NATURAL RESOURCES

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

compiled by
Stephen P. Reidel
and Karl R. Fecht

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 94-8
June 1994

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

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ILLUSTRATIONS

PLATE (accompanies report)

GEOLOGIC MAP OF THE RICHLAND 1:100,000 QUADRANGLE, WASHINGTON

compiled by

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INTRODUCTION

This map of the Richland 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 below). 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.

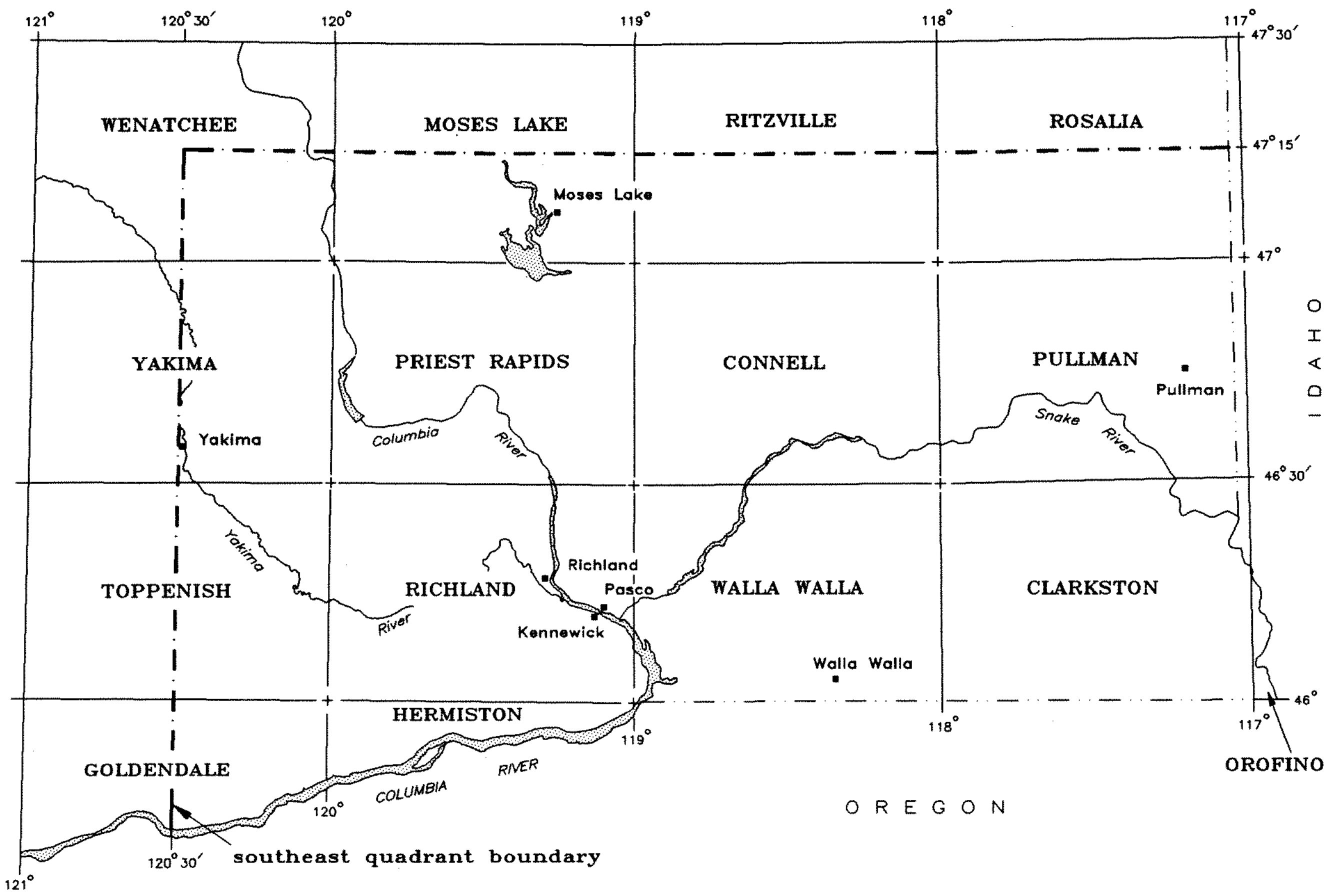


Figure 1. 1:100,000-scale quadrangles in the southeast quadrant of Washington.

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

The geology of the Richland 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.

This map was compiled in 1992 and 1993 using published and unpublished geologic maps as sources of data.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

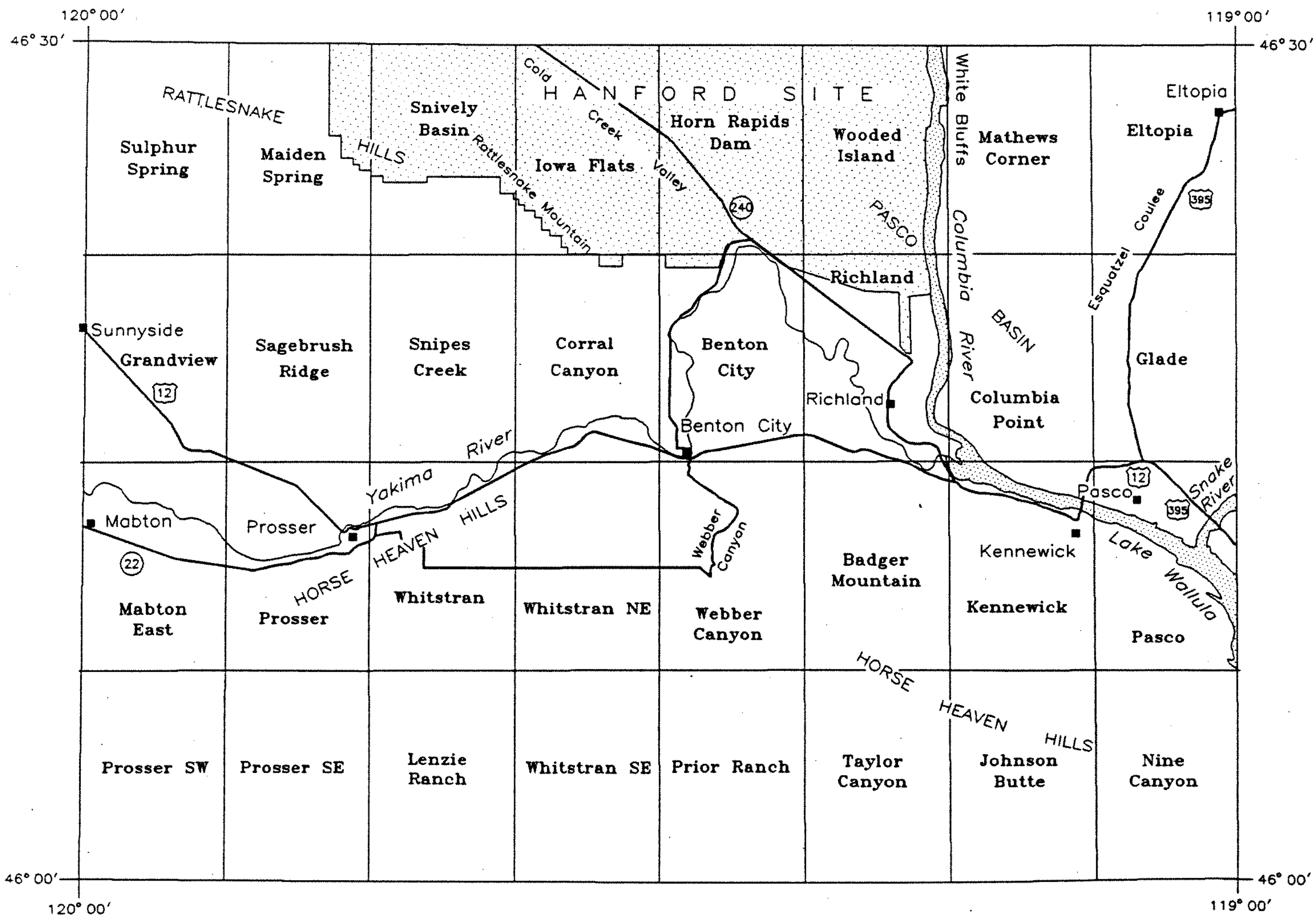


Figure 2. Index map showing geographic names and 7.5-minute quadrangles, Richland quadrangle.

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, with assistance by M. A. Chamness, for much of the map area (particularly the Rattlesnake Hills area) 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; 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 Columbia River Basalt Group units 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, 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 pl.

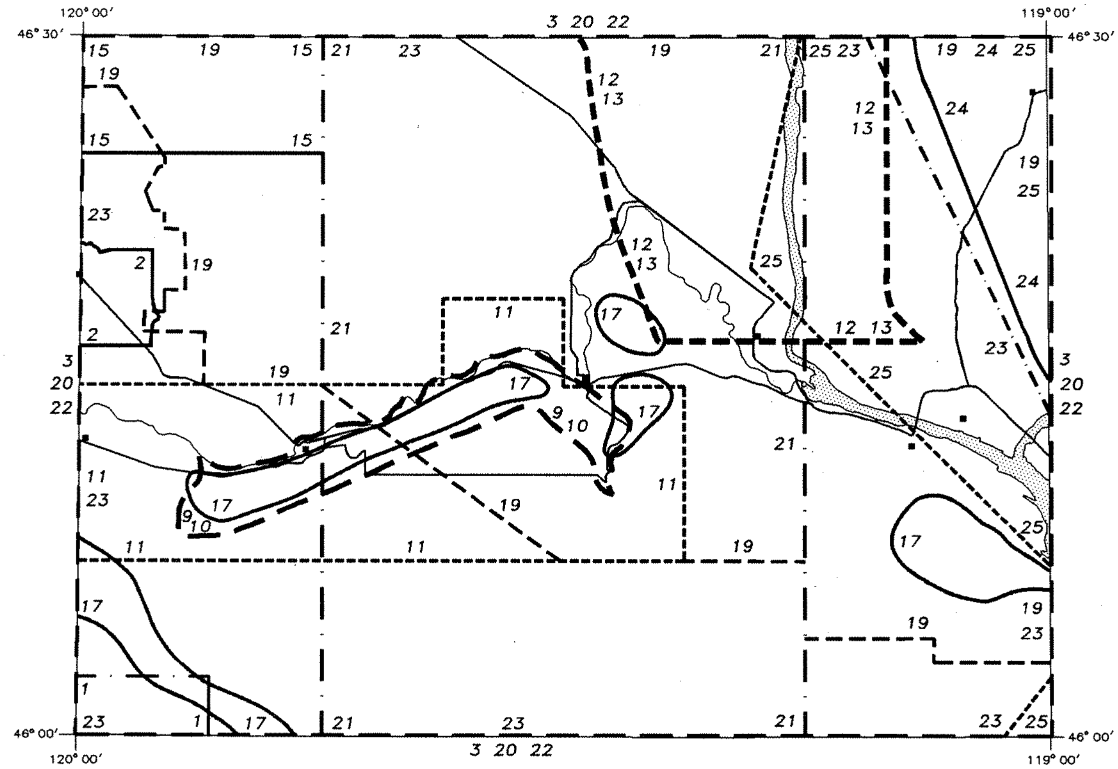
Reidel, S. P.; Fecht, K. R., compilers, in press, Geologic map of the Priest Rapids 1:100,000 quadrangle, Washington: Washington Division of Geology and Earth Resources open-file report.

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

Figure 3 (facing page). Sources of geologic mapping for the Richland 1:100,000 quadrangle. The primary sources of geologic data used in this compilation are marked with asterisks. The area mapped by the authors for this report is labeled "this report".

1.	Brown, J. C., 1979, plate V, scale 1:94,000.
2.	Campbell, N. P., 1977, 3 sheets, scale 1:24,000.
3.	Campbell, N. P.; and others, 1979, scale 1:250,000.
4.	Foundation Sciences, Inc., 1980, plate 2, scale 1:170,000.
5.	Geomatrix Consultants, Inc., 1990, fig. 2, scale 1:250,000.
6.	Geoscience Research Consultants, 1978, plates 1-A through 1-P, scale 1:24,000.
7.	Grolier, M. J.; Bingham, J. W., 1965, scale 1:62,500.
8.*	Grolier, M. J.; Bingham, J. W., 1971, sheet 5, scale 1:62,500.
9.*	Hagood, M. C., 1985, scale 1:24,000.
10.*	Hagood, M. C., 1986, scale 1:24,000.
11.*	Hagood, M. C., Westinghouse Hanford Corp., written commun., 1986, Geologic maps of the Mabton East, Prosser, Whitstran, Whitstran NE, Webber Canyon, and S. 1/2 Corral Canyon 7.5-minute quadrangles, scale 1:24,000.
12.*	Hays, W. H.; Schuster, R. L., 1983, scale 1:100,000.
13.*	Hays, W. H.; Schuster, R. L., 1987, scale 1:100,000.
14.	Jones, M. G.; Landon, R. D., 1978, plates 1-4, scale 1:24,000.
15.	Kienle, C. F., Jr.; and others, 1977, scale 1:63,360.
16.	Kinnison, H. B.; Sceva, J. E., 1963, plate 1, scale 1:250,000.
17.	Laval, W. N., 1956, plates XXVII, XXIX, and XXXI, scale 1:62,500.
18.	Lillie, J. T.; and others, 1978, plates 7-13, scale 1:62,500.
19.*	Myers, C. W.; Price, S. M.; and others, 1979, plate III-3, sheets 7,8,10,11; scale 1:62,500.
20.	Myers, C. W.; Price, S. M.; and others, 1979, plates II-7 and II-16, scale 1:250,000.
21.	Newcomb, R. C.; and others, 1972, plate 1, scale 1:62,500.
22.	Shedd, Solon, 1925, scale 1:125,000.
23.*	Swanson, D. A.; and others, 1979a, sheet 7, scale 1:250,000.
24.*	Swanson, D. A.; Helz, R. T., 1979, sheet 3, scale 1:24,000.
25.	Swanson, D. A.; and others, 1980, scale 1:250,000.
26.	U.S. Army Corps of Engineers, 1978, plate 18, scale 1:250,000.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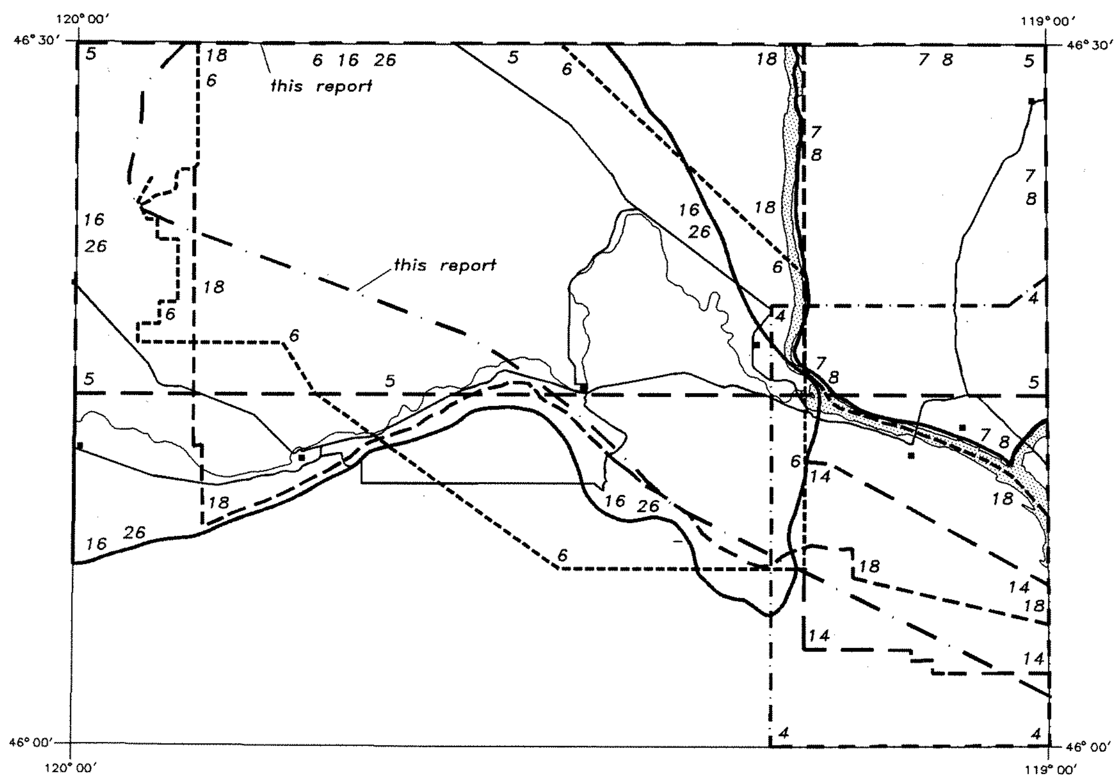
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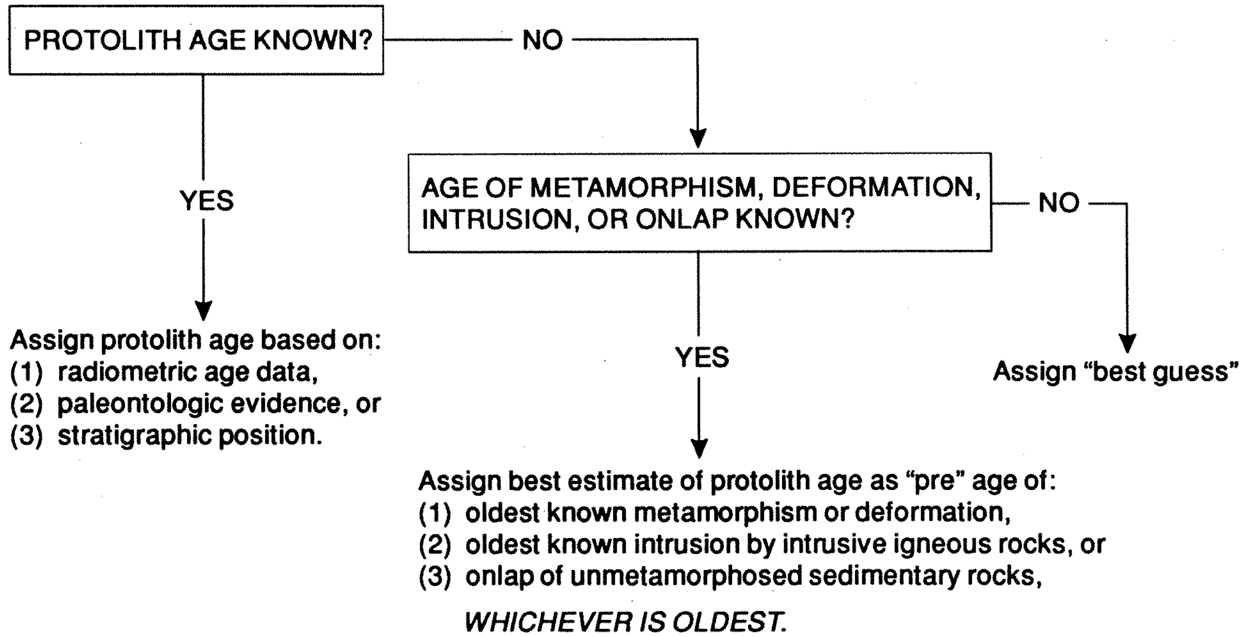

Figure 4. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description includes information on how the age of the unit was determined.

Schuster, J. E., compiler, in press, 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.

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, 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, 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.

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; PICTURE GORGE 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		
				China Creek unit		N_1
				Downey Gulch unit		
				Center Creek unit		R_1
				Rogersburg unit		
				Teepee Butte unit		
				Buckhorn Springs unit	16.9	
	lower		IMNAHA BASALT	See Hooper and others (1984) for Imnaha units	17.0	R_1
						T
						N_0
					17.3	R_0

Figure 5. Generalized nomenclature and stratigraphic relations of Columbia River Basalt Group units. This diagram includes units that do not occur in the Richland quadrangle. Modified from Reidel and others, 1989a.

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 mostly in the northeastern part of the map area; 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 paleomagnetics, 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; Mehringer 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 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; thickness locally greater than 30 m in southern map area; 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 slopewash; 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.

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 and 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, Columbia, and Yakima 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 north-central map area on a glacial outburst flood bar. Includes Touchet Beds.

Qfs_3

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.

Qfs_2

Normal polarity, U-Th age estimate of about 200 ka, capped by pedogenic carbonate (stage III or IV of Machette, 1985). Description compiled from Baker and others (1991, p. 230-233) and authors' unpublished data.

Qfs_1

Oldest outburst 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, Snake, and Yakima 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).

Qfg_4

Youngest outburst flood deposits from ice dams along the Columbia River; consists mainly of reworked Qfg_3 and mapped as Qfg_{3-4}. Description from authors' unpublished data.

Qfg_3

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

Qfg_2

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.

Qfg_1

Oldest outburst deposits; fine sediments in this unit have reversed magnetic polarity, indicating an age of at lease 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 unconsolidated, clasts include quartzite, gneiss diorite, volcanic porphyries and basalt, and rounded gravel with micaceous quartzo-feldspathic sand matrix; includes quartzo-feldspathic sand facies and silty overbank facies; as much as 25 m thick; confined to Pasco Basin principally west of Richland; may be correlative with older eolian and sidestream fluvial deposits between Rattlesnake Hills and Umtanum Ridge to the north of the map area; overbank facies has reversed magnetic polarity (Van Alstine, 1982); underlies oldest Pleistocene outburst flood deposits and overlies Ringold Formation and Ice Harbor Member of Saddle Mountain Basalt; age is greater than about 1 Ma and less than 3 Ma; lithologies indicate deposition by Columbia and Yakima Rivers. Description from the authors' unpublished data.

Tertiary Sedimentary Deposits

Ringold Formation

The Ringold Formation consists of fine and coarse, semi-indurated, fluvial and lacustrine deposits in and near the Pasco Basin (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 Johnson, 1979). Vertebrate fossils (Gustafson, 1978) and magnetic polarity data indicate that the Ringold is about 3.4 Ma (Fecht and others, 1987; authors' unpublished data). Exposed along flanks of anticlinal ridges and the Columbia and Yakima Rivers; 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, eastern Rattlesnake Hills, and as isolated outcrops between Richland and Kennewick. 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 along flank of basaltic ridge west of Richland. Consists of the conglomeratic facies of Newcomb and others (1972), Myers, Price, and others (1979), and Lindsey (1991).

M_c

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; palesols 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; locally overlies Elephant Mountain Member

(10.5 Ma, McKee and others, 1977) of Saddle Mountain Basalt on lower flanks of Rattlesnake Mountain and Rattlesnake Hills; 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.

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 Richland 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. 11 N., R. 25 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 along the Snake River at the eastern edge of the map area and in the south-central part of 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; feeder dikes occur near Ice Harbor Dam near the west edge of the Walla Walla quadrangle (to the east of the Richland quadrangle) and in Esquatzel Coulee.

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 south-central part of map area; dikes and vents upstream and downstream of Ice Harbor Dam (on the Walla Walla quadrangle to the east).

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 north of the northeast corner of this map area.

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 in corehole in Cold Creek syncline; 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 $\pm$ 0.7 Ma and 10.7 $\pm$ 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 1.0- to 2.0-m-diameter columns; local pillows and vesicle cylinders (Myers, Price, and others, 1979).

$\mathrm{Mv_{sp}}$

Pomona Member (middle Miocene)—Two flows or 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 but at least 60 m in Cold Creek syncline; 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 (^{40}Ar-^{39}Ar method) (S. P. Reidel, Wash. State Univ., unpub. data, 1991). Description from Swanson and others (1980). Myers, Price, and others (1979) describe two flows:

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

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

$\mathrm{Mv_{se}}$

Esquatzel Member (middle Miocene)—Two or more flows or flow units; blue-black; weathers brownish; fine-grained; plagioclase phyric to glomerophyric; locally diktytaxtic; 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; pinches out on anticlinal ridges (Reidel and Fecht, 1981; Reidel and others, 1989b); in the map area crops out only on Rattlesnake Mountain and Rattlesnake Hills; 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 TiO_2 and P_2O_5 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_{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 but thinner on anticlinal ridges (Reidel and Fecht, 1981; Hagood, 1986: Reidel and others, 1989b) present throughout map area; 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 P_2O_5 and higher TiO_2 contents than the basalt of Sillusi; the two flows are known to physically mix in the map area, forming one cooling unit (authors' unpublished data). Description compiled from Reidel and Fecht (1981), Myers, Price, and others (1979), Swanson and others (1980), and authors' unpublished data.

Wanapum Basalt

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 70 m thick in the Cold Creek syncline; thinner on anticlinal ridges (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 TiO_2 contents than the Rosalia (Swanson and others, 1979b, p. G11, G37). Description compiled from Reidel and Fecht (1981), Myers, Price, and others (1979), Swanson and others (1980), and authors' unpublished data.

Mv_{wr}

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 60 m in Cold Creek syncline but thinner on anticlinal ridges (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 phyric; lower as much as 230 m thick in the Cold Creek syncline; flows thin and (or) pinch out onto anticlinal ridges (Reidel and Fecht, 1981; Hagood, 1986; Reidel and others, 1989b); present in most of the 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 2.0-m-diameter columns and locally pillowed bases. Phyric 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. The formation is divided into four magnetostratigraphic units, but only the upper unit is exposed in the map area. The N_2 magnetostratigraphic unit is exposed along the north face of the Rattlesnake Mountain. Feeder dikes for CRBG flows are exposed to the east. The Grande Ronde 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.

Description compiled from Reidel (1983), Hooper and others (1985), Reidel and others (1989a), Swanson and others (1980), and Swanson and Wright (1983).

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