Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington

compiled by
Stephen P. Reidel
and Karl R. Fecht

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 94-13
September 1994

MASTER

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

1	Introduction
8	Descriptions of map units
8	Sedimentary deposits and rocks
12	Tertiary volcanic rocks
17	References cited

ILLUSTRATIONS

FIGURES

- 1 Figure 1. Map showing 1:100,000-scale quadrangles in the southeast quadrant of Washington
- 2 Figure 2. Index map showing geographic names and 7.5-minute quadrangle locations
- 4 Figure 3. Sketch map showing sources of geologic mapping for the Priest Rapids 1:100,000 quadrangle.
- 5 Figure 4. Flow chart for age assignment of geologic units.
- 6 Figure 5. Generalized nomenclature and stratigraphic relations of the Columbia River Basalt Group.

PLATE (accompanies text)

Plate 1. Geologic map of the Priest Rapids 1:100,000 quadrangle, Washington

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

GEOLOGIC MAP OF THE PRIEST RAPIDS 1:100,000 QUADRANGLE, WASHINGTON

compiled by

Stephen P. Reidel^{1,2} and Karl R. Fecht¹

¹ Westinghouse Hanford Co., P.O. Box 1970, Richland WA 98352

² Also Geology Department, Washington State University, Pullman, WA 99164

INTRODUCTION

This map of the Priest Rapids 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. 3). 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. Index map showing geographic names and 7.5-minute quadrangle locations

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

The geology of the Priest Rapids quadrangle has not previously been compiled at 1:100,000 scale. This geologic map incorporates geologic mapping since the publication of Myers, Price, and others, 1979, Plate IIIb.

This map was compiled in 1992 and 1993 using published and unpublished geologic maps as sources of data. The areas covered by these sources are shown on Figure 3. Source maps with scales smaller than 1:125,000 were not used, except for Swanson and others (1979a, 1980). Maps produced before 1979 were not used as sources of data for the Columbia River Basalt Group because prior to that year mappers generally did not use geochemistry or magnetic polarity to confirm assignment of basalt flows to stratigraphic units, nor did they employ the stratigraphy that was proposed by Swanson and others (1979b) and, with subsequent modifications, is universally used today. As noted below, maps issued before 1979 were used as data sources for geologic units younger than the Columbia River Basalt Group.

Figure 3 also includes maps that were not used in compiling the geology shown in this report. These maps are included in an attempt to make the sources-of-data listing exhaustive and to inform the reader that these sources of data were not overlooked. Figure 3 identifies some of the sources of data as primary; these were the main sources of geologic map data.

Unpublished geologic mapping by S. P. Reidel, and K. R. Fecht for the map area south of the Saddle Mountains has been incorporated in this map. This forms the primary source of information for revisions since the map of Myers, Price, and others (1979).

Age assignments of geologic units were made following the flow chart in Figure 4 and were derived from the following sources: Baksi (1989), Tolan and others (1989), McKee and others (1977), and Reidel and Fecht (1987).

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

DGER Southeast Quadrant Open File Reports

Gulick, C. W., compiler, 1990a, Geologic map of the Moses Lake 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-1, 9 p., 1 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 Connell 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 94-14, 18 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.

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 pl.

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

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 pl.

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 pl.

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, 20 p., 1 pl.

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 pl.

3a

3b

Figure 4. (right) 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 descriptions include information on how the ages of the units were determined.

Figure 3 (facing page). Sources of geologic mapping for the Priest Rapids 1:100,000 quadrangle. *, primary sources of geologic data used in this compilation; 3a and 3b identify the figure on which the source map area is shown.

1.	3a	Alto, 1955 (plate 5, scale 1:44,350)	19.	3a	Lillie and others, 1978 (plates 1-6, scale 1:62,500)
2.	3a	Bingham and others, 1970 (figure 6, scale 1:24,000)	20.	3b	Mason, 1953 (figures 6, 7, 8, scale 1:62,500)
3.	3a	Bingham and others, 1970 (figure 13, scale 1:24,000)	21.	3a	Moak and Wintczak, 1980 (figure 9, scale 1:31,680)
4.	3a	Brooks, 1974 (figure 3, scale 1:20,000)	22.*	3a	Myers, 1973 (figure 4, scale 1:31,680)
5.*	3a	Campbell and others, 1979 (scale 1:250,000)	23.	3b	Myers and Price, 1981 (figure 8-2b, scale 1:71,000)
6.	3b	Carson and others, 1987 (figure 3, scale 1:70,000)	24.	3a	Myers, Price, and others, 1979 (plates II-7 and II-16, scale 1:250,000)
7.	3a	Carson and others, 1987 (figure 5, scale 1:70,000)	25.*	3a	Myers, Price, and others, 1979 (plate III-1, scale 1:62,500)
8.*	3b	Fecht, 1978 (plate 1, scale 1:24,000)	26.	3a	Newcomb and others, 1972 (plate 1, scale 1:62,500)
9.	3a	Geomatrix Consultants, Inc., 1990 (figure 2, scale 1:250,000)	27.*	3a	Price, 1982 (plate 4, scale 1:5,300)
10.	3a	Geomatrix Consultants, Inc., 1990 (figure 3.5, scale approx. 1:200,000)	28.	3a	Reidel, 1978 (plates 1, 2, 3, scale 1:24,000)
11.*	3a	Goff, 1981 (plate 1, scale 1:24,000)	29.*	3b	Reidel, 1988 (plates 1, 2, 3, scale 1:48,000)
12.	3b	Grolier and Bingham, 1965 (scale 1:62,500)	30.*	3a	Rigby and others, 1979 (plate 7, scale 1:250,000)
13.*	3b	Grolier and Bingham, 1971 (sheets 3, 4, 5, scale 1:62,500)	31.	3a	Rigby and others, 1979 (plate 11, scale 1:12,000)
14.	3b	Hays and Schuster, 1983 (scale 1:100,000)	32.*	3b	Swanson and others, 1979a (sheet 7, scale 1:250,000)
15.*	3b	Hays and Schuster, 1987 (scale 1:100,000)	33.*	3b	Swanson and Helz, 1979 (sheet 2, scale 1:62,500)
16.	3a	Kinnison and Sceva, 1963 (plate 1, scale 1:250,000)	34.*	3a	Swanson and others, 1980 (scale 1:250,000)
17.	3a	Laval, 1956 (plate XXI, scale 1:62,500)	35.	3b	Taylor, 1976 (scale 1:18,000)
18.	3a	Laval, 1956 (plate XXIII, scale 1:31,680)	36.	3b	Tolan, T. L., 1986, unpub. mapping, scale 1:24,000
			37.	3b	Twiss, 1933 (scale 1:62,500)

SERIES	GROUP	FORMATION	MEMBER	ISOTOPIC AGE (Ma)	MAGNETIC POLARITY		
MIOCENE	upper	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6	N		
			ICE HARBOR MEMBER	8.5	N		
			basalt of Goose Island		N		
			basalt of Martindale		R		
			basalt of Basin City		N		
			BUFORD MEMBER				
			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		
			middle	COLUMBIA RIVER BASALT GROUP	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		
	PRINEVILLE BASALT	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		
					Meyer Ridge unit		
					Grouse Creek unit		
			Wapshilla Ridge unit				
Mt. Horrible unit							
PICTURE GORGE BASALT			GRANDE RONDE BASALT	↗ China Creek unit		N ₁	
	↗ Downey Gulch unit						
	Center Creek unit						
	Rogersburg unit						
	Teepee Butte unit						
	Buckhorn Springs unit	16.9					
		17.0					
		17.3					
lower	COLUMBIA RIVER BASALT GROUP	IMNAHA BASALT	See Hooper and others (1984) for Imnaha units		R ₁		
					T		
					N ₀		
					R ₀		

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

GEOLOGIC MAP OF THE

CORREL

GEOLOGIC

SEDIMENTARY DEPOSITS

QUATERNARY SEDIMENTARY DEPOSITS

Qd Dune sand

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

PLATE 1
OPEN FILE REPORT 94-13

GEOLOGIC MAP OF THE PRIEST RAPIDS 1:100,000 QUADRANGLE,
WASHINGTON

CORRELATION DIAGRAM

GEOLOGIC UNITS

SEDIMENTARY DEPOSITS AND ROCKS

QUATERNARY SEDIMENTARY DEPOSITS

Qd Dune sand (Holocene)

Mioc
Middle
17 Ma -

Ellensburg

Mv_wpr
Mv_wr
Mv_wfs
Mv_gN2
Mv_gN2L
Mv_gR2

Wanapun
Basalt
Grande
Ronde
Basalt
Columbia Riv

GEOLOGIC UNITS

SEDIMENTARY DEPOSITS AND ROCKS

QUATERNARY SEDIMENTARY DEPOSITS

- Qd Dune sand (Holocene)
- Qda Active sand dunes
- Qds Stabilized sand dune deposits
- Qa Alluvium (Holocene to Pleistocene)
- Qls Mass-wasting deposits (Holocene to Pleistocene)
- Ql Loess (Holocene to Pleistocene)
- Qaf Alluvial fans (Holocene to Pleistocene)
- Qta Talus (Holocene to Pleistocene)
- Qfs Outburst flood deposits, silt and sand (Pleistocene)
- Qfs4 Youngest outburst flood deposits, silt and sand
- Qfs3
- Qfs1 Oldest outburst flood deposits, silt and sand
- Qfg Outburst flood deposits, gravel (Pleistocene)
- Qfg4 Youngest outburst flood deposits, gravel
- Qfg3
- Qfg2
- Qfg1 Oldest outburst flood deposits, gravel

QUATERNARY-TERTIARY SEDIMENTARY DEPOSITS

- QRg Gravel (Pleistocene to Pliocene)

TERTIARY SEDIMENTARY DEPOSITS AND ROCKS

- RMc Continental sand, silt, and clay beds (Pliocene to Miocene). Ringold Formation.
- RMcg Continental conglomerate (Pliocene to Miocene). Ringold Formation.
- RMaf Fanglomerate (Pliocene to Miocene)
- Mc Continental sedimentary deposits (upper and middle Miocene). Includes Ellensburg Formation.
- Mcg Conglomerate (Miocene). Ellensburg Formation.

TERTIARY VOLCANIC ROCKS

SCALE 1:100,000

KILOMETERS

MILES

FEET

CONTOUR INTERVAL 50 METERS

WITH SUPPLEMENTARY CONTOURS AT 10-METER INTERVALS

NATIONAL GEODETIC VERTICAL DATUM OF 1929

PROJECTION AND 10,000-METER GRID, ZONE 11:

UNIVERSAL TRANSVERSE MERCATOR

25,000-FOOT GRID TICKS BASED ON WASHINGTON COORDINATE
SYSTEM, SOUTH ZONE

BASE MAP BY USGS
EDITED - 1979

GEOL OGI

UTM GRID AND 1978 M
DECLINATION AT CEN

LOGIC MAP OF THE PRIEST RAPIDS

STEPHEN P. REI
SEP

M GRID AND 1978 MAGNETIC NORTH
DECLINATION AT CENTER OF MAP

PRIEST RAPIDS 1:100,000 QUADRA

Compiled by
STEPHEN P. REIDEL AND KARL R. FECHT
SEPTEMBER 1994

100,000 QUADRANGLE, WASHINGTON

FECHT

E, WASHINGTON

- contact, dashed where approximately located.
- fault, dotted where concealed.
- normal fault, dotted where concealed, bar and downthrown side.
- thrust fault, dashed where approximately located, where concealed, teeth on upper plate.
- strike-slip fault, dotted where concealed, arrow direction of movement.

Conglomerate (Miocene). Ellensburg Formation.

COLUMBIA RIVER BASALT GROUP

SADDLE MOUNTAINS BASALT

Mv _s	Saddle Mountains Basalt, undivided
Mv _{sih}	Ice Harbor Member (upper Miocene)
Mv _{sem}	Elephant Mountain Member (upper Miocene)
Mv _{sp}	Pomona Member (middle Miocene)
Mv _{se}	Esquatzel Member (middle Miocene)
Mv _{sa}	Asotin Member (middle Miocene)
Mv _{swc}	Wilbur Creek Member (middle Miocene)
Mv _{su}	Umatilla Member (middle Miocene)

WANAPUM BASALT (MIDDLE MIOCENE)

Mv _w	Wanapum Basalt, undivided
Mv _{wpr}	Priest Rapids Member
Mv _{wr}	Roza Member
Mv _{wrs}	Frenchman Springs Member

GRANDE RONDE BASALT (MIDDLE MIOCENE)

M _{GN2}	Upper flows of normal magnetic polarity
M _{GN2u}	Upper flows, normal magnetic polarity, Umtanum unit
M _{GR2}	Upper flows of reversed magnetic polarity

EXPLANATION

dotted where concealed, arrows show movement.

4

same geologic unit.

PRIEST RAPIDS 1:100,000 QUADRANGLE

**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.**

**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.**

Acknowledgments

Support for Reidel was provided by U.S. Department of Energy, Office of Basic Energy Sciences grant number DE-FG06-91ER14172 to S. P. Reidel at Washington State University. N. A. Eberle, C. F. T. Harris, and K. G. Ikerd of the DGER cartographic staff and J. M. Roloff and K. M. Reed of the DGER editorial staff prepared final copy and provided editorial support.

DESCRIPTIONS OF MAP UNITS

Sedimentary Deposits and Rocks

Quaternary Sedimentary Deposits

Qd

Dune sand (Holocene)—Eolian medium to fine sand and silt; grains composed of quartz, basalt, and (or) feldspar; includes Mazama tephra at numerous places; active and stabilized dunes occur throughout the low terrain; age inferred from geomorphology, ages of parent materials, and presence of Mazama tephra (about 7 ka; Kittleman, 1973, p. 2958; about 6.85 ka, Bacon, 1983). Description compiled from Myers, Price, and others (1979) and authors' unpublished data.

Qda Active sand dunes.

Qds Stabilized sand dune deposits.

Qa

Alluvium (Holocene to Pleistocene)—Clay, silt, sand, and gravel deposits of varied thickness, sorting, and composition; commonly includes reworked loess, Ellensburg Formation sediments, and (or) basalt in sidestreams, and Ringold Formation and Pleistocene outburst flood sediments in mainstreams and below maximum Pleistocene flood elevation; occurs in valley bottoms throughout the map area; includes mainchannel coarse sand and gravel and overbank deposits marginal to channelways; older alluvial deposits form terraces above modern-day river channels and are more compact than younger alluvial sediments; normal to reversed magnetic polarity (Baker and others, 1991, p. 233); older alluvial units capped by pedogenic carbonates (stages I to IV of Machette, 1985) or silcrete; age inferred from paleomagnetism, geomorphology, ages of parent materials, and the presence of Mazama tephra (about 6.8-7 ka), Mount St. Helens set S tephra (about 13 ka; Mullineaux and others, 1978, p. 178) and Glacier Peak tephras G and B (about 11.25 ka; Mack and others 1983; Mehrlinger and others, 1984). Description compiled from Myers, Price, and others (1979), Baker and others (1991), and authors' unpublished data.

Qls

Mass-wasting deposits (Holocene to Pleistocene)—Landslide deposits associated with steep flanks of anticlinal ridges and high bluffs along rivers and abandoned channels; age inferred from geomorphology, stratigraphic position, and ages of parent materials. Description compiled from Myers, Price, and others (1979) and authors' unpublished data.

Ql

Loess (Holocene to Pleistocene)—Eolian silt and fine sand; pale brown to yellowish-brown to reddish-yellow; grain size decreases to the northeast; occurs as discontinuous sheets and lenses; includes interstratified Mazama tephra (about 6.8-7 ka), Glacier Peak G and B tephras (about 11.25 ka), Mount St.

Helens set S (about 13 ka), and Mount St. Helens set M (about 20 ka; Smith, 1980) tephra beds (Baker and others, 1991, p. 231-233), pedogenic carbonates (stages I to IV of Machette, 1985), silcrete and cambic horizons; uppermost loess locally contains Mazama tephra (Baker and others, 1991, p. 233); paleomagnetic measurements show that the second oldest loess unit was deposited during the Matuyama reversed polarity epoch at (least 790 ka); oldest loess unit is commonly capped by silcrete and is early Pleistocene or perhaps late Pliocene in age. Includes Palouse Formation. Description compiled from Myers, Price, and others (1979) and authors' unpublished data.

Qaf

Alluvial fans (Holocene to Pleistocene)—Gravel, sand, and silt of varied thickness, poorly sorted and of varied composition; commonly includes reworked basalt, Ellensburg Formation sediments, and loess; formed where intermittent tributary streams in ridge terrain enter valleys; generally cone-shaped; in places overlain by and interstratified with loess and slope wash; contains horizons capped with pedogenic carbonate (stages I to IV of Machette, 1985); age inferred from geomorphic form and ages of parent materials; fans located at elevations below maximum Pleistocene flood elevation are younger than the outburst flood deposits and are, therefore, Holocene. Those located above the maximum elevation of Pleistocene outburst flooding are Holocene and older. Description from authors' unpublished data.

Qta

Talus (Holocene to Pleistocene)—Scree deposits found at the base of cliffs and steep flanks of anticlinal ridges; composed of angular rock and loose debris on active slopes; may be cemented with pedogenic carbonates on older, inactive slopes; clasts primarily basalt in composition; occurs east and west of the Columbia River along the north flank of the Saddle Mountains and in the south-central map area on the south flank of Gable Mountain; age inferred from geomorphology, stratigraphic position, and pedogenic carbonate development. Description compiled from Fecht (1978), Reidel (1988), and authors' unpublished data.

Qfs

Outburst flood deposits, silt and sand (Pleistocene)—Lacustrine silt and fine sand and fluvial coarse to fine sand; predominantly quartz and feldspar with basalt in coarser sands; rhythmically bedded, with stringers of coarse sand and gravel, small-scale cross-bedding, ice-rafted diamicton, and ice-melt structures present locally; sand-dominated facies typically planar laminated; sporadic channel fill sequences; silt-dominated facies is planar laminated and ripple cross laminated, commonly displaying normal graded rhythmites; discrete ash layers common; divided into four time-stratigraphic units on the basis of magnetic polarity, presence of ash beds, pedogenic carbonate and other soil development, and stratigraphic position; deposited by outburst floods from glacial Lake Missoula and other ice-margin lakes; found along the Snake and Columbia Rivers and to elevations of more than 1,200 ft, but generally not extensive above about 900 ft; more than 20 m thick in the south-central map area on a glacial outburst flood bar. Includes Touchet Beds. Only three of four Qfs time units are differentiated in the Priest Rapids quadrangle.

Qfs₄

Youngest outburst flood deposits that originated from ice dams along the Columbia River; planar laminated sands; consists mainly of reworked Qfs₃; overlies unit Qfg₃ (about 13 ka) and eolian sands

and underlies unit Qd containing Mount Mazama tephra (about 6.8-7 ka). Description from authors' unpublished data.

Qfs₃

Normal polarity; contains Mount St. Helens set S tephra (about 13 ka). Description compiled from Baker and others (1991, p. 230-233) and authors' unpublished data.

Qfs₁

Oldest outburst flood deposits; reversed magnetic polarity, age at least 790 ka. Description compiled from Van Alstine (1982), Baker and others (1991, p. 230-233), and authors' unpublished data.

Qfg

Outburst flood deposits, gravel (Pleistocene)—Gravels; grain size ranges from sand to boulders, size generally decreases away from major Pleistocene outburst flood channels; clasts chiefly basalt in abandoned flood channels in northeastern map area; clasts chiefly basalt, granite, quartzite, diorite, and volcanic porphyries along the Columbia and Snake Rivers; generally matrix-poor, and where matrix is present, it is composed of basalt, quartz, and feldspar sand to granule grains; divided into four units on the basis of magnetic polarity, presence of ash beds, pedogenic carbonate development, and stratigraphic position; deposited by outburst floods from glacial Lake Missoula and other ice-margin lakes; displays numerous bedding forms including massive, large-scale cross-bedded and plane-bedded channel and bar deposits; same age as outburst flood deposits, silt and sand (unit Qfs).

Qfg₄

Youngest outburst flood deposits from ice dams along the Columbia River; consists mainly of reworked Qfg₃ and mapped as Qfg_{3-4u}. Description from authors' unpublished data.

Qfg₃

Outburst flood gravels with beds of fine sediment that have normal polarity; contains Mount St. Helens set S ash (13 ka); includes older, undifferentiated outburst flood gravels on the Wahluke Slope. Description compiled from Baker and others (1991, p. 230-233) and authors' unpublished data.

Qfg₂

Outburst flood gravels with beds of fine sediment that have normal polarity; U-Th age estimate of 200 ka (authors' unpublished data) from capping pedogenic carbonate (stage III or IV of Machette, 1985). Description compiled from Baker and others (1991, p. 230-233) and authors' unpublished data.

Qfg₁

Oldest outburst flood deposits; fine sediments in this unit have reversed magnetic polarity, indicating an age of at least 790 ka; capped by pedogenic carbonate and cambic soil horizons. Description compiled from Baker and others (1991, p. 230-233) and authors' unpublished data.

Quaternary-Tertiary Sedimentary Deposits

QP_{Lg}

Gravel (Pleistocene to Pliocene)-Fluvial deposits; compact to weakly cemented; clasts include quartzite, diorite, volcanic porphyries, and basalt; rounded clasts with quartzo-feldspathic sand matrix; occurs as small exposures on the north flank of the Saddle Mountains northwest of Sentinel Gap; overlies Ringold Formation; top scoured by Pleistocene outburst floods; may be correlative to fluvial deposits in the southern Pasco Basin (unit QP_{Lg} on the Richland quadrangle to the south); lithologies indicate deposition by the Columbia River. Description compiled from Reidel (1988) and authors' unpublished data.

Tertiary Sedimentary Deposits and Rocks

Ringold Formation

The Ringold Formation consists of fine and coarse, semi-indurated, fluvial and lacustrine deposits in and near the Pasco Basin (Newcomb and others, 1972; Fecht and others, 1987; Lindsey, 1991). The formation is as thick as 185 m in the deepest part of the Pasco Basin. 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, 1987), which was dated at 8.5 Ma by McKee and others (1977). At the White Bluffs northwest of Pasco, the lower 20 m of the Ringold has normal magnetic polarity, and the upper 100 m has reversed polarity (Packer and Johnston, 1979). Vertebrate fossils (Gustafson, 1978) and magnetic polarity data indicate that the top of the Ringold is about 3.4 Ma (Fecht and others, 1987; authors' unpublished data). It is exposed along flanks of anticlinal ridges and the Columbia River; lithologies indicate deposition by ancestral Columbia and Snake Rivers. Two facies are shown on the map: finer deposits (unit P_LMc) and coarser sediments, chiefly conglomerate (unit P_LMcg).

P_LMc

Continental sand, silt, and clay beds (Pliocene to Miocene)—Interbedded fluvial and lacustrine facies, local pebble lenses and stringers; 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, locally micaceous; commonly capped by pedogenic carbonate or silcrete; contains diatomite beds, ash beds, and fossils; white, gray, green, red, and tan. Exposed along the east side of the Columbia River. Consists of the finer facies of the Ringold Formation of Newcomb and others (1972), Myers, Price, and others (1979), and Lindsey (1991).

P_LMcg

Continental conglomerate (Pliocene to Miocene)—Varicolored pebble to cobble conglomerate with sand matrix; clasts well rounded and chiefly composed of quartzite, granite, basalt, metamorphic rocks, and volcanic porphyries; generally well sorted, massively bedded; locally imbricated; includes lenses of coarse to medium quartzo-feldspathic sand that are cross bedded or foreset bedded in places; commonly uncemented, but in places moderately to poorly indurated with silica, iron oxide, and calcite. Exposed along the White Bluffs and at Coyote Rapids along the Hanford reach of the Columbia River. Consists of the conglomeratic facies of Newcomb and others (1972), Myers, Price, and others (1979), and Lindsey (1991).

P_LMaf

Fanglomerate (Pliocene to Miocene)--Pebble to cobble fanglomerate, subangular to angular basalt fragments and Ellensburg sediments ranging in size from cobble to medium sand. Various indurated with pedogenic carbonate. Generally poorly bedded; includes fluvial, mass wastage, and landslide deposits. Exposed primarily along the northern flank of the Saddle Mountains in the Smyrna Bench segment. Description compiled from Myers, Price, and others (1979), Reidel (1988), and Rigby and others (1979).

Mc

Continental sedimentary deposits (upper and middle Miocene)—Clay, silt, sand, pebble, and gravel beds with scattered lignite beds; light-yellow, cream, off-white, or gray; orange oxide staining in places; silts and sands locally tuffaceous; sands generally composed of quartz and feldspar, with minor mica; some sands rich in basalt grains; paleosols common in fine-grained units; clasts composed of basalt, quartzite, diorite, and volcanic porphyries; poorly lithified; occurs as interbeds between various flows of Columbia River basalt; poorly exposed except in roadcuts; slope-former, prone to landslides (unit Qls) that involve both interbeds and basalt flows; within the Saddle Mountains Basalt, interbeds are present between more units and are thicker than in the Wanapum or Grande Ronde Basalts; gravels form trains across map area and represent ancestral courses of Columbia and Clearwater-Salmon Rivers (Fecht and others 1987); individual interbeds as much as 50 m thick in the Pasco Basin; contacts conformable except where lava flows are invasive into unit; interbedded with Saddle Mountains, Wanapum, and Grande Ronde Basalts. Interbeds record subsidence and formation of Pasco Basin during Saddle Mountains Basalt time. Includes Ellensburg Formation. Description compiled from Reidel and Fecht (1981) and authors' unpublished data.

Mcg

Conglomerate (Miocene)—Principally unconsolidated quartzite and lesser amounts of basalt conglomerate deposited by the ancestral Columbia River; overlies eroded basalt near Sentinel Gap up to 2,000 ft elevation; estimated by Reidel (1984) to be 8.5 My and correlative with the conglomerate of Snipes Mountain of Schmincke (1967). Consists of the conglomerate of the Ellensburg Formation. Description from Reidel (1988).

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

Saddle Mountains Basalt

Mv_s

Saddle Mountains Basalt, undivided (upper and/or middle Miocene)—Occurs at one location in sec. 14, T. 15 N., R. 27 E. where lack of information precludes showing members.

Mv_{sih}

Ice Harbor Member (upper Miocene)—Flows, vents, northwest-trending feeder dikes, and minor tephra between flows; plagioclase phenocrysts commonly more tabular (needlelike in cross section) than in other Saddle Mountains Basalt flows; less than 30 m thick in most places; flows crop out from the Eagle Lakes area, through the Basin City area, to the southeast corner of the map area; about 8.5 Ma, based on K-Ar age estimates (McKee and others, 1977); consists of three informal units (Swanson and others, 1980; Swanson and Helz, 1979), described by Myers, Price, and others (1979) and Swanson and others (1980) as follows:

Basalt of Goose Island—Dark-gray, tan-weathering flow; scattered phenocrysts of plagioclase (2-10 mm long), pyroxene (2 mm long), and olivine and magnetite (less than 5 mm across); plagioclase-pyroxene glomerocrysts 1-3 cm in diameter; microvesicular entablature with brick-bat jointing; well-formed colonnade with 0.5- to 1.5-m-diameter columns; low-latitude normal (transitional) magnetic polarity (Choiniere and Swanson, 1979); crops out near Ice Harbor Dam and a few miles to the northwest in the Glade quadrangle, Richland 1:100,000-scale quadrangle; feeder dikes occur near Ice Harbor Dam near the west edge of the Walla Walla quadrangle (to the southeast of the Priest Rapids quadrangle).

Basalt of Martindale—Two or more flows; black to gray, reddish-weathering, fine- to medium-grained, vesicular to microvesicular, sparse to abundant augite, plagioclase, and olivine phenocrysts; locally abundant glomerophyric clots of plagioclase and augite 20 mm or more in diameter; lower flow has a thick scoria top and a well-developed entablature overlying a poorly developed colonnade with columns as much as 1.5 m in diameter; reversed magnetic polarity (Choiniere and Swanson, 1979); upper flow or flows are less phyric and lack glomerophyric clots (Swanson and Helz, 1979); crops out in the southeast part of map area; dikes and vents upstream and downstream of Ice Harbor Dam (on the Walla Walla quadrangle to the southeast of the Priest Rapids quadrangle).

Basalt of Basin City—Gray to black, fine-grained flows; plagioclase phenocrysts generally less than 10 mm wide; plagioclase glomerocrysts as much as 2 cm in diameter; olivine phenocrysts; no clinopyroxene phenocrysts; normal magnetic polarity (Choiniere and Swanson, 1979); feeder dikes occur south of the Eagle Lakes near Basin City on the eastern end of the Saddle Mountains.

Mv_{sem}

Elephant Mountain Member (upper Miocene)—Two aphyric flows (Swanson and others, 1980); fine-grained; well-developed colonnade and entablature; present throughout the map area; normal to transitional magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979; Reidel and Fecht, 1981); average total thickness of about 30 m but at least 50 m on the north flank of the Saddle Mountains and in coreholes in Cold Creek syncline on the Richland 1:100,000 sheet south of this map; thinner on ridges (Reidel, 1984; Reidel and Fecht, 1981; Reidel and others, 1989b); K-Ar age estimates of 10.5 Ma (McKee and others, 1977) and 9.4 ± 0.7 Ma and 10.7 ± 0.8 Ma (Stoffel, 1984).

Upper flow (Ward Gap 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 (Elephant Mountain flow)—Black to dark-gray; weathers reddish-gray; fine-grained to glassy, locally diktytaxitic; felty texture caused by abundant plagioclase microphenocrysts; thick entablature locally tiered by horizontal vesicle sheets; well-developed colonnade with 1- to 2-m-diameter columns; local pillows and vesicle cylinders (Myers, Price, and others, 1979).

Mv_{sp}

Pomona Member (middle Miocene)—Two flows, or most probably, two flow units; small phenocrysts of plagioclase (generally less than 5 mm long), clinopyroxene, and olivine; plagioclase phenocrysts commonly wedge-shaped; locally contains large clots (as much as 100 mm or more across) of plagioclase, pyroxene (including rare hypersthene), and olivine thought by Swanson and others (1980) to have formed during crystallization after eruption; reversed magnetic polarity (Choiniere and Swanson, 1979; Reidel and others, 1984); occurs as nearly sheet-like flow(s); average thickness in map area is about 30 m; thinner on ridges (Reidel, 1984; Reidel and Fecht, 1981; Reidel and others, 1989b); isotopically dated at 12 Ma (K-Ar method) by McKee and others (1977) and 12 Ma (⁴⁰Ar-³⁹Ar 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 unit—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 unit—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.

Mv_{se}

Esquatzel Member (middle Miocene)—Two or more flows or flow units; blue-black; weathers brownish; fine-grained; plagioclase phyric to glomerophyric; locally diktytaxitic; vesicle pipes and sheets; well-developed entablature with hackly jointing; well-developed colonnade with 1-m-diameter columns; normal magnetic polarity (Choiniere and Swanson, 1979; Reidel and Fecht, 1981); as much as 30 m thick in coreholes in Cold Creek syncline on the Richland 1:100,000 quadrangle; pinches out on anticlinal ridges (Reidel and Fecht, 1981; Reidel and others, 1989b); in the map area crops out in the southern part along the Umtanum-Gable Mountain anticlinal trend and Yakima Ridge; older than the Pomona Member (McKee and others, 1977) and younger than the Asotin Member (13 Ma, Reidel and Fecht, 1987, p. 666); no known feeder dikes, but presence of this unit in the Snake River canyon suggests a vent up the Snake River, distinguished by higher TiO₂ and P₂O₅ contents than in the overlying Pomona Member and underlying Asotin Member. Descriptions compiled from Reidel and Fecht (1981), Swanson and others (1979b), Myers, Price, and others (1979), and authors' unpublished data.

Mv_{sa}

Asotin Member (middle Miocene)—Basalt flow; black to gray; weathers gray; glassy, fine- to medium-grained; aphyric with microphenocrysts of olivine as much as 0.5 mm long and rare plagioclase phenocrysts;

locally ophitic and diktytaxitic; well-developed entablature with hackly jointing and fanning columns; well-developed colonnade with columns as much as 1 m in diameter; normal magnetic polarity (Choiniere and Swanson, 1979; Reidel and Fecht, 1981); no thicker than 30 m in map area; pinches out to south onto constructive topography of the Umatilla Member and thins onto Umtanum Ridge (Reidel and Fecht, 1981; Reidel and others, 1989b); crops out on Gable Mountain (NE 1/4 sec. 22, T. 13 N., R. 26 E.); younger than underlying Wilbur Creek Member and older than overlying Esquatzel Member; no known feeder dike but present as far east as Idaho; locally mixed with Wilbur Creek Member to form Huntzinger flow, indicating nearly simultaneous eruption of the two members (Reidel and Fecht, 1987). Descriptions from Reidel and Fecht (1981, 1987), Swanson and others (1979b), and Myers, Price, and others (1979).

Mv_{swc}

Wilbur Creek Member (middle Miocene)—Basalt flow; black to blue-black; weathers gray-black; fine- to medium-grained; aphyric with rare microphenocrysts of plagioclase; thin entablature with well-developed colonnade with columns 0.5 to 1 m in diameter; locally developed hackly jointing and pillows at base of flow; normal magnetic polarity (Choiniere and Swanson, 1979; Reidel and Fecht, 1981); approximately 10 m thick in map area; exposed on Umtanum Ridge (SW 1/4, sec. 24, T. 13 N., R. 23 E.) and Yakima Ridge as part of intracanyon flow along flow front of Umatilla flow (Reidel and Fecht, 1981); younger than underlying Umatilla Member and older than overlying Asotin Member; no known feeder dike; locally mixed with Asotin Member to form Huntzinger flow, indicating nearly simultaneous eruption of the two members (Reidel and Fecht, 1987). Descriptions from Reidel and Fecht (1981, 1987), Swanson and others (1979b); Myers, Price, and others (1979).

Mv_{su}

Umatilla Member (middle Miocene)—Two flows; black; weather yellow-orange; glassy to very fine grained, locally medium-grained; sparse plagioclase phenocrysts as much as 0.7 cm across; well-developed entablature (normally 80 percent of flows) with hackly jointing; local colonnade; normal magnetic polarity (Rietman, 1966); as much as 60 m thick in Cold Creek syncline on the Richland quadrangle but thinner on anticlinal ridges (Reidel and Fecht, 1981; Hagood, 1986; Reidel and others, 1989b); present in southern part of map area; pinches out north of the Umtanum-Gable Mountain anticlinal trend (Reidel and Fecht, 1981); 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); consists of an upper subunit called the basalt of Sillusi and a lower subunit called the basalt of Umatilla; basalt of Umatilla has lower P₂O₅ and higher TiO₂ contents than the basalt of Sillusi; the two flows are known to physically mix in the map area, forming one cooling unit (Reidel and Fecht, 1987). Description compiled from Reidel and Fecht (1981), Myers, Price, and others (1979), Swanson and others (1980), and authors' unpublished data.

Wanapum Basalt

Mv_w

Wanapum Basalt, undivided (middle Miocene)—Occurs at one location in sec. 34, T. 16 N., R. 25 E. where lack of information precludes showing members.

Mv_{wpr}

Priest Rapids Member (middle Miocene)—Two or more flows; black; weather rusty brown; fine- to medium-grained; aphyric; diktytaxitic; local diabasic texture and pegmatoids in uppermost flow; lower flows generally coarser grained than upper flow; scattered but prominent plagioclase phenocrysts generally less than 5 mm long but some as much as 10 mm long; olivine phenocrysts 0.5 to 1 mm in diameter; well-developed colonnade with 0.5- to 1.5-m-diameter columns; uppermost flow has well-developed, hackly jointed entablature; reversed magnetic polarity (Rietman, 1966); as much as 100 m thick on the north flank of the Saddle Mountains at the east end of Smyrna Bench (Reidel, 1984); thinner on anticlinal ridges (Reidel, 1984; Reidel and others, 1989b; Hagood, 1986); present throughout map area; K-Ar age estimate of 14.5 Ma (Tolan and others, 1989). Uppermost flow is designated the basalt of Lolo and the lower flows the basalt of Rosalia; the Lolo has higher MgO and lower TiO₂ contents than the Rosalia (Swanson and others, 1979b, p. G11, G37). Lolo flow pinches out north of the Saddle Mountains (Reidel, 1984). Description compiled from Reidel and Fecht (1981), Myers, Price, and others (1979), Swanson and others (1980), and authors' unpublished data.

Mv_{wt}

Roza Member (middle Miocene)—One or two flows; gray-black; weather reddish-brown; fine- to medium-grained; consistently contain(s) several percent discrete (in places clotted) plagioclase phenocrysts averaging nearly 10 mm across; locally diktytaxitic; well-developed colonnade with columns as much as 1 m in diameter; columns locally pinch and swell; transitional to reversed magnetic polarity (Choiniere and Swanson, 1979); average thickness about 30 m; reaches 45 m in the Saddle Mountains but thinner on anticlinal ridges (Reidel, 1984; Reidel and Fecht, 1981; Hagood, 1986; Reidel and others, 1989b); present throughout the map area; older than Priest Rapids Member (14.5 Ma, Tolan and others, 1989) and younger than Frenchman Springs Member (15.3 Ma, Tolan and others, 1989). The Roza Member, because of its large and nearly ubiquitous plagioclase phenocrysts and wide distribution, is a key marker across much of the Columbia Basin. Description compiled from Reidel and Fecht (1981), Martin (1989), Myers, Price, and others (1979), and Swanson and others (1980).

Mv_{wfs}

Frenchman Springs Member (middle Miocene)—Five or more flows; sparsely to abundantly plagioclase aphyric; lower flow as much as 230 m thick in the Cold Creek syncline on the Richland quadrangle; flows thin and (or) pinch out onto anticlinal ridges (Reidel and Fecht, 1981; Hagood, 1986; Reidel and others, 1989b); present throughout map area; feeder dikes east of the map area (Tolan and others, 1989); Beeson and others (1985) defined the informal Frenchman Springs subunits shown on Figure 5. Aphyric flows are gray-black and fine grained and have well-developed entablatures with hackly jointing and colonnades with 1.5- to 2-m-diameter columns and locally pillowed bases. Aphyric flow(s) are gray-black and weather reddish-gray, are fine to medium grained, and have abundant plagioclase phenocrysts and glomerocrysts, thin entablatures, and well-developed colonnades with 0.5- to 1.5-m-diameter columns. Description compiled from Beeson and others (1985), Myers, Price, and others (1979), Reidel and Fecht (1981), and Swanson and others (1980).

Grande Ronde Basalt

The middle Miocene Grande Ronde Basalt makes up 87 percent of the volume of the Columbia River Basalt Group (CRBG). Flows of the Grande Ronde Basalt are generally aphyric and fine grained. The groundmass contains plagioclase, augite, and pigeonite. 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, 1989a, p. 23, 36; Fig. 5). In the Blue Mountains, east 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. In the BN 1-9 borehole on the Saddle Mountains, the base of the Grande Ronde Basalt was encountered at approximately 3,500 m drilled depth, making the Grande Ronde Basalt approximately 3,200 m thick (Reidel and others, 1989a).

The formation is divided into four magnetostratigraphic units, but only the upper two units are exposed in the map area. The N_2 magnetostratigraphic unit is exposed along the north face of Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Frenchman Hills. The R_2 magnetostratigraphic unit is exposed on the Saddle Mountains near Sentinel Gap. The feeder dikes for CRBG flows are exposed to the east. The Grande Ronde Basalt conformably overlies the Imnaha Basalt, and it is overlain by the Wanapum Basalt, commonly with an intervening saprolite or sedimentary interbed. The formation is isotopically (K-Ar, ^{40}Ar - ^{39}Ar) dated at about 15.6 to 16.9 Ma (Baksi, 1989, p. 109; age information summarized by Reidel and others, 1989a, 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 (Reidel, 1983; Reidel and others, 1992).

Mv_{gN2}	Upper flows of normal magnetic polarity. Consists of the Sentinel Bluffs, Slack Canyon, and Orley units of Reidel and others (1989a).
Mv_{gN2u}	Upper flows of normal magnetic polarity, Umtanum unit of Reidel and others (1989a).
Mv_{gR2}	Upper flows of reversed magnetic polarity. Consists of the Wapshilla Ridge unit of Reidel and others (1989a).

Description compiled from Reidel (1983), Reidel and others (1989a), Swanson and others (1980), and Swanson and Wright (1983).

REFERENCES CITED

- Aguirre, Emiliano; Pasini, Giancarlo, 1985, The Pliocene-Pleistocene boundary: Episodes, v. 8, no. 2, p. 116-120.
- Alto, B. R., 1955, Geology of a part of the Boylston quadrangle and adjacent areas in central Washington: University of Washington Master of Science thesis, 38 p., 2 pl.
- Bacon, C. R., 1983, Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal of Volcanology and Geothermal Research, v. 18, no. 1-4, p. 57-115.
- 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.

OPEN FILE REPORT 94-13

- 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.; Londquist, C. J.; Baltz, E. H., Jr., 1970, Geologic investigation of faulting in the Hanford region, Washington: U.S. Geological Survey Open-File Report 70-27, 104 p., 10 pl.
- Brooks, W. E., Jr., 1974, Stratigraphy and structure of the Columbia River basalt in the vicinity of Gable Mountain, Benton County, Washington: University of Washington Master of Science thesis, 39 p., 2 pl.
- 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.
- Carson, R. J.; Tolan, T. L.; Reidel, S. P., 1987, Geology of the Vantage area, south-central Washington— An introduction to the Miocene flood basalts, Yakima Fold Belt, and the Channeled Scabland. *In* Hill, M. L., editor, 1987, *Cordilleran Section of the Geological Society of America: Geological Society of America DNAG Centennial Field Guide 1*, p. 357-362.
- 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.
- Fecht, K. R., 1978, Geology of Gable Mountain-Gable Butte area: Rockwell Hanford Operations RHO-BWI-LD-5, 57 p., 4 pl., scale 1:24,000.
- Fecht, K. R.; Reidel, S. P.; Tallman, A. M., 1987, Paleodrainage of the Columbia River system on the Columbia plateau of Washington State—A summary. *In* Schuster, J. E., editor, *Selected papers on the geology of Washington: Washington Division of Geology and Earth Resources Bulletin 77*, p. 219-248.
- Geomatrix Consultants, Inc., 1990, Seismotectonic evaluation, Walla Walla section of the Columbia plateau geomorphic province; Final report: Geomatrix Consultants, Inc. [under contract to] U.S. Bureau of Reclamation, 1 v., 6 pl.
- Goff, F. E., 1981, Preliminary geology of eastern Umtanum Ridge, south-central Washington: Rockwell Hanford Operations RHO-BWI-C-21, 99 p., 2 pl., scale 1:24,000.
- 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.
- 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.
- Gustafson, E. P., 1978, The vertebrate faunas of the Pliocene Ringold Formation, south-central Washington: University of Oregon Museum of Natural History Bulletin 23, 62 p.
- Hagood, M. C., 1985, Structure and evolution of the Horse Heaven Hills in south-central Washington: Portland State University Master of Science thesis, 201 p., 1 pl.
- Hagood, M. C., 1986, Structure and evolution of the Horse Heaven Hills in south-central Washington: Rockwell Hanford Operations RHO-BW-SA-344 P, 190 p., 1 pl.
- Hays, W. H.; Schuster, R. L., 1983, Evidence of tectonic stability along the middle Columbia River, Washington, in Quaternary time: U.S. Geological Survey Open-File Report 83-365, 8 p., 1 pl., scale 1:100,000.
- Hays, W. H.; Schuster, R. L., 1987, Maps showing ground-failure hazards in the Columbia River valley between Richland and Priest Rapids Dam, south-central Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1699, 2 sheets.
- 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, pt. 2, p. 473-500.
- Kinnison, H. B.; Sceva, J. E., 1963, Effects of hydraulic and geologic factors on streamflow of the Yakima River basin, Washington: U.S. Geological Survey Water-Supply Paper 1595, 134 p., 3 pl.
- Kittleman, L. R., 1973, Mineralogy, correlation, and grain-size distributions of Mazama tephra and other postglacial pyroclastic layers, Pacific Northwest: Geological Society of America Bulletin, v. 84, no. 9, p. 2957-2980.
- Laval, W. N., 1956, Stratigraphy and structural geology of portions of south-central Washington: University of Washington Doctor of Philosophy thesis, 223 p., 11 pl.
- Lillie, J. T.; Tallman, A. M.; Caggiano, J. A., 1978, Preliminary geologic map of the late Cenozoic sediments of the western half of the Pasco Basin: Rockwell Hanford Operations RHO-BWI-LD-8, 16 p., 13 pl., scale 1:62,500.
- Lindsey, K. A., 1991, Revised stratigraphy for the Ringold Formation, Hanford site, south-central Washington: Westinghouse Hanford Company WHC-SD-EN-EE-004, 12 p.
- Machette, M. N., 1985, Calcic soils of the southwestern United States. In Weide, D. L.; Faber, M. L., editors, Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.
- Mack, R. N.; Rutter, N. W.; Valastro, S., 1983, Holocene vegetational history of the Kootenai River valley, Montana: Quaternary Research, v. 20, no. 2, p. 177-193.

OPEN FILE REPORT 94-13

- Martin, B. S., 1989, The Roza Member, Columbia River Basalt Group; Chemical stratigraphy and flow distribution. *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. 85-104.
- Mason, G. W., 1953, Interbasalt sediments of south central Washington: State College of Washington Master of Science thesis, 116 p., 3 pl.
- 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.
- Mehring, P. J., Jr.; Sheppard, J. C.; Foit, F. F., Jr., 1984, The age of Glacier Peak tephra in west-central Montana: *Quaternary Research*, v. 21, no. 2, p. 36-41.
- Moak, D. J.; Wintczak, T. M., 1980, Near-surface test facility phase I geologic site characterization report: Rockwell Hanford Operations RHO-BWI-ST-8, 235 p.
- 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. R.; 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., 1973, Yakima Basalt flows near Vantage, and from core holes in the Pasco Basin, Washington: University of California at Santa Cruz Doctor of Philosophy thesis, 147 p.
- Myers, C. W.; Price, S. M., editors, 1981, Subsurface geology of the Cold Creek syncline: Rockwell Hanford Operations RHO-BWI-ST-14, 1 v.
- 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.
- Newcomb, R. C.; Strand, J. R.; Frank, F. J., 1972, Geology and ground-water characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington: U.S. Geological Survey Professional Paper 717, 78 p., 3 pl.
- Packer, D. R.; Johnston, J. M., 1979, A preliminary investigation of the magnetostratigraphy of the Ringold Formation: Rockwell Hanford Operations RHO-BWI-C-42, 60 p.
- Price, E. H., 1982, Structural geometry, strain distribution, and mechanical evolution of eastern Umtanum Ridge and a comparison with other selected localities within Yakima fold structures, south-central Washington: Rockwell Hanford Operations RHO-BWI-SA-138; Washington State University Doctor of Philosophy thesis, 199 p., 6 pl.
- Reidel, S. P., 1978, Geology of the Saddle Mountains between Sentinel Gap and 119 degrees, 30 minutes longitude: Rockwell Hanford Operations RHO-BWI-LD-4, 75 p., 4 pl.

- Reidel, S. P., 1983, Stratigraphy and petrogenesis of the Grande Ronde Basalt from the deep canyon country of Washington, Oregon, and Idaho: *Geological Society of America Bulletin*, v. 94, no. 4, p. 519-542.
- Reidel, S. P., 1984, The Saddle Mountains—The evolution of an anticline in the Yakima fold belt: *American Journal of Science*, v. 284, no. 8, p. 942-978.
- Reidel, S. P., 1988, Geologic map of the Saddle Mountains, south-central Washington: Washington Division of Geology and Earth Resources Geologic Map GM-38, 5 pl., scale 1:48,000, with 28 p. text.
- Reidel, S. P.; Fecht, K. R., 1981, Wanapum and Saddle Mountains Basalts of the Cold Creek syncline area. *In* Myers, C. W.; Price, S. M., editors, *Subsurface geology of the Cold Creek syncline*: Rockwell Hanford Operations RHO-BWI-ST-14, p. 3-1 - 3-45.
- 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.; Fecht, K. R.; Hagood, M. C.; Tolan, T. L., 1989b, The geologic evolution of the central Columbia plateau. *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. 247-264.
- 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.; Scott, G. R.; Bazard, D. R.; Cross, R. W.; Dick, Brian, 1984, Post-12 million year clockwise rotation in the central Columbia plateau, Washington: *Tectonics*, v. 3, no. 2, p. 251-273.
- Reidel, S. P.; Tolan, T. L.; Hooper, P. R.; Beeson, M. H.; Fecht, K. R.; Bentley, R. D.; Anderson, James Lee, 1989a, 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 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.
- Schmincke, H., 1967, Stratigraphy and petrography of four upper Yakima Basalt flows in south-central Washington: *Geological Society of America Bulletin*, v. 78, no. 11, p. 1385-1422.
- Smith, D. R., 1980, Mineralogy and phase chemistry of silicic tephras: Rice University Master of Science thesis, 161 p.

OPEN FILE REPORT 94-13

- 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., scale 1:48,000.
- Swanson, D. A.; Anderson, James Lee; Bentley, R. D.; Byerly, G. R.; Camp, V. E.; Gardner, J. N.; Wright, T. L., 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in eastern Washington and northern Idaho: U.S. Geological Survey Open-File Report 79-1363, 26 p., 12 pl., scale 1:250,000.
- Swanson, D. A.; Helz, R. T., 1979, Bedrock geologic map of the vent system for the Ice Harbor Member of the Saddle Mountains Basalt, Ice Harbor Dam-Basin City area, southeast Washington: U.S. Geological Survey Open-File Report 79-292, 8 sheets, scale 1:24,000.
- Swanson, D. A.; Wright, T. L., 1983, Geologic map of the Wenaha Tucannon Wilderness, Washington and Oregon: U.S. Geological Survey Miscellaneous Field Studies Map MF-1536, 1 sheet, scale 1:48,000.
- 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 Investigations Series Map I-1139, 2 sheets, scale 1:250,000.
- Swanson, D. A.; Wright, T. L.; Hooper, P. R.; Bentley, R. D., 1979b, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.
- 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.
- Taylor, T. L., 1976, The basalt stratigraphy and structure of the Saddle Mountains of south-central Washington: Washington State University Master of Science thesis, 116 p., 1 pl., scale 1:18,000.
- 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.
- Twiss, S. N., 1933, Stratigraphy of Saddle Mountains: State College of Washington Master of Science thesis, 30 p., 1 pl., scale 1:62,500.
- Van Alstine, D. R., 1982, Paleomagnetic investigation of pre-Missoula gravels, Pasco Basin and vicinity, Washington: Sierra Geophysics, Inc. [Renton, Wash.] SGI-R-82-055, for Golder Associates, 1 v.
- Waggoner, S. Z., compiler, 1990, Geologic map of the Rosalia 1:100,000 quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-7, 20 p., 1 pl.