palouse scabland tract; a second, southwest-trending cluster of exposures begins along the southern edge of T. 16 N., R. 38 E., which is just west of the confluence of Union Flat Creek and the Palouse River on the Pullman quadrangle to the east; in the Lewiston Basin, the flow is sparsely plagioclase- and olivine-phyric and hackly jointed and forms prominent cliffs. Description compiled from: Hooper and Webster (1982); Swanson and others (1980).

Mv_{swc}

Wilbur Creek Member (middle Miocene)—One, possibly two flows; fine-grained to glassy; sparse large, locally skeletal plagioclase phenocrysts and scarce olivine microphenocrysts; composition similar to the Grande Ronde chemical type except for higher P_2O_5 and K_2O contents; normal magnetic polarity; average thickness less than 20 m; exposed in two large areas in the Cheney-Palouse scabland tract in the northeast portion of the map (T. 16 N., R. 36-37 E.); locally includes underlying thin sedimentary deposits. Occurs adjacent to the Asotin Member, with which it is known to mix in the Pasco Basin (Reidel and Fecht, 1987). Description compiled from: Hooper and Webster (1982); Swanson and others (1980).

Wanapum Basalt

Mv_{wpr}

Priest Rapids Member (middle Miocene)—Multiple flows; medium-grained; scattered phenocrysts of plagioclase (typically less than 5 mm, rarely as much as 10 mm long) and olivine (0.5-1 mm in diameter) in a matrix of intergranular pyroxene, ilmenite blades, and some devitrified glass; reversed magnetic polarity (Rietman, 1966); average thickness 35 m; consists of Lolo and Rosalia chemical types (Wright and others, 1979); the only dikes of Lolo composition capable of feeding such broad westward-travelling sheet flows lie east of the map area; isotopic age estimate of 14.5 Ma (Tolan and others, 1989). Description compiled from: Hooper and Webster (1982); Swanson and others (1980).

Mv_{wr}

Roza Member (middle Miocene)—Two or more flows of the Roza chemical type (Wright and others, 1973); several percent conspicuous, evenly distributed, single or locally clotted plagioclase phenocrysts averaging about 10 mm across and microphenocrysts of olivine and augite in an intergranular matrix; some flows distinguishable on the basis of phenocryst size and abundance; minor tephra; locally includes several meters of saprolite, subarkosic sandstone, and siltstone at the base of the member where the Frenchman Springs Member is absent; locally, especially near vents, several thin flows may be present; transitional magnetic polarity (Rietman, 1966), but some flows of reversed magnetic polarity (Choiniere and Swanson, 1979); average thickness 40 m; flows emanated from a narrow, linear vent system evidenced by dikes and vents, tephra deposits (including welded spatter), and relict cones that trend northwest from just north of Enterprise, Oregon, to an area on the Pullman quadrangle to the east (T. 17 N., R. 39 E.), a distance of >120 km (Bingham, 1970; Swanson and others, 1975); prevailing slope directed flows westward; 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). Description compiled from: Swanson and others (1980); Hooper and Webster (1982).

Mv_{wfs}

Frenchman Springs Member (middle Miocene)—Multiple flows, minor tephra, and dikes of the Frenchman Springs chemical type (Wright and others, 1973); many flows contain plagioclase glomerocrysts as much as 50 mm across, elsewhere nearly aphyric flows resemble the underlying Grande Ronde Basalt; lower flow(s) generally more phyric than middle and upper flows; basal flow commonly pillowed; normal (Rietman, 1966) to excursional magnetic polarity; isotopic age estimate of 15.3 Ma for basalt of Sand Hollow in the middle of the member (Tolan and others, 1989); includes saprolite; subarkosic sedimentary rocks commonly occur at the base of the member; informal Frenchman Springs subunits defined by Beeson and others (1985) are shown on Figure 5. Description from Swanson and others (1980).

Grande Ronde Basalt

Grande Ronde Basalt (middle Miocene)—Multiple flows, dikes, and minor tephra that form the thickest and most voluminous portion (87%) of the Columbia River Basalt Group; generally aphyric and fine-grained; groundmass contains plagioclase, augite, pigeonite, and glass; altered glass locally constitutes as much as 75 percent of a flow but is typically less than 50 percent; plagioclase phenocrysts are sparse, and microphenocrysts of orthopyroxene, pigeonite, and olivine are rare; blocky jointing is common, but entablature and columnar jointing are also present. At least 120 flows are known; these are divided into 17 informal units (Reidel and others, 1989, p. 23, 36; Fig. 5). In the Blue Mountains, southeast of the map area, the Grande Ronde has a maximum aggregate thickness of more than 1,235 m, and the maximum thickness exposed at a single locality is about 1,050 m. Polarity determination using a portable fluxgate magnetometer is the primary means of subdivision for these flows. The formation is divided into four magnetostratigraphic units (R_1, N_1, R_2, N_2), the uppermost one of which crops out on the Connell quadrangle. Unit Mv_{gN2} occurs extensively in the Snake River canyon as well as in the canyons of Alkali Flat Creek and the Palouse River, both of which are tributaries of the Snake River along the southern border of this map. The Grande Ronde is the oldest identified rock unit on this map and is overlain by the Wanapum Basalt, commonly with an intervening saprolite, sedimentary interbed, or both. Isotopic age estimates range from 15.6 to 16.9 Ma (Baksi, 1989, p. 109; age information is summarized by Reidel and others, 1989, p. 24-25). The type locality is in the canyon of the Grande Ronde River north of the mouth of Joseph Creek (secs. 21-23, T. 7 N., R. 46 E.) in the Clarkston 1:100,000-scale quadrangle (Camp and others, 1978). Description compiled from: Swanson and others (1980); Reidel and others (1989); Schuster (1994). The single magnetostratigraphic unit on the Connell quadrangle is:

Mv_{gN2} Upper flows of normal magnetic polarity.

REFERENCES CITED

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

Atwater, B. F., 1986, Pleistocene glacial-lake deposits of the Sanpoil River valley, northeastern Washington: U.S. Geological Survey Bulletin 1661, 39 p., 3 plates.

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, p. 57-115.

Baker, V. R.; Bjornstad, B. N.; Busacca, A. J.; Fecht, K. R.; Kiver, E. P.; Moody, U. L.; Rigby, J. G.; Stradling, D. F.; Tallman, A. M., 1991, Quaternary geology of the Columbia Plateau. *In* Morrison, R. B., editor, Quaternary nonglacial geology—Conterminous U.S.: Geological Society of America DNAG Geology of North America, v. K-2, p. 215-250.

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.

Bingham, J. W., 1970, Several probable source vents for the Roza and Priest Rapids type basalts in Whitman and Adams Counties, Washington. *In* Gilmour, E. H.; Stradling, D. F., editors, Proceedings of the second Columbia River basalt symposium: Eastern Washington State College Press, p. 171-172.

Burlington Environmental, Inc., 1990, Site characterization report, T-16 Ranch, Lind, Washington. *In* ECOS Corporation, ECOS Corporation RCRA permit application, Section E—Groundwater monitoring, submitted to Washington Dept. of Ecology July 31, 1990: ECOS Corporation, 3 v., 1 pl.

Camp, V. E., 1976, Petrochemical stratigraphy and structure of the Columbia River basalt, Lewiston Basin area, Idaho-Washington: Washington State University Doctor of Philosophy thesis, 201 p., 1 pl.

Camp, V. E.; Price, S. M.; Reidel, S. P., 1978, Descriptive summary of the Grande Ronde Basalt type section, Columbia River Basalt Group: Rockwell Hanford Operations RHO-BWI-LD-15, 26 p.

Campbell, N. P.; Lillie, J. T.; Webster, G. D., 1979, Surficial geologic map of the Walla Walla quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 79-13, 1 sheet, scale 1:250,000.

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.

Fecht, K. R.; Reidel, S. P.; Tallman, A. M., 1985, Paleodrainage of the Columbia River on the Columbia Plateau of Washington State—A summary: Rockwell Hanford Operations RHO-BW-SA-318 P, 55 p.

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

Foundation Sciences, Inc., 1980, Geologic reconnaissance of parts of the Walla Walla and Pullman, Washington, and Pendleton, Oregon 1° x 2° AMS quadrangles: U.S. Army Corps of Engineers [Seattle, Wash.], 83 p., 3 pl.

Gard, L. M., Jr.; Waldron, H. H., 1954, Geology of the Starbuck quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-38, 1 sheet, scale 1:62,500.

Geomatrix Consultants, Inc., 1990, Seismotectonic evaluation, Walla Walla section of the Columbia Plateau geomorphic province; Final report: Geomatrix Consultants, Inc. [San Francisco, Calif., under contract to] U.S. Bureau of Reclamation, 1 v., 6 pl.

Golder Associates, Inc., 1992, Draft geohydrological assessment report for proposed municipal solid waste landfill and recycling center, Washtucna, Adams County, Washington: Golder Associates, Inc. [under contract to] Waste Management of Washington, 1 v.

Grolier, M. J.; Bingham, J. W., 1965, Geologic map of parts of Grant, Adams, and Franklin Counties, Washington: U.S. Geological Survey Open-File Report, 7 sheets, scale 1:62,500. (Same as Grolier and Bingham, 1971, U.S. Geological Survey Miscellaneous Geologic Investigations Map I-589.)

Grolier, M. J.; Bingham, J. W., 1971, Geologic map and sections of parts of Grant, Adams, and Franklin Counties, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-589, 6 sheets, scale 1:62,500.

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 pl.

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 pl.

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, 22 p., 1 pl.

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.

Hooper, P. R.; Webster, G. D., 1982, Geology of the Pullman, Moscow West, Colton, and Uniontown 7.5-minute quadrangles, Washington and Idaho: Washington Division of Geology and Earth Resources Geologic Map GM-26, 1 sheet, scale 1:62,500.

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.

Lindsey, K. A., 1991, Revised stratigraphy for the Ringold Formation, Hanford site, south-central, Washington: Westinghouse Hanford Co. WHC-SD-EN-EE-004, 12 p.

Marshall, A. G., 1971, An alluvial chronology of the lower Palouse River canyon and its relation to local archaeological sites: Washington State University Master of Arts thesis, 73 p., 1 pl.

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.

Molenaar, Dee, 1968, A geohydrologic reconnaissance of northwestern Walla Walla County, Washington: Washington Department of Water Resources Monograph 1, 1 sheet, scale 1:63,360.

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 pl.

Nassar, E. G.; Walters, K. L., 1975, Water in the Palouse River basin, Washington: Washington Department of Ecology Water-Supply Bulletin 39, 246 p., 1 pl.

Pardee, J. T., 1928, Geology of reservoir sites near Washtucna and Kahlotus, Washington: U.S. Geological Survey Open-File Report, 25 p., 1 pl.

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 pl.

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.

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 pl.

Scott, W. E.; Pierce, K. L.; Bradbury, J. P.; Forester, R. M., 1982, Revised Quaternary stratigraphy and chronology in the American Falls area, southeastern Idaho. *In* Bonnichsen, Bill; Breckenridge, R. M., editors, Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 581-595.

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 pl.

Swanson, D. A.; Wright, T. L.; Camp, V. E.; Gardner, J. N.; Helz, R. T.; Price, S. M.; Reidel, S. P.; 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, 2 sheets, scale 1:250,000.

Swanson, D. A.; Wright, T. L.; Camp, V. E.; Gardner, J. N.; Helz, R. T.; Price, S. A.; Ross, M. E., 1977, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Open-File Report 77-100, 10 p., 2 pl.

Swanson, D. A.; Wright, T. L.; Helz, R. T., 1975, Linear vent systems and estimated rates of magma production and eruption for the Yakima Basalt on the Columbia Plateau: American Journal of Science, v. 275, no. 8, p. 877-905.

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

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 pl., 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.

Trimble, D. E., 1954, Geology of the Haas quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-43, 1 sheet, scale 1:62,500.

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 pl.

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

Waitt, R. B., 1984, Periodic jökulhlaups from Pleistocene Lake Missoula—New evidence from varved sediment in northern Idaho and Washington: Quaternary Research, v. 22, no. 1, p. 46-58.

Waitt, R. B., 1985, Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271-1286.

Walters, K. L,; Glancy, P. A., 1969, Reconnaissance of geology and of ground-water occurrence in Whitman County, Washington: Washington Department of Water Resources Water Supply Bulletin 26, 169 p.

Webster, G. D.; Kuhns, M. J. P.; Waggoner, G. L., 1982, Late Cenozoic gravels in Hells Canyon and the Lewiston basin, Washington and Idaho. *In* Bonnichsen, Bill; Breckenridge, R. M., editors, Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 669-683.

Wright, T. L.; Grolier, M. J.; Swanson, D. A., 1973, Chemical variation related to the stratigraphy of the Columbia River basalt: Geological Society of America Bulletin, v. 84, no. 2, p. 371-385.

Wright, T. L.; Swanson, D. A.; Helz, R. T.; Byerly, G. R., 1979, Major oxide, trace element, and glass chemistry of Columbia River basalt samples collected between 1971 and 1977: U.S. Geological Survey Open-File Report 79-711, 146 p.

Unpublished Mapping

Webster, G. D., 1978, Washington State University: Geologic maps of the Burr Canyon, Hatton, Kahlotus, Lind, Lind SE, Lind SW, Lower Monumental, Pizarro, Providence, Ralston, Sulphur Lake, Washtucna North, and Washtucna SW (subsequently renamed West of Washtucna) 7.5-minute quadrangles, scale 1:24,000, 13 sheets; and the Benge, Haas (subsequently renamed Ayer) and Starbuck 15-minute quadrangles, scale 1:62,500, 3 sheets.