NATURAL RESOURCES

Geologic Map of the Pullman 1:100,000 Quadrangle, Washington–Idaho

compiled by
Charles W. Gulick

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 94-6
June 1994

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

CONTENTS

1 Introduction
8 Description of map units
8 Sedimentary deposits and rocks
8 Quaternary and older sedimentary deposits
10 Tertiary sedimentary rocks
11 Igneous intrusive and volcanic rocks
11 Tertiary volcanic rocks
11 Columbia River Basalt Group
15 Tertiary or Cretaceous intrusive igneous rocks
16 Cretaceous intrusive igneous rocks
17 Metamorphic rocks
17 Pre-Cretaceous metasedimentary rocks
18 References cited

ILLUSTRATIONS

1 Figure 1. Map showing location of 1:100,000-scale quadrangles in the southeast quadrant of Washington.
2 Figure 2. Map showing selected geographic features and 7.5- and 15-minute quadrangles in the Pullman 1:100,000 quadrangle.
4 Figure 3. Map showing sources of geologic map data for the Pullman 1:100,000 quadrangle.
5 Figure 4. Flow chart for age assignment of geologic units.
6 Figure 5. Diagram showing nomenclature and generalized stratigraphic relations of Columbia River Basalt Group units.

TABLE

5 Table 1. Radiometric age data, Pullman 1:100,000 quadrangle, Washington–Idaho.

PLATE [accompanies report]

Plate 1. Geologic map of the Pullman 1:100,000 quadrangle, Washington–Idaho.

GEOLOGIC MAP OF THE PULLMAN 1:100,000 QUADRANGLE, WASHINGTON–IDAHO

compiled by
Charles W. Gulick

INTRODUCTION

This map of the Pullman 1:100,000-scale quadrangle, Washington–Idaho, 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. 5). 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 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 Pullman 1:100,000-scale quadrangle.

This map was compiled in 1992, 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

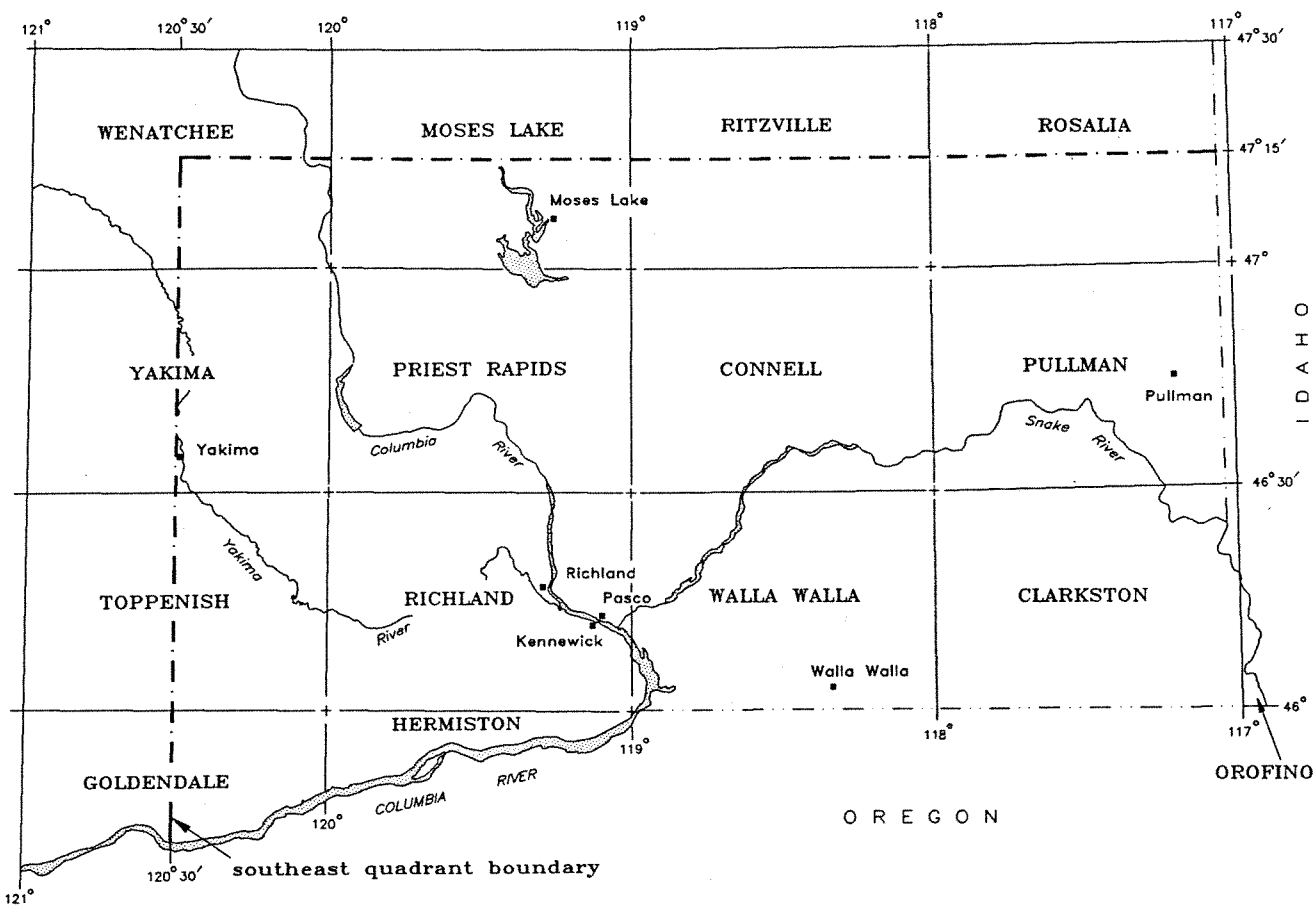

Figure 1. 1:100,000-scale quadrangles in the southeast quadrant of Washington.

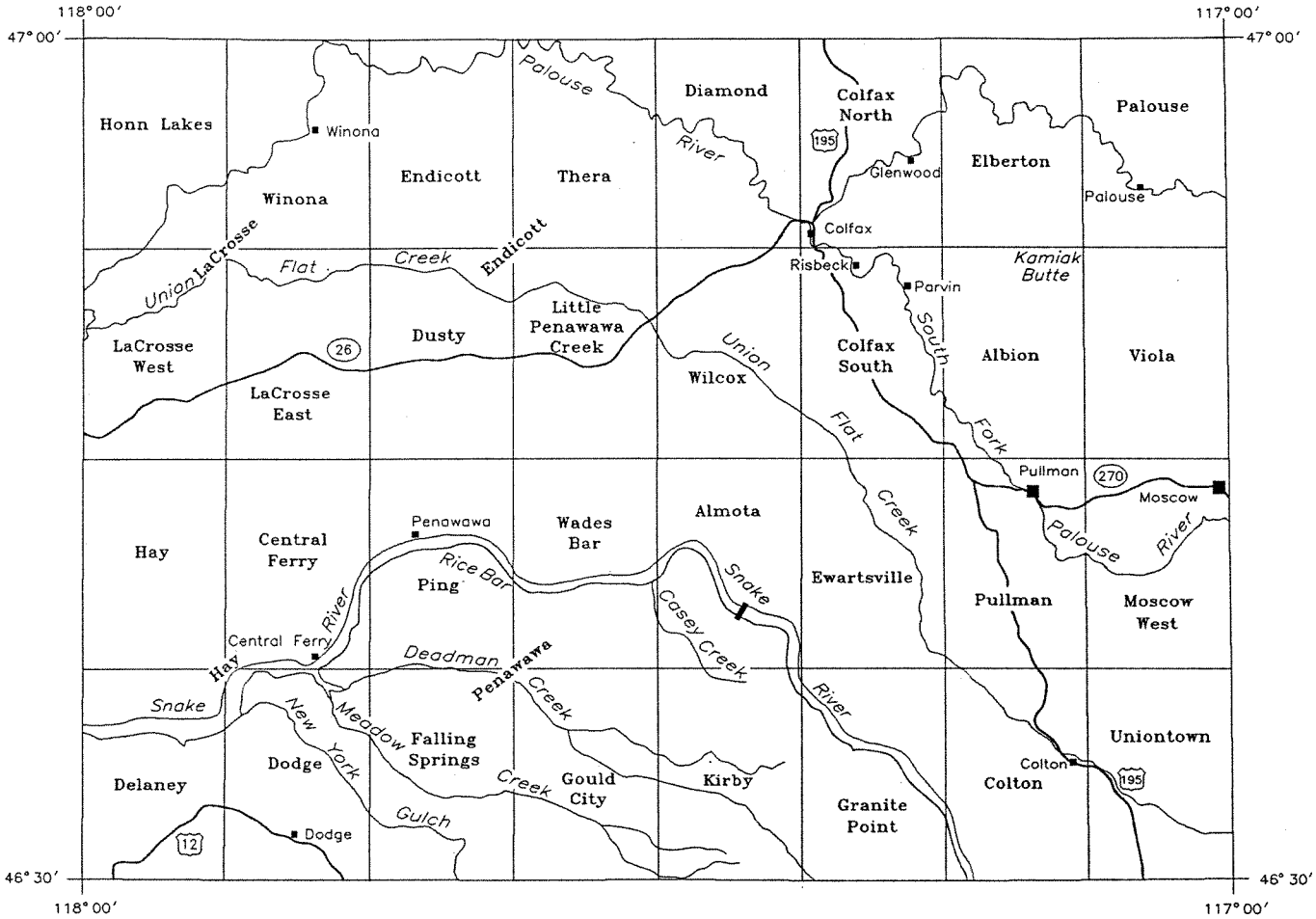

Figure 2. Index map showing selected geographic features and the 7.5-minute quadrangles that make up the Pullman 1:100,000 quadrangle.

(1980) and Shannon & Wilson, Inc. (1973), 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 which, with subsequent modifications, is the currently accepted classification. Figure 3 includes maps that were not used in compiling the geology shown in this report. These maps are included in an attempt to make the source-of-data listing exhaustive and to inform the reader that these sources of data were not overlooked.

One group of unpublished documents was used as a source of geologic data: G. D. Webster's 7.5-minute and 15-minute surficial geologic maps, which constitute complete coverage of the Pullman 1:100,000-scale quadrangle. These maps are cited as G. D. Webster, Wash. State Univ., unpub. maps, 1978.

Figure 3 identifies some of the sources of data as primary. These were the main sources of geologic map data. The mapping of Swanson and others (1980) was used to differentiate units of the Columbia River Basalt Group by superimposing the distribution of these members on outcrop patterns that were derived from Hammatt (1977), Hooper and Webster (1982), Waldron and Gard (1954, 1955), or G. D. Webster (Wash. State Univ., unpub. maps, 1978). Swanson and others (1980), Foundation Sciences, Inc. (1980), and Shannon & Wilson, Inc. (1973) were the sole sources used for compiling

structural features (faults and folds).

Two issues pertaining to the structural geology on this map remain unresolved:

(1) The Hite fault extends from the south onto the Pullman 1:100,000 quadrangle, but its location is not certain. It might be the northeast-trending fault in T. 14 N., R. 42 E. that crosses the Snake River at Almota, with the downthrown block on the west side (Foundation Sciences, Inc., 1980; Shannon & Wilson, Inc., 1973), but this appears to be an interpreted structure (lineament?) that is not substantiated by field evidence (D. A. Swanson, written commun., 1994). Another northeast-trending fault, at the confluence of the Snake River and Casey Creek (Swanson and others, 1980) less than 1 mile to the west of the aforementioned fault, may define the Hite fault, but in this case the downthrown block is on the east side of the fault. Both faults are shown on the map, and either or both may define the extension of the Hite fault from the Clarkston sheet to the south (Schuster, 1993). If both are present they appear to define a small graben south of the Snake River.

(2) The dip of the Columbia River basalts that are exposed along the Snake River between the southern map boundary and Central Ferry may not be as steep as indicated on this map. The basalt contacts shown here were compiled from Swanson and others (1980). However, reconnaissance paleomagnetic work by R. E. Wells (unpub. data, 1989) shows that the contact between the R1 and N1 magnetostratigraphic units of the Grande Ronde Basalt is at a much higher elevation than indicated on Swanson and others' (1980) map (and on this map). If true, the position of this contact would be extended to the west, and this extension may suggest offset, at some location farther to the west, along some as-yet-unidentified structure(s?) (S. P. Reidel, oral commun., 1994).

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; Hooper and Webster, 1982; Webster and Nunez, 1982) 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). Fission-track and K-Ar age estimates for pre-basalt bedrock units in the Pullman quadrangle are listed in Table 1.

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 series of open-file reports, 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 Columbia River Basalt Group units are shown in Figure 5.

Two sets of townships and ranges are shown on the map (Plate 1) because the part covering Idaho relates to the Boise meridian whereas the Washington portion of the map relates to the Willamette meridian.

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.

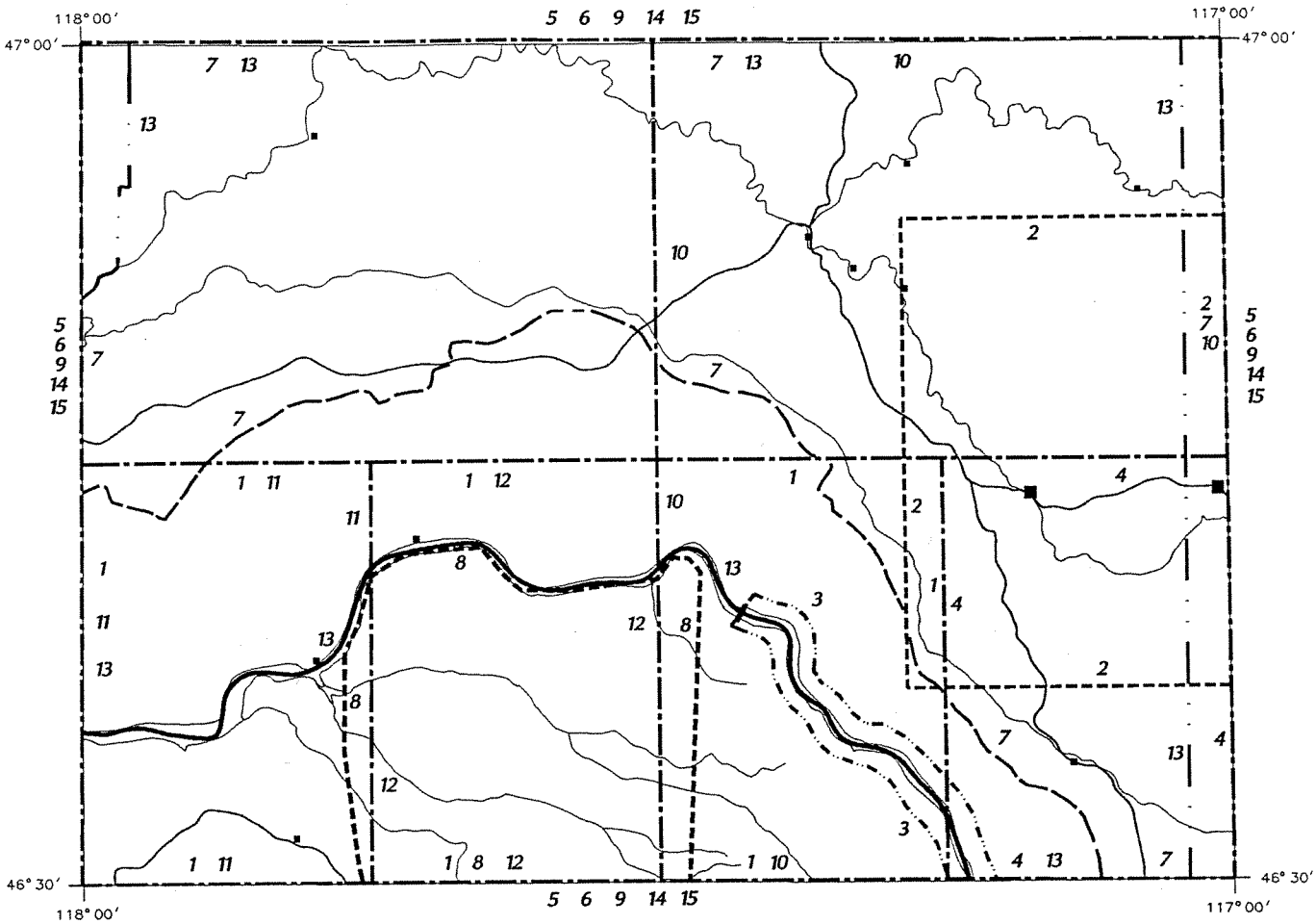

Figure 3. Sources of geologic map data for the Pullman 1:100,000 quadrangle, Washington-Idaho.
* sources of geologic data (outcrop/polygon pattern, contacts) used in this compilation
$ sources of structural data (folds, faults) used in this compilation.

1. Foundation Sciences, Inc., 1980 (plate 3, scale 1:125,000) $
2. Foxworthy and Washburn, 1963 (plate 1, scale 1:63,360)
3. Hammatt, 1977 (1 sheet, scale 1:24,000) *
4. Hooper and Webster, 1982 (1 sheet, scale 1:62,500) *
5. International Exploration, 1980 (1 sheet, scale 1:250,000)
6. Myers, Price, and others, 1979 (plate II-19, scale 1:250,000)
7. Nassar and Walters, 1975 (1 plate, scale 1:250,000)
8. Shannon & Wilson, Inc., 1973 (figure 8, scale 1:250,000) $
9. Swanson and others, 1980 (2 sheets, scale 1:250,000) *,$
10. Treasher, 1925 (plate 1, scale 1:125,000)
11. Waldron and Gard, 1954 (1 sheet, 1:62,500) *
12. Waldron and Gard, 1955 (1 sheet, 1:62,500) *
13. Walters and Glancy, 1969 (plates 3 and 4, scale 1:84,480)
14. Webster, 1979 (1 sheet, scale 1:250,000)
15. G. D. Webster, Wash. State Univ., unpub. maps, 1978 (16 sheets, scale 1:24,000; 4 sheets, scale 1:62,500) *

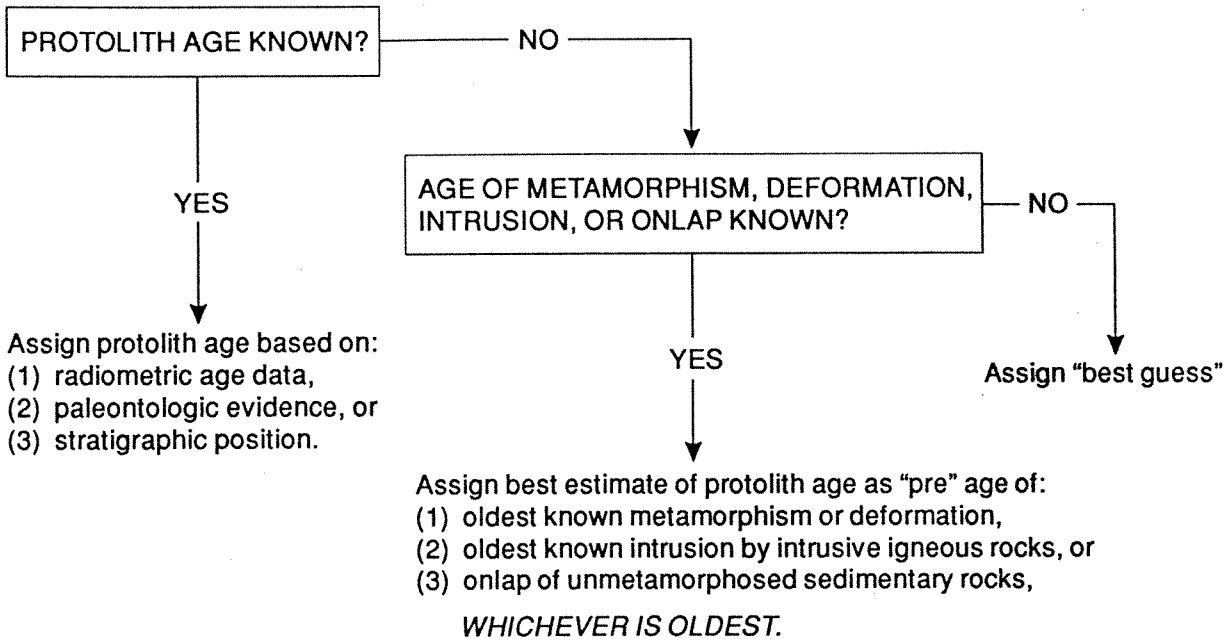

Figure 4. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description includes information about how the age of the unit was determined.

Table 1. Radiometric age data for the Pullman 1:100,000-scale quadrangle, Washington–Idaho

Sample no.	Unit	Map symbol	Location	Method	Material	Age (Ma)	Reference
Geochron no. B-4992	tonalite	Kit	Long 117°11'8" Lat 46°38'46" East side of railway cut 250 m N of Chambers Rd at junction of Chambers Rd and US Highway 195	K-Ar	biotite	69.8±2.6	Hooper and Webster, 1982
Geochron no. B-4991	granodiorite	Kia	Long 117°01'19" Lat 46°50'30" North wall of abandoned quarry, north edge of Viola	K-Ar	biotite	67.8±2.5	Webster and Nunez, 1982
88-2	monzodiorite	TKimd	Southeast of Moscow, ID, east of US Highway 95	Fission-track	titanite titanite apatite	64.0±7.7 58.6±6.4 53.2±5.4	Miller and others, 1990

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 (PRINEVILLE BASALT)	Sentinel Bluffs unit	15.6	N_2
				Slack Canyon unit		
				Fields Spring unit		
				Winter Water unit		
				Umtanum unit		
				Ortley unit		
				Armstrong Canyon unit		
				Meyer Ridge unit		R_2
				Grouse Creek unit		
				Wapshilla Ridge unit		
				Mt. Horrible unit		
			GRANDE RONDE BASALT (PICTURE GORGE BASALT)	China Creek unit		N_1
				Downey Gulch unit		
			GRANDE RONDE BASALT	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 appear on the Pullman 1:100,000 quadrangle. Modified from Reidel and others (1989).

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, 22 p., 1 plate.

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, in press, Geologic map of the Richland 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources open file report.

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, in press, Geologic map of the east half of the Toppenish 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources open file report.

Schuster, J. E., compiler, in press, Geologic map of the east half of the Washington portion of the Goldendale 1:100,000 quadrangle, Washington, and the Washington portion of the Hermiston 1:100,000 quadrangle: Washington Division of Geology and Earth Resources open file report.

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.

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. P. Weyant color-edited the map. J. E. Schuster coordinated the project and attended to many of the details required to release this report. N. A. Eberle 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.

DESCRIPTIONS OF MAP UNITS

Sedimentary Deposits and Rocks

Quaternary and Older Sedimentary Deposits

Qlf

Landfill (Holocene)—Loess that has been leveled or moved, or loess-covered rubbish in landfills; southeast and southwest of Pullman. Description from Hooper and Webster (1982).

Qd

Dune sand (Holocene)—Eolian sand and silt in dunes south of the Snake River at Almota; overlies gravel of unit QMg. Description from G. D. Webster (Wash. State Univ., unpub. maps, 1978).

Qla

Lacustrine and fluvial deposits (Holocene)—Clay, silt, and sand in interior drainage basins; occurs at two localities in the channeled scabland tract in the northwest part of the map area (secs. 15 and 31, T. 16 N., R. 39 E.). Description from Rigby and others (1979).

Qa

Alluvium (Holocene to Pleistocene)—Fluvial sand, silt, and gravel of varied thickness in stream beds and floodplains; commonly comprises reworked loess or mixtures of loess and basalt; locally includes volcanic ash. In Paradise Creek and the South Fork Palouse River, alluvial gravels commonly contain clasts of quartz and granitoid rocks derived from exposures of bedrock that composes steptoes, which are isolated or island-like hills or mountains of bedrock surrounded by younger lava flows, in the eastern part of the map area. Description from Hooper and Webster (1982).

Qt

Terrace deposits (Holocene to Pleistocene)—A cluster of alluvial terraces in the Palouse River valley in secs. 25, 35, and 36, T. 17 N., R. 39 E. (G. D. Webster, Wash. State Univ., unpub. maps, 1978) that occur at an elevation higher than that of unit Qa. Younger than Missoula flood deposits (units Qfs, Qfg).

Qaf

Alluvial fans (Holocene to Pleistocene)—Fluvial deposits of varied composition including silt, sand, and gravel, or nearly pure reworked loess, or mixtures of loess with angular to rounded clasts of basalt; typically occur where tributaries enter major drainage canyons; commonly cone-shaped; overlain in places by loess. Description compiled from: Rigby and others (1979); Hooper and Webster (1982).

Ql

Loess (Holocene to Pleistocene)—Buff, tan, gray-tan, light-brown, and orange, massive, homogeneous, unconsolidated eolian silt and fine sand; locally contains thin, discontinuous caliche layers, volcanic ash deposits, 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) or 6,845 $\pm$ 50 yr BP (Bacon, 1983); locally contains Mount St. Helens set S tephra dated at 13 ka (Mullineaux and others, 1978); magnetic polarity indicates 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 throughout the region is as 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 decreasing grain size to the northeast; includes the Palouse Formation. Description compiled from: G. D. Webster (Wash. State Univ., unpub. maps, 1978); Rigby and others (1979); Hooper and Webster (1982).

Periglacial frost-related(?) patterned ground features, mantled by or entirely(?) composed of loess, occur at many localities along the Snake River south and southwest of Pullman and also at the following localities on the Pullman quadrangle: sec. 11, T. 12 N., R. 41 E.; center of the common border between secs. 21 and 28, T. 17 N., R. 39 E.; SE1/4 sec. 33, T. 17 N., R. 39 E.; NW1/4 sec. 17, T. 17 N., R. 40 E. Loosely termed "Mima mounds" owing to their gross similarity to Mima mounds in the southern Puget Sound area (Washburn, 1988), these features overlie either basalt or flood gravel. Another proposed genesis of these features is as erosional remnants in a formerly continuous blanket of loess.

Qls

Mass-wasting deposits (Holocene to Miocene?)—Talus, predominantly basalt, and colluvium; includes slump blocks of basalt and overlying sediments along the South Fork Palouse River northwest of Pullman in sec. 31, T. 15 N., R. 45 E. and sec. 6, T. 16 N., R. 45 E. (Hooper and Webster, 1982); Other landslide, earthslide, or rockslide blocks shown on the map were differentiated by G. D. Webster (Wash. State Univ., unpub. maps, 1978) along the Palouse River at Glenwood (secs. 29 and 32, T. 17 N., R. 44 E.) and along the South Fork Palouse River near Risbeck and Parvin (secs. 17, 19, and 20, T. 16 N., R. 44 E.).

Also includes deposits of pre-Cretaceous(?) rocks that may have been created by landslides as early as Cretaceous time. These occur on the heavily wooded north side of Kamiak Butte (G. D. Webster, Wash. State Univ., unpub. maps, 1978).

Qfs

Outburst flood deposits, sand and silt (Pleistocene)—Rhythmically bedded sand, silt, and minor gravel deposited by lower energy slack waters of catastrophic floods and/or surges of catastrophic floods released by glacial Lake Missoula; locally contain ice-rafted cobbles, clastic dikes, tephra beds, and ice-melt structures; commonly cross-bedded; dark-gray basalt-rich gravels commonly grade upward into quartz- and feldspar-rich tan sands and silts; equivalent to the Touchet Beds of the Walla Walla area; deposited between 17.5 and 13 ka.

Periodic, colossal, subglacial 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 rhythmites occur where stream velocity and erosional power would have been high during a cataclysmic flood (Baker and others, 1991). Description compiled from: Hooper and Webster (1982); Rigby and others (1979).

Qfg

Outburst flood deposits, gravel (Pleistocene)—Poorly sorted deposits of angular to subrounded pebbles, cobbles, and boulders in a matrix of gravel and sand; local foreset bedding; clasts of diverse rock types but dominantly basaltic; some fragments as much as several feet across; generally less than 50 ft thick; locally contains tephra and locally overlain by loess; deposited by high-energy floodwaters associated with the repeated failure of an ice dam(s) that impounded glacial Lake Missoula; occurs in the channeled scabland area in the northwest corner of the map area (T. 15-17 N., R. 38-39 E.). 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; formed as back-eddy deposits along canyons tributary to the Snake River (Hooper and Webster, 1982). In the Clarkston 1:100,000-scale quadrangle to the south, flood deposits from Lake Bonneville underlie outburst flood slackwater deposits associated with glacial Lake Missoula. Currently accepted age estimates based on radiocarbon (^{14}C) dates from wood collected in Lake Bonneville paleodeltas are 14-15 ka (Scott and others, 1982). This unit also includes three deposits along the Snake River (T. 13 N., R. 43-44 E.) that are composed of moderately bedded, poorly sorted, basaltic gravel that contains interbedded silt lenses and scattered rounded granitic and quartzitic pebbles and cobbles and that forms benches in steep tributaries to 1,100 feet elevation. These were mapped and described by Hammatt (1977), who named them "scabland eddy deposits", but misidentified them as originating from younger Missoula flood events (Webster and others, 1982). Description from Hooper and Webster (1982).

Q~~M~~g

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 200 ft thick; occurs in large bars along the Snake River and referred to as older Snake River gravels by Rigby and others (1979); almost everywhere 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) 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 flood and/or Bonneville flood deposits and possibly as old as Miocene? (younger than intracanyon basalt flows of the Lower Monumental Member (6 Ma); may be derived from a flooding event(s) associated with the ancestral Salmon River (Webster and others, 1982). Because many Q~~M~~g gravel bars were inundated when the Snake River was dammed (by Lower Monumental Dam) the presence of unit Q~~M~~g at New York Bar and on the island just to the northwest (at the common corner of secs. 13, 14, 23, and 24, T. 13 N., R 39 E.) was queried by G. D. Webster and may instead be unit Qfs. Description from G. D. Webster (Wash. State Univ., unpub. maps, 1978).

Tertiary Sedimentary Deposits

~~M~~c

Continental sedimentary rocks (upper and middle Miocene)—Lacustrine and alluvial sandstone and

siltstone present along the Snake River in the Colton 7.5-minute quadrangle (Hooper and Webster, 1982); quartz-rich; fragmentary plant fossils common.

Also exposed in and adjacent to the town of Pullman, where they separate Grand Ronde Basalt from the overlying Priest Rapids Member of the Wanapum Basalt and are stratigraphically equivalent to the Vantage Member of the Ellensburg Formation. However, the rocks near Pullman and numerous other interflow sedimentary beds that occur at various stratigraphic levels in the basalt throughout the map area are too small to depict at the scale of this map.

Igneous Intrusive and Volcanic Rocks

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

Volcanic units in the Columbia River Basalt Group are often 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 of about 25 m with a maximum preserved thickness of 60 m; occurs at two outcrops at the mouth of New York Gulch (sec. 13, T. 13 N., R. 39 E.), one outcrop between Meadow and Deadman Creeks near their confluence (sec. 15, T. 13 N., R. 40 E.), three outcrops north of the Snake River (Lake Bryan) at Penawawa (sec. 13, T. 14 N., R. 40 E.; secs. 6 and 18, T. 14 N., R. 41 E.), and an outcrop east of the confluence of Casey Creek and the Snake River (Lake Bryan) (sec. 23, T. 14 N., R. 42 E.); the single flow is also the youngest known flow of the Columbia River Basalt Group; K-Ar age approximately 6 Ma (McKee and others, 1977). Underlying fluvial sand and gravel (included in the definition of the member) are locally present. Description from Swanson and others (1980).

Mv_{sp}

Pomona Member (middle Miocene)—One or more flows; medium-grained, medium-gray basalt; 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 in two outcrops at the mouth of New York Gulch (sec. 24, T. 13 N., R. 39 E.), in one outcrop 3 km upstream of Central Ferry (sec. 2, T. 13 N., R. 40 E.), in four exposures along Rice Bar (T. 14 N., R. 41 E.), and in three outcrops west of Casey Creek (secs. 27-29, T. 14 N., R. 42 E.); 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).

$\cancel{M}v_{se}$

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 a remnant of an intracanyon flow near the mouth of New York Gulch at the Snake River (Lake Bryan)(sec. 24, T. 13 N., R. 39 E.); normal magnetic polarity (Choiniere and Swanson, 1979). Description from Swanson and others (1980).

$\cancel{M}v_{s}$

Intracanyon basalt (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; normal magnetic polarity (D. A. Swanson, written commun., 1994); 3 km upstream of Central Ferry (sec. 2, T. 13 N., R. 40 E.); considered by Wright and others (1979) to be older than the intracanyon Pomona Member flow that crops out immediately in contact to the east; quenched Pomona at the contact with this unnamed intracanyon flow provides unequivocal evidence that it predates the Pomona Member (D. A. Swanson, U.S. Geol. Survey, written commun., 1994); isotopically dated (K-Ar method) at 12.5 Ma. Description from Swanson and others (1980).

$\cancel{M}v_{swr}$

Weissenfels Ridge Member (middle Miocene)—Single flow; medium-grained; microphenocrysts of plagioclase and olivine in an intergranular matrix with some tachylitic glass; normal polarity; the flow is known as "the basalt of Lewiston Orchards" (Swanson and others, 1980); crops out in three areas east of Colton and an area southwest of Colton (sec. 6, T. 12 N., R. 45 E.). Description from Hooper and Webster (1982).

$\cancel{M}v_{sa}$

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 south of the map area, where it is particularly thick, then followed Union Flat Creek (which then drained the basin) to the north side of the Saddle Mountains west of the map area (Swanson and others, 1980); the flow is poorly exposed along Union Flat Creek; 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)—Two or more 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; occurs along Union Flat Creek and southwest to the rim of the Snake River Canyon where it fills a shallow paleovalley in the Priest Rapids Member; part of the Uniontown flows of Swanson and others (1975), who interpreted the elongate outcrop pattern on Uniontown plateau as a constructional high along a linear vent system or a filled valley between two such systems; locally includes underlying thin sedimentary deposits. Description compiled from: Hooper and Webster (1982); Swanson and others (1980).

Mv_{su}

Umatilla Member (middle Miocene)—Two or more flows; dense, black; weathers yellow-orange; glassy to very fine grained; virtually aphyric; consists of an upper flow then called the Umatilla flow by Hooper and Webster (1982), but which is now called the basalt of Sillusi (see Reidel and others, 1992, for explanation); Hooper and Webster (1982) also differentiated a second, high-Ti Umatilla Member flow that they described as a fine-grained aphyric basalt flow with abundant opaque oxide grains in a matrix of clinopyroxene and feldspar; this high-Ti subunit, now known as the basalt of Umatilla, underlies the basalt of Sillusi and is chemically differentiated by its lower P_2O_5 and higher TiO_2 contents (Reidel and others, 1992); older than Asotin Member (13 Ma, Reidel and Fecht, 1987, p. 666) and younger than Priest Rapids Member (14.5 Ma, Tolan and others, 1989); normal magnetic polarity (Rietman, 1966; Swanson and others, 1977, 1979); welded spatter, thick piles of flows, and a dike at Puffer Butte in the Clarkston 1:100,000-scale quadrangle are the vent area for at least part of the Umatilla Member; scale limitations do not permit subdivision of the two flows on this map. 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; includes an 8-m-thick tuffaceous claystone and siltstone unit 3 km north-northeast of Colfax along U.S. Highway 195; also includes bedded tephra intermixed with arkosic sediments at the base of this flow at the vent area on the east edge of Palouse; reversed magnetic polarity (Rietman, 1966); average thickness 35 m; Lolo and Rosalia chemical types (Wright and others, 1979); on the "Pullman" 15-minute quadrangle high-magnesium Lolo type covers much of the map area, and small patches of Rosalia type occur above the Lolo flow; a third chemical type is represented by dikes in the Pullman area that cut the main flow of the Lolo type; 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 and dikes 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/or 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; typically consists of one or two flows, although 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, OR, to the northwest part of this map area (T. 17 N., R. 39 E.), a distance of more than 120 km (Bingham, 1970; Swanson and others, 1975); dikes present along the Snake River in the south-central part of the map area; prevailing slope directed flows westward; rubbly margin of a columnar Roza flow exposed on the east edge of the Snake River canyon (sec. 35, T. 13 N., R. 44 E.) (Walters and Glancy, 1969); 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, whereas 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).

Mv_{wfe}

Frenchman Springs and Eckler Mountain Members, undivided (middle Miocene)—Shown where these members are portrayed as undivided by Swanson and others (1980; their map unit Tfd) in the southwest part of the map area. Frenchman Springs Member is described above. Eckler Mountain Member contains three flow sequences, but only the middle sequence (basalt of Dodge) is present in the map area; basalt of Dodge occurs as one flow that is blocky jointed and very coarse grained plagioclase-phyric (laths as much as 20 mm long); grussy; olivine typically weathered to clay; coarse grain size, plagioclase phenocrysts, and spheroidal and yellow weathering make the basalt of Dodge an important marker unit; normal magnetic polarity (Choiniere and Swanson, 1979; Swanson and others, 1980); saprolites and, in places, sedimentary interbeds above and below; Eckler Mountain Member underlies Frenchman Springs Member (15.3 Ma, Tolan and others, 1989) and overlies Grande Ronde Basalt (as young as 15.6 Ma, Baksi, 1989). Description compiled from: Swanson and others (1980); Schuster (1994).

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, south 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 subdividing these flows. The formation is divided into four magnetostratigraphic units (R_1, N_1, R_2, N_2) all of which are present in the Snake River canyon on the southern border of this map. The Grande Ronde overlies Cretaceous bedrock at Granite Point (secs. 13 and 23, T. 13 N., R. 43 E.), and it is overlain by the Wanapum Basalt, commonly with an intervening saprolite or 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). Descriptions of these units compiled from: Swanson and others (1980); Reidel and others (1989); Schuster (1994).

$\cancel{M}v_{gN2}$ Magnetostratigraphic unit N2—Upper flows of normal magnetic polarity.

$\cancel{M}v_{gR2}$ Magnetostratigraphic unit R2—Upper flows of reversed magnetic polarity.

$\cancel{M}v_{gN1}$ Magnetostratigraphic unit N1—Lower flows of normal magnetic polarity.

$\cancel{M}v_{gR1}$ Magnetostratigraphic unit R1—Lower flows of reversed magnetic polarity.

$\cancel{M}v_{g}$ Feeder dikes, undivided—Feeders for magnetostratigraphic units N2 and R2 but not divided on original source map; generally 2-5 m wide; occur along the Snake River in the south-central part of the map. Description from Swanson and others (1980).

Tertiary or Cretaceous Intrusive Igneous Rocks

TKimd

Monzodiorite (Paleocene? or Cretaceous)—Hornblende monzodiorite; dark; medium-grained; principal mineral phases are oligoclase (An_{27}) with slight normal zoning, microcline, and clots of dark-green hornblende (pseudomorphs after pyroxene?) associated with small crystals of titanite, apatite, and opaque oxides; rare quartz in small myrmekitic patches; inequigranular texture; strong foliation; occurs along the east edge of the map (primarily in Idaho) where it forms the westernmost edge of Paradise Ridge; preliminary fission-track analyses of apatite and titanite yielded age estimates of 53.2 $\pm$ 5.4 Ma and 58.6 $\pm$ 6.4 Ma respectively (Miller and others, 1990); another fission-track analysis of titanite in the same sample yielded an age of 64.0 $\pm$ 7.7 Ma (Miller and others, 1990). Description from Hooper and Webster (1982).

The monzodiorite is petrologically distinct from nearby stocks of Cretaceous acidic igneous rocks. However, both the consanguineous(?) acidic rocks and the monzodiorite have been associated

with or assigned to units of the Idaho batholith. Older Cretaceous basic igneous rocks that occur at another steptoe at Gold Hill in Idaho may represent earlier products of fractional crystallization in the Idaho batholith; these rocks are known as the Gold Hill syenite and pyroxenite and were dated at 97.5 ± 4.9 Ma (Wong, 1980).

Cretaceous Intrusive Igneous Rocks

Kit, Kip

Tonalite (Cretaceous)—Biotite tonalite that consists of quartz, unzoned andesine ($An_{38\pm2}$), muscovite, and biotite (partially altered to chlorite) with accessory apatite, zircon, and carbonate; inequigranular texture; subordinate hornblende-biotite-tonalite schlieren; cut by dikes of various compositions; at Bald Butte this unit has a crystallization order of hornblende-biotite-tonalite (first), biotite-tonalite, aplite dikes, quartz-gabbro dikes, pegmatite dikes, and quartz dikes (last) (Hoffman, 1932); weak foliation dips steeply and trends approximately east or parallel to the ridge of Bald Butte; a sample from the Chambers Road-U.S. Highway 195 junction yields a K-Ar age of 69.8 ± 2.6 Ma (Geochron No. B-4992) (Hooper and Webster, 1982). A pegmatite vein thought to be related to this tonalite cuts quartzite (unit pKqz) south of Moscow, ID, and is indicated by the symbol Kip. Description compiled from Hooper and Webster (1982); Hoffman (1932).

Kia

Granodiorite (Cretaceous)—Granodiorite and tonalite plutons; light-gray and yellow-gray; typically foliated or gneissose; crop out as isolated steptoes that may represent stocks of the Idaho batholith; granodiorite at Viola, Idaho (northwest end of Moscow Mountain) yielded a K-Ar age estimate of 67.8 ± 2.5 Ma (Geochron No. B-4991) (Webster and Nunez, 1982). Treasher (1925) reported 1- to 3-in.-diameter garnet crystals near a slickensided contact of the granodiorite and quartzite near Viola and noted that the contact becomes indistinct owing to severe metamorphism. Description from: Rigby and others (1979); G. D. Webster (Wash. State Univ., unpub. maps, 1978).

Kigd

Granodiorite of Granite Point (Cretaceous?)—Biotite granodiorite or quartz monzonite; light-gray; coarse-grained; foliated; zoned potassium feldspar crystals reminiscent of Rapakivi texture and minor hornblende; indistinct biotite bands, elongate feldspar crystals, and sheet-like, sharply bounded, concordant hornblende-bearing mafic segregations that define a foliation and impart a gneissic appearance to the rock; cut by dikes of pegmatite; contain feldspathic segregations immediately adjacent to dark-green slickensided surfaces; exposed on both sides of the Snake River at Granite Point (secs. 13, 14, 23, and 24, T. 13 N., R. 43 E.); the westernmost of several Cretaceous igneous stocks that include the monzodiorite on Paradise Ridge (unit TKimd), the tonalite (unit Kit) of Bald Butte, and the granodiorite (unit Kia) at and near Viola; underlies magnetostratigraphic unit N1 of the Grande Ronde Basalt. Owing to similarity to the Cretaceous silicic igneous stocks to the east, a Cretaceous age is likely; while the actual contact of the Granite Point bedrock with overlying basalt is in part obscured by talus (Hooper and Rosenberg, 1970), newer railroad cuts expose an unconformity, with basalt overlying a thin paleosol on top of the granodiorite (G. D. Webster, written commun., 1994). Description compiled from: Hammatt (1977); Hooper and Rosenberg (1970); Shedd (1903); Treasher (1925).

Metamorphic Rocks

Pre-Cretaceous Metasedimentary Rocks

pKph

Phyllite (pre-Cretaceous)—Phyllite and low-grade schist; greenish-gray; micaceous; some relict bedding; age and stratigraphic relations unknown, but occurrences in steptoes of Cretaceous intrusive rock strongly suggest that the metamorphic rocks (including unit pKqz) are pre-Cretaceous; occurs on Kamiak Butte as magnetite-bearing mica schist near the summit; mapped occurrences are limited to two small outcrops in sec. 31, T. 17 N., R. 45 E. Description from G. D. Webster, Wash. State Univ., unpub. maps, 1978.

pKqz

Quartzite (pre-Cretaceous)—Orthoquartzite; white to creamy white, light-gray to bluish- and purplish-gray, pink and reddish-brown; nearly pure quartz with magnetite-cored goethite grains, sparse small crystals of feldspar, muscovite, biotite, zircon, and rutile and rare tourmaline grains; recrystallized to coarse granoblastic texture; relict cross-lamination; massive bedding, inconspicuous bedding planes; dense and fresh to friable; locally includes minor schist; occurs as small bodies (not shown on map) surrounding and on tonalite (unit Kit) at Bald Butte and monzodiorite (unit Kimd) at Paradise Ridge, where contact or subsequent metamorphic effects (including a diopside hornfels) have made the "granite" difficult to distinguish from the orthoquartzite in places; orthoquartzite on the Cretaceous intrusive core of the Viola Hills, Paradise Ridge, and Bald Butte steptoes supports a pre-Cretaceous age, but the unit pKqz may be early Paleozoic or late Proterozoic (see discussion below); orthoquartzite pendants(?) resemble the massive, recrystallized orthoquartzite of Angel, Ladow, Parker, Ringo, and Kamiak Buttes. G. D. Webster (Wash. State Univ., unpub. maps, 1978) suggested that most hills higher than 2,700 ft in the northeast part of the map area are composed of quartzite or related metamorphic rocks.

At Kamiak Butte is a 261-m-thick section of arenaceous orthoquartzite (Webster and Nunez, 1982, p. 53), as well as intercalated metaconglomeratic quartzite chiefly composed of 1/2-in.-diameter, reddish-brown to white, subangular to well-rounded quartzite pebbles that, excepting grain size, resemble the matrix. Orthoquartzite on Kamiak Butte dips south or southeast; beds appear truncated on the steeper north side by faulting and well developed, commonly iron-stained joints. At least five, smaller, northwest-trending faults offset the main ridge slightly. Savage (1973) reported cataclastic textures in the orthoquartzite that include undulatory extinction, deformed twin lamellae, and differentially sheared quartz with sutured boundaries. Rocks of Kamiak Butte and other quartzite-supported steptoes have been assigned to the Precambrian Belt Supergroup (Ravalli Group, Revett Formation) (Savage, 1973). Savage (1973) suggested that Kamiak Butte and similar steptoes are block-faulted remnants isolated from the main mass of the northern Rocky Mountains and that the sediments originally formed in a shallow, shoreline-intertidal environment. However, others believe that these pure quartzites are unlike the relatively impure, laminated, micaceous quartzites typical of the Belt Supergroup and have instead tentatively correlated "orthoquartzites of Kamiak Butte type" with similar Upper Proterozoic to Lower Cambrian quartzites (Addy and Gypsy Quartzites) of northeastern Washington (Hooper and Webster, 1982). Description compiled from: Hooper and Webster (1982); Webster and Nunez (1982); Savage (1973); Treasher (1925).

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* Gilmore, E. H.; Stradling, D. F., editors, Proceedings of the second Columbia River basalt symposium: Eastern Washington State College Press, p. 171-172.

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 plate.

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.

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.

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 plates.

Foxworthy, B. L.; Washburn, R. L., 1963, Ground water in the Pullman area, Whitman County, Washington: U.S. Geological Survey Water-Supply Paper 1655, 71 p., 3 plates.

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.

Hammatt, H. H.; Blinman, Eric, drafter, 1976, Late Quaternary geology of the lower Granite Reservoir area, lower Snake River, Washington: Geological Society of America Map and Chart Series MC-18, 1 sheet, scale 1:24,000.

Hoffman, M. G., 1932, The geology of the Bald Butte Ridge, Washington: Journal of Geology, v. 40, p. 634-650.

Hooper, P. R.; Rosenberg, P. E., 1970, The petrology of Granite Point, southeastern Washington: Northwest Science, v. 44, no. 2, p. 131-142.

Hooper, P. R.; Kleck, W. D.; Knowles, C. R.; Reidel, S. P.; Theissen, 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 7½ minute quadrangles, Washington and Idaho: Washington Division of Geology and Earth Resources Geologic Map GM-26, 1 sheet, scale 1:62,500.

International Exploration, 1980, Geology of the Pullman quadrangle: U.S. Department of Energy, 1 sheet, scale 1:250,000.

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.

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.

Miller, D. S.; Eby, Nelson; McCorkell, Robert; Rosenberg, P. E.; Suzuki, Mazao, 1990, Results of interlaboratory comparison of fission track ages for the 1988 Fission Track Workshop: Nuclear Tracks and Radiation Measurements, v. 17, no. 3, p. 237-245.

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.

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 plate, scale 1:250,000.

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.; Hooper, P. R.; Webster, G. D.; Camp, V. E., 1992, Geologic map of southeastern Asotin County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-40, 1 sheet, scale 1:48,000, with 22 p. text.

Reidel, S. P.; Tolan, T. L.; Hooper, P. R.; Beeson, M. H.; Fecht, K. R.; Bentley, R. D.; Anderson, J. L., 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.

Savage, C. N., 1973, A geological field trip in Benewah and Whitman Counties, Idaho and Washington, respectively. *In* Bishop, D. T.; Powell, J. D., compilers, Belt Symposium 1973: University of Idaho-Idaho Bureau of Mines and Geology, v. 1, p. 253-320.

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 Walla Walla 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-3, 18 p., 1 plate.

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.

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 v., 2 plates.

Shedd, Solon, 1903, The building and ornamental stones of Washington: Washington Geological Survey Annual Report 1902, pt. 1, p. 1-163.

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 plates.

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 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, J. L.; 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.

Treasher, R. C., 1925, Geology of the Pullman quadrangle: State College of Washington Master of Science thesis, 74 p., 3 plates.

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., 1980, About forty last-glacial Lake Missoula jokulhlaups 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.

Waldron, H. H.; Gard, L. M., Jr., 1954, Geology of the Hay quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-48, 1 sheet, scale 1:62,500.

Waldron, H. H.; Gard, L. M., Jr., 1955, Geology of the Penawawa quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ-56, 1 sheet, scale 1:62,500.

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., 4 plates.

Washburn, A. L., 1988, Mima mounds—An evaluation of proposed origins with special reference to the Puget Lowland: Washington Division of Geology and Earth Resources Report of Investigations 29, 53 p.

Webster, G. D., 1979, Surficial geologic map of the Pullman quad, Washington: Washington Division of Geology and Earth Resources Open-File Report 79-9, 1 sheet, scale 1:250,000.

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.

Webster, G. D.; Nunez, Luis, 1982, Geology of the steptoes and Palouse Hills of eastern Washington, a roadlog of the area south of Spokane, Washington. *In* Roberts, Sheila; Fountain, David, editors, Tobacco Root Geological Society 1980 field conference guidebook: Tobacco Root Geological Society [Spokane, Wash.], p. 45-57.

Wong, J. S., 1980, The petrology and petrochemistry of the Gold Hill syenite- pyroxenite complex, Potlatch quadrangle, Idaho: Washington State University Master of Science thesis, 104 p., 1 plate.

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 Albion, Almota, Bishop (subsequently renamed Granite Point), Colfax North, Colfax South, Colton, Diamond, Elberton, Ewartsville, Kirby, Moscow West, Palouse, Pullman, Uniontown, Viola, and Wilcox 7.5-minute quadrangles, scale 1:24,000, 16 sheets; and the Endicott, Hay, La Crosse, and Penawawa 15-minute quadrangles, scale 1:62,500, 4 sheets.