Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group

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By D. A. SWANSON, T. L. WRIGHT, P. R. HOOPER,
and R. D. BENTLEY

CONTRIBUTIONS TO STRATIGRAPHY

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REVISIONS IN STRATIGRAPHIC NOMENCLATURE OF THE COLUMBIA RIVER BASALT GROUP

By D. A. Swanson, T. L. Wright, P. R. Hooper,[1]
and R. D. Bentley[2]

ABSTRACT

New stratigraphic nomenclature for units within the Columbia River Basalt Group is introduced to revise and expand that currently in use; it is based largely on subdivisions made informally by T. L. Wright, M. J. Grolier, and D. A. Swanson in 1973. The Yakima Basalt is raised to subgroup status, and three formations—the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt, in order of decreasing age—are defined within it. The Wanapum contains four formally named members, from oldest to youngest, the Eckler Mountain, Frenchman Springs, Roza, and Priest Rapids Members. The Saddle Mountains Basalt is divided into 10 members, from oldest to youngest, the Umatilla, Wilbur Creek, Asotin, Weissenfels Ridge, Esquatzel, Pomona, Elephant Mountain, Buford, Ice Harbor, and Lower Monumental Members. The Picture Gorge Basalt is restricted to north-central Oregon, and a new name, the Imnaha Basalt, is used for basalt probably of pre-Picture Gorge age in the tristate area of Washington, Oregon, and Idaho. All significant sedimentary interbeds between basalt flows are excluded from the Columbia River Basalt Group. The age of the group is revised to early, middle, and late Miocene, on the basis of potassium-argon dates ranging from about 16.5 to about 6 m.y. and reinterpretation of the age of vertebrate fossils in the interbedded Ellensburg Formation.

INTRODUCTION

The basalt on the Columbia Plateau (fig. 1) in Washington, Oregon, and Idaho has been the subject of much study during the last 20 years. As geologic mapping has progressed, the need for a revised formal stratigraphic nomenclature has become apparent. Nomenclature used by current workers is a mixture of formal and informal names based largely on terms suggested by Mackin (1961), Waters (1955; 1961), Bond (1963), Schmincke (1967a), Wright and others (1973), and Hooper (1974). Despite the proliferation of informal

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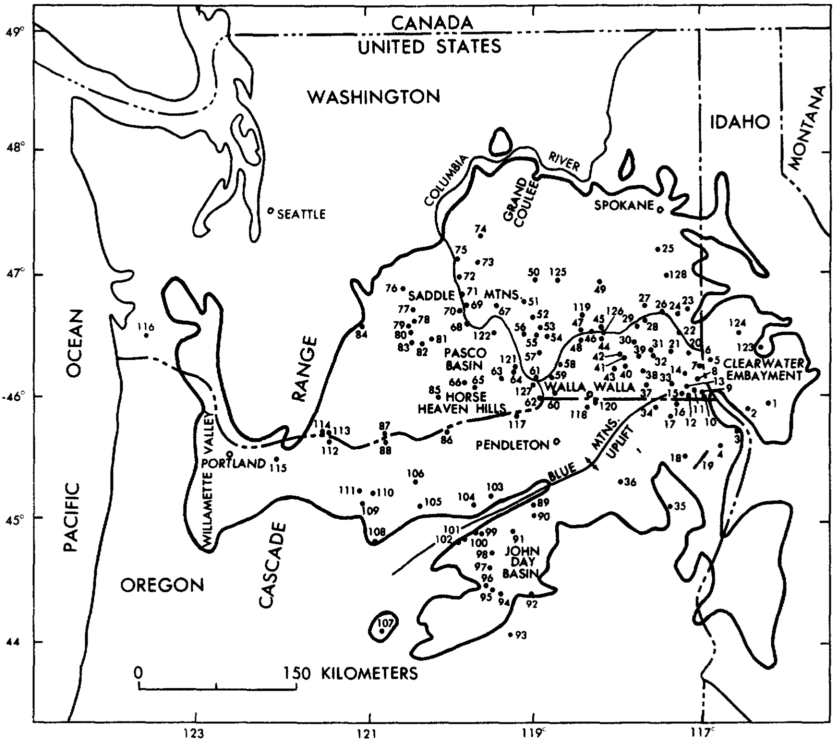


FIGURE 1.—Localities mentioned in text and approximate area covered by Columbia River Basalt Group (outlined).

NUMERICAL KEY

1, Grangeville
2, Rocky Canyon
3, Dug Bar
4, Imnaha
5, Lewiston Orchards
6, Lewiston, Idaho and Clarkston, Wash.
7, Asotin
8, Weissenfels and Montgomery Ridges
9, Grande Ronde Basalt type locality
10, Joseph Creek (mouth)
11, Slippery Creek
12, Shumaker Creek
13, Anatone
14, Cloverland Grade
15, Puffer Butte
16, Buford Creek
17, Flora
18, Enterprise
19, Little Sheep Creek
20, Silcott
21, Alpowa Summit
22, Uniontown Plateau
23, Pullman
24, Wilbur Creek
25, Malden
26, Almota Creek
27, Horton Grade
28, Hastings Hill Road
29, New York Gulch
30, Dodge
31, Pomeroy
32, Benjamin Gulch
33, Anatone Butte
34, Troy, Oreg.
35, China Cap Ridge
36, La Grande
37, Wenatchee Guard Station
38, Patrick Grade
39, Marengo (Garfield Co.)
40, Eckler Mountain
41, Rodgers Gulch
42, Crall Hollow
43, Robinette Mountain
44, Tucannon River (mouth)
45, Palouse Falls
46, Skookum Canyon
47, Devils Canyon
48, Lower Monumental Dam
49, Cow Creek
50, Warden
51, Othello
52, Scooteny Reservoir
53, Esquatzel Coulee
54, Old Maid Coulee
55, Mesa
56, Basin City
57, Eltopia
58, Walker grain elevator
59, Ice Harbor Dam
60, Reese
61, Pasco
62, Wallula Gap
63, Benton City
64, Richland
65, Ward Gap
66, Mabton
67, Wahatis Peak
68, Priest Rapids Dam
69, Sentinel Gap
70, Huntzinger
71, Wanapum Dam
72, Frenchman Springs Coulee
73, Quincy Basin (SW part)
74, Rattlesnake Spring
75, Crescent Bar
76, Ellensburg
77, Roza Station
78, Pomona
79, Selah Gap
80, Yakima

81, Elephant Mountain
82, Donald Pass
83, Union Gap
84, Tieton River area
85, Bickleton
86, Arlington
87, Maryhill
88, Biggs
89, Camus Creek
90, Dale
91, Monument Mountain and Monument
92, John Day
93, Izee
94, Flat Creek
95, Dayville
96, Picture Gorge
97, Foree Fossil Beds
98, Holmes Creek
99, Spray
100, Service Creek
101, Twickenham
102, Girds Creek
103, Hardman
104, Lone Rock
105, Butte Creek
106, Beef Hollow
107, Prineville Dam
108, Cow Canyon
109, Maupin
110, Sherars Bridge
111, Tygh Ridge
112, Mosier
113, Bingen
114, White Salmon
115, Bull Run area
116, Pack Sack Lookout
117, Umatilla
118, Milton-Freewater
119, Kahlotus
120, Pikes Peak
121, DDH-3 ⎫ Drill holes in Pasco Basin
122, DDH-1 ⎭
123, Orofino
124, Cavendish
125, Lind
126, Palouse River (mouth)
127, Kennewick
128, Colfax

ALPHABETICAL KEY

26, Almota Creek
21, Alpowa Summit
13, Anatone
33, Anatone Butte
86, Arlington
7, Asotin
56, Basin City
106, Beef Hollow
32, Benjamin Gulch
63, Benton City
85, Bickleton
88, Biggs
113, Bingen
16, Buford Creek
115, Bull Run area
105, Butte Creek
89, Camus Creek
124, Cavendish
35, China Cap Ridge
14, Cloverland Grade
128, Colfax
108, Cow Canyon
49, Cow Creek
42, Crall Hollow
75, Crescent Bar
90, Dale
95, Dayville
122, DDH-1 ⎫ Drill holes in Pasco Basin
121, DDH-3 ⎭
47, Devils Canyon
30, Dodge
82, Donald Pass
3, Dug Bar
40, Eckler Mountain
81, Elephant Mountain
76, Ellensburg
57, Eltopia
18, Enterprise
53, Esquatzel Coulee
94, Flat Creek
17, Flora
97, Foree Fossil Beds
72, Frenchman Springs Coulee
102, Girds Creek
9, Grande Ronde Basalt type locality
1, Grangeville
103, Hardman
28, Hastings Hill Road
98, Holmes Creek
27, Horton Grade
70, Huntzinger
59, Ice Harbor Dam
4, Imnaha
93, Izee
92, John Day
10, Joseph Creek (mouth)
119, Kahlotus
127, Kennewick
36, La Grande
6, Lewiston, Idaho and Clarkston, Wash.
5, Lewiston Orchards
125, Lind
19, Little Sheep Creek
104, Lone Rock
48, Lower Monumental Dam
66, Mabton
25, Malden
39, Marengo
87, Maryhill
109, Maupin
55, Mesa
118, Milton-Freewater
91, Monument Mountain and Monument
112, Mosier
29, New York Gulch
54, Old Maid Coulee
123, Orofino
51, Othello
116, Pack Sack Lookout
45, Palouse Falls
126, Palouse River (mouth)
61, Pasco
38, Patrick Grade
96, Picture Gorge
120, Pikes Peak
31, Pomeroy
78, Pomona
68, Priest Rapids Dam
107, Prineville Dam
15, Puffer Butte
23, Pullman
73, Quincy Basin (SW part)
74, Rattlesnake Spring
60, Reese
64, Richland
43, Robinette Mountain
2, Rocky Canyon
41, Rodgers Gulch
77, Roza Station
52, Scooteny Reservoir
79, Selah Gap
69, Sentinel Gap
100, Service Creek
110, Sherars Bridge
12, Shumaker Creek
20, Silcott
46, Skookum Canyon
11, Slippery Creek
99, Spray
84, Tieton River area
34, Troy, Oreg.
44, Tucannon River (mouth)
101, Twickenham
111, Tygh Ridge
117, Umatilla
83, Union Gap
22, Uniontown Plateau
67, Wahatis Peak
58, Walker grain elevator
62, Wallula Gap
71, Wanapum Dam
65, Ward Gap
50, Warden
8, Weissenfels and Montgomery Ridges
37, Wenatchee Guard Station
114, White Salmon
24, Wilbur Creek
80, Yakima

names, agreement among current workers regarding stratigraphic sequence, lateral variations, and flow correlations is generally excellent. It appears timely to revise and supplement the existing nomenclature to take into account the persistence of stratigraphic relations across the Columbia Plateau.

Earlier attempts at formal stratigraphic subdivision have been adequately summarized by Waters (1961), Mackin (1961), and Bingham and Grolier (1966). Griggs (1976) recently introduced the term Columbia River Basalt Group to include all the extrusive volcanic rocks previously assigned to the Columbia River Group and to exclude formations that are largely nonbasaltic. We follow this usage and subdivide the group into 1 subgroup, 5 formations, and 14 members, utilizing both previous nomenclature, in some cases slightly modified, and new names. The revised stratigraphic nomenclature is shown in figure 2, and its relation to the terminology of Bingham and Grolier (1966) and Wright and others (1973) in table 1.

TABLE 1.—*Comparison of stratigraphic terminology within the Columbia River Basalt Group used by Bingham and Grolier (1966) and Wright and others (1973) with that of this paper*

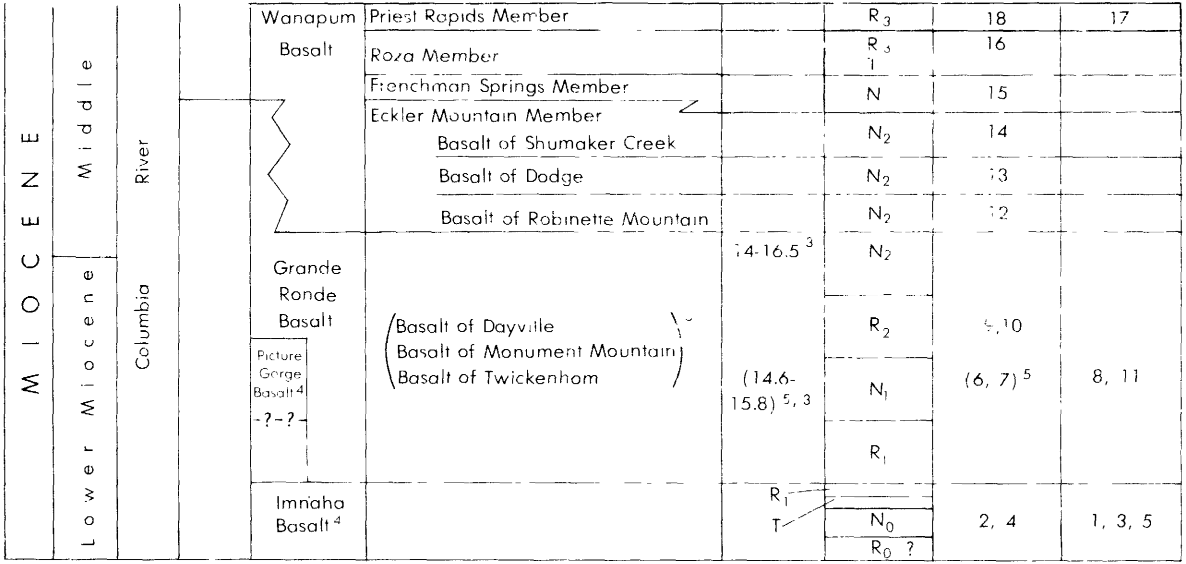
Bingham and Grolier (1966, fig. 1)		Informal nomenclature of Wright and others (1973, table 1)		This report	
Yakima Basalt	Saddle Mountains Member	Yakima basalt	Upper Yakima basalt:	Yakima Basalt Subgroup	Saddle Mountains Basalt:
					Lower Monumental Member (new)
			Flows at Ice Harbor Dam		Ice Harbor Member (new)
					Buford Member (new)
			Ward Gap and Elephant Mountain basalt of Schmincke (1967a)		Elephant Mountain Member
			Pomona basalt of Schmincke (1967a)		Pomona Member
					Esquatzel Member (new)
					Weissenfels Ridge Member (new)
					Asotin Member (new)
					Wilbur Creek Member (new)
					Umatilla Member
			Middle Yakima basalt:		Wanapum Basalt (new):
	Priest Rapids Member		Priest Rapids member, including Umatilla basalt of Schmincke (1967a); Lolo Creek flow of Bond (1963)		Priest Rapids Member
	Quincy Diatomite Bed				
	Roza Member		Roza Member		Roza Member
	Squaw Creek Diatomite Bed				
	Frenchman Springs Member		Frenchman Springs Member		Frenchman Springs Member
					Eckler Mountain Member (new)
	Vantage Sandstone Member				
	Lower basalt flows		Lower Yakima basalt		Grande Ronde Basalt (new)
			Picture Gorge basalt		Picture Gorge Basalt
			Lower basalt of Bond (1963)		Imnaha Basalt

One reviewer of this paper felt that the nomenclature was "unbalanced" because the Columbia River Basalt Group contains only one subgroup. He suggested abandoning the name Yakima Basalt Subgroup, or introducing a new term for a subgroup containing both the Imnaha and Picture Gorge Basalts, or raising both the Imnaha and Picture Gorge to subgroup status. We believe the proposed nomenclature provides more flexibility than any of these suggested changes. The term Yakima is well known, and there is little to be gained by dropping it from formal status. Coining a new subgroup to contain the Imnaha and Picture Gorge in effect freezes them as formations. Elevating each to subgroup status requires, according to the Code of Stratigraphic Nomenclature, that formations be defined within them, a premature step at this time. We recommend that, as work progresses, the Imnaha and Picture Gorge Basalts be subdivided into members. If these members are themselves subdivisible into mappable units, the two formations and their members can be elevated to subgroup and formational status, respectively. Work in progress on the Columbia Plateau is expected to result in the recognition of more members within all of the formations, and perhaps even new formations. The stratigraphic nomenclature proposed in this paper is flexible enough to accommodate such changes readily.

Many whole-rock potassium-argon age determinations have been made on rocks of the Columbia River Basalt Group in recent years. Early results were inconsistent (Gray and Kittleman, 1967), but nearly all dates published since 1970 have been between about 16.5 m.y. and 6 m.y. (Holmgren, 1970; Baksi and Watkins, 1973; Watkins and Baksi, 1974; Atlantic Richfield Hanford Co., 1976; McKee and others, 1977). Flows stratigraphically below those dated at 16.5 m.y. are known. The youngest date is from the stratigraphically youngest known flow in the group (McKee and others, 1977). According to Berggren and Van Couvering (1974, p. 172), the early Miocene extends from about 23.5 m.y. (22.7 to 24.2 m.y.) to about 15 m.y. (14.8 to 15.3 m.y.), and the middle Miocene to about 10.7 m.y. (10.5 to 10.8 m.y.). Their work and that of others (Berggren, 1972; Gill and McDougall, 1973; Kennett and Watkins, 1974; McDougall and Page, 1975; McDougall and others, 1977) indicate the Miocene-Pliocene boundary is no older than about 5.3 m.y. Rocks of the Columbia River Basalt Group, then, were erupted within the early, middle, and late Miocene, but not the Pliocene, according to the potassium-argon age determinations.

The group was previously considered to extend into the Pliocene on the basis of vertebrate fossils in the Ellensburg Formation, which intertongues with and overlies the group in central Washington. The vertebrate ages have recently been reinterpreted as late

Series		Group	Sub-group	Formation	Member	K-Ar age (m. y.)	Magnetic polarity	Chemical type[1]	
								Dominant	Subordinate
MIOCENE	Upper Miocene	Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	Lower Monumental Member	6[2]	N	31	
					Erosional unconformity				
					Ice Harbor Member				
					Basalt of Goose Island	8.5[2]	N	30	
					Basalt of Martindale	8.5[2]	R	29	
					Basalt of Basin City	8.5[2]	N	28	
					Erosional unconformity				
					Buford Member		R	27	
					Elephant Mountain Member	10.5[2]	N, T	26	
	Miocene				Erosional unconformity				
					Pomona Member	12[2]	R	25	
					Erosional unconformity				
					Esquatzel Member		N	24	
					Erosional unconformity				
					Weissenfels Ridge Member				
					Basalt of Slippery Creek		N	22	
					Basalt of Lewiston Orchards		N	23	18
					Asotin Member		N	21	
					Local erosional unconformity				
					Wilbur Creek Member		N	20	
					Umatilla Member		N	19	
					Local erosional unconformity				



MIOCENE	Middle	Columbia River	Wanapum Basalt	Priest Rapids Member		R_3	18	17
				Roza Member		R_3 T	16	
				Frenchman Springs Member		N	15	
				Eckler Mountain Member Basalt of Shumaker Creek		N_2	14	
				Basalt of Dodge		N_2	13	
				Basalt of Robinette Mountain		N_2	12	
	Lower Miocene	Columbia	Grande Ronde Basalt		14-16.5 [3]	N_2		
				Basalt of Dayville Basalt of Monument Mountain Basalt of Twickenhom		R_2	9, 10	
			Picture Gorge Basalt [4] -?-?-		(14.6-15.8) [5, 3]	N_1	(6, 7) [5]	8, 11
						R_1		
			Imnaha Basalt [4]		R_1 T	N_0 R_0 ?	2, 4	1, 3, 5

[1] See table 2 for key to chemical types.

[2] Data from McKee and others (1977) [3] Data mostly from Watkins and Baksi (1974)

[4] The Imnaha and Picture Gorge Basalts are nowhere known to be in contact. Interpretation of preliminary magnetostratigraphic data suggests that the Imnaha is everywhere older than the Picture Gorge. See text.

[5] Information in parentheses refers to Picture Gorge Basalt

FIGURE 2.—Proposed terminology for the Columbia River Basalt Group. N is normal magnetic polarity; R, reversed; and T, transitional. Polarity intervals are numbered sequentially, oldest to youngest, for the Imnaha through Wanapum Basalts, as we believe no major intervals are missing. Polarity intervals are not numbered in the Saddle Mountains Basalt, as one or more major intervals are probably missing owing to long periods of time between eruptions. For the Ice Harbor Member, probably no major intervals are missing, as potassium-argon ages for flows of the three magnetostratigraphic units are similar. Interbedded sedimentary deposits not shown.

Miocene by C. A. Repenning (written commun., 1977). The age of the Columbia River Basalt Group as presently known is therefore almost certainly restricted to the Miocene on a paleontologic as well as a radiometric basis.

The stratigraphic units shown in figure 2 are described here, oldest to youngest, and their inferred original distributions are presented in plate 1. Localities mentioned in the text are indicated on figure 1, which should be referred to whenever type or reference localities or other sites of interest are given. Township and range designations are referenced to the Willamette Base Line and Meridian in Washington and Oregon and the Boise Base Line and Meridian in Idaho. Chemical analyses used to define chemical types in the Yakima Basalt Subgroup are given by Wright and others (1979).

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IMNAHA BASALT

The Imnaha Basalt is the oldest formation within the Columbia River Basalt Group. The Imnaha was informally named by Hooper (1974), following a suggestion by Taubeneck (1970). Hooper designated a type locality at Dug Bar, on the Snake River near the mouth of the Imnaha River in extreme northeast Oregon. The formal name Imnaha Basalt is adopted here and replaces the informal term "lower basalt" used by Bond (1963) and Wright and others (1973).

The type locality is the exposures in cliffs on the west side of the Snake River above the north end of Dug Bar, Wallowa County, Oreg. (Cactus Mountain quadrangle, Idaho-Oregon: pl. 1, fig. *A*). It is reached by boat or by a dirt road down the Imnaha Valley from the town of Imnaha, Oreg. Fourteen flows, totaling nearly 500 m in thickness, have been described at the type locality by Kleck (1976) and Vallier and Hooper (1976). The base of the formation is not exposed at the type locality but can be seen at the south end of Dug Bar, where the basalt unconformably overlies deformed pre-Tertiary rocks. The Imnaha Basalt is conformably overlain by the Grande

Ronde Basalt at the type locality.

Good reference localities for the Imnaha Basalt are: (1) the area near the confluence of Lower Sheep Creek and the Imnaha River near the town of Imnaha, Oreg. (Kleck, 1976); (2) the core of the faulted anticline forming the north side of the Lewiston Basin, particularly near the center of T. 11 N., R. 45 E. (Camp, 1976); and (3) the lower part of Rocky Canyon in SE¼ sec. 18, T. 30 N., R. 1 W., 25 km west of Grangeville, Idaho, in the Salmon River drainage (Holden and Hooper, 1976).

Waters (1961) tentatively included what is here defined as the Imnaha Basalt in his Picture Gorge Basalt, although he recognized slight petrographic differences between them (1961, p. 608). Later work (Wright and others, 1973; Nathan and Fruchter, 1974; Hooper, 1974; McDougall, 1976) has demonstrated that the two units occur in different areas and that most flows in the two units show significant chemical and isotopic differences. Magnetostratigraphic mapping, discussed in a later section, further suggests that at least the upper part of the Picture Gorge in central Oregon is younger than the Imnaha. For these reasons, we designate the two as separate formations.

The Imnaha Basalt has been found only in northeast Oregon and adjacent Washington and Idaho (pl. 1, fig. *A*), where it conformably underlies the Grande Ronde Basalt. These contact relations are discussed in the section on the Grande Ronde Basalt. Imnaha flows may occur as far west as along the upper Grande Ronde River southwest of La Grande, Oreg. The Imnaha Basalt overlies pre-Tertiary metamorphic and plutonic rocks along a rugged erosional unconformity having local relief of more than 500 m. Some of its flows are as much as 120 m thick as a result of local ponding on this irregular surface.

Most flows of Imnaha Basalt are coarse grained and plagioclase phyric, some, such as the informally named Rock Creek flow (Hooper, 1974; see also Kleck, 1976, and Bond, 1963), highly so. Five chemical types have been distinguished by Hooper, Kleck, and Knowles (1976), Holden and Hooper (1976), Kleck (1976), Vallier and Hooper (1976), and Reidel (1978) (table 2). Many flows contain zeolite amygdules (Kleck, 1976; Hooper, 1974), and smectitic alteration is widespread. Most flows in a typical section of the Imnaha weather to a grus owing to their coarse grain size and abundance of secondary minerals. Waters (1961) accurately described the contact between the Imnaha and Grande Ronde Basalts as commonly marked by a distinct topographic break between grus-covered slopes developed in the Imnaha and bold cliffs in the fine grained and generally fresher Grande Ronde.

TABLE 2—*Average major-element compositionsfor chemical types in the Columbia River Basalt Group*

[Averages include analyses available through March 1977. Variation within chemical types 9–31 given by Wright and others (1979, table 3)]

Chemical type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Oxide	(7)[1]	(44)	(21)	(68)	(7)	(8)	(4)	(13)	(13)	(8)	(10)	(9)	(20)	(4)	(8)
SiO_2	50.99	51.14	51.18	49.53	50.73	50.36	51.46	51.57	53.78	55.94	54.37	50.01	52.13	54.80	52.29
Al_2O_3	15.42	15.06	14.06	16.34	17.10	15.54	15.39	13.87	14.45	14.04	15.28	17.08	15.41	13.86	13.21
"FeO"[2]	12.24	13.04	14.11	12.38	11.26	11.25	12.46	12.28	11.35	11.77	9.46	10.01	10.66	13.32	14.38
MgO	5.94	5.07	4.60	6.06	5.42	6.68	4.86	4.44	5.25	3.36	5.91	7.84	5.92	2.84	4.04
CaO	10.11	9.31	8.59	9.15	9.30	10.67	9.45	8.12	9.07	6.88	9.79	11.01	10.18	6.48	7.90
Na_2O	2.55	2.58	2.65	2.58	2.45	2.95	3.29	3.36	2.83	3.14	2.80	2.44	3.00	3.18	2.67
K_2O	.53	.91	1.19	.93	.85	.57	.74	2.02	1.05	1.99	.77	.27	.68	1.87	1.41
TiO_2	1.66	2.24	2.93	2.41	2.32	1.56	1.79	2.71	1.78	2.27	1.17	1.00	1.48	2.46	3.17
P_2O_5	.34	.42	.48	.41	.38	.22	.33	1.39	.28	.43	.29	.19	.35	.93	.71
MnO	.22	.22	.22	.20	.19	.20	.23	.24	.19	.19	.16	.14	.19	.26	.22
Total[3]	100.00	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.01	100.01	100.00	99.99	100.00	100.00	100.00

TABLE 2—*Average major-element compositions for chemical types in the Columbia River Basalt Group*—Continued

Chemical type	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Oxide	(35)	(15)	(55)	(13)	(11)	(6)	(3)	(2)	(12)	(30)	(41)	(8)	(12)	(13)	(8)	(24)
SiO_2	51.19	50.27	50.09	54.70	54.41	50.72	52.12	49.75	54.16	51.88	51.08	54.46	47.45	48.73	47.50	50.44
Al_2O_3	14.07	13.69	14.31	14.10	14.51	16.23	14.33	15.26	13.84	14.88	13.54	14.29	13.84	13.88	12.50	14.07
"FeO"[2]	13.91	15.04	13.78	12.63	11.07	9.64	11.64	11.82	12.60	10.55	14.75	11.05	15.22	14.41	17.53	13.78
MgO	4.39	4.29	5.18	2.71	4.51	8.19	5.58	7.10	3.91	6.96	4.28	4.85	5.99	5.88	4.41	5.01
CaO	8.48	8.31	8.88	6.14	8.32	10.70	9.64	10.13	7.71	10.67	8.34	8.54	9.71	9.72	8.80	8.67
Na_2O	2.72	2.67	2.57	3.20	2.69	2.22	2.69	2.32	2.66	2.36	2.45	2.75	2.31	2.42	2.44	2.79
K_2O	1.22	1.16	1.07	2.68	1.77	.51	.87	.46	1.70	.64	1.25	1.39	.72	.73	1.23	1.47
TiO_2	3.13	3.55	3.15	2.80	1.95	1.45	2.48	2.42	2.82	1.62	3.52	2.17	3.62	3.30	3.79	2.90
P_2O_5	.67	.81	.78	.88	.56	.18	.49	.55	.41	.25	.59	.35	.91	.73	1.54	.66
MnO	.23	.21	.19	.17	.21	.17	.17	.21	.19	.17	.20	.15	.23	.20	.27	.21
Total[3]	100.01	100.00	100.00	100.01	100.00	100.01	100.00	100.02	100.00	99.98	100.00	100.00	100.00	100.00	100.01	100.00

[1] Number of analyses used in computing average.

[2] FeO + 0.9 Fe_2O_3.

[3] Difference between total and 100 is due to rounding during normalization.

Chemical types defined by method of Wright and Hamilton (1978):

1. Picture Gorge (Imnaha Basalt)
2. American Bar (equivalent to the high-Ti Picture Gorge chemical type of Wright and others, 1973)
3. Frenchman Springs (Imnaha Basalt)
4. Rock Creek
5. Fall Creek (Kleck, 1976)
6. High-Mg Picture Gorge (Wright and others, 1973)
7. Low-Mg Picture Gorge (Wright and others, 1973)
8. Prineville (recalculated from Uppuluri, 1974)
9. High-Mg Grande Ronde (one flow)
10. Low-Mg Grande Ronde (one flow)
11. Very high Mg Grande Ronde (one flow)
12. Robinette Mountain
13. Dodge
14. Shumaker Creek
15. Frenchman Springs (one flow)
16. Roza
17. Rosalia
18. Lolo
19. Umatilla
20. Wilbur Creek
21. Asotin
22. Slippery Creek
23. Lewiston Orchards
24. Esquatzel
25. Pomona
26. Elephant Mountain
27. Buford
28. Basin City
29. Martindale (Ice Harbor 1)
30. Goose Island (Ice Harbor 2)
31. Lower Monumental

A few thick feeder dikes of the Imnaha Basalt have been found along the Imnaha River in extreme northeast Oregon (Kleck, 1976), and many others are inferred, on the basis of chemical composition and the age of the rocks cut by the dikes, to be present in western Idaho and northeast Oregon (pl. 1, fig. *A*; W. H. Taubeneck, T. L. Wright, and D. A. Swanson, unpub. data, 1978).

Most flows of Imnaha Basalt have normal magnetic polarity (Hooper, Camp, Kleck, Reidel, and Sundstrom, 1976; Hooper and others, 1979). The upper two flows in the Imnaha area have transitional polarity. Several thin reversed flows along the Minam River east of La Grande, Oreg., conformably underlie reversely magnetized flows in the Grande Ronde Basalt, and two or three flows beneath a thick section of normally magnetized Imnaha Basalt on China Gap Ridge in the Wallowa Mountains are tentatively identified as magnetically reversed (W. H. Taubeneck, D. A. Swanson, and D. O. Nelson, unpub. portable fluxgate magnetometer data, 1976). These two reversed sequences are, respectively, the youngest and oldest flows in the Imnaha Basalt recognized to date. We consider it likely that future work may find that the uppermost Imnaha is interbedded with the lowermost Grande Ronde Basalt.

PICTURE GORGE BASALT

Miocene flood basalt in the John Day basin of north-central Oregon was named the Picture Gorge Basalt by Waters (1961) for exposures at the type locality (pl. 1, fig *B*), Picture George, Oreg. Waters tentatively extended the term to cover flows in extreme northeast Oregon herein assigned to the Imnaha Basalt. He considered the Picture Gorge to be separated from the younger Yakima Basalt (now subgroup) by an angular unconformity.

The original definition of the Picture Gorge Basalt is retained here, except that the term is restricted to basalt in north-central Oregon (pl. 1, fig *B*) and excludes the flows in northeast Oregon, southeast Washington, and western Idaho herein assigned to the Imnaha Basalt (pl. 1, fig. *A*). Stratigraphic and magnetostratigraphic relations, described in a later section, indicate that the Picture Gorge is locally interlayered and hence coeval with the middle part of the Grande Ronde Basalt of the Yakima Basalt Subgroup.

The type section of the Picture Gorge Basalt is in roadcuts along U.S. Highway 26 near its junction with Oregon State Highway 19, SW¼ sec. 17, NE¼ sec. 18, and NW¼ sec. 20, T. 12 S., R. 26 W., in Picture Gorge, western Grant County, north-central Oregon (Waters, 1961). Here the formation contains 17 flows and is about 430 m thick, values revised from those in Waters (1961, table 1) as a result of unpublished mapping by R. D. Bentley in 1975. At Picture Gorge, the formation unconformably overlies tuffaceous rocks of the John Day Formation and conformably underlies the Mascall Formation, a sequence of Miocene volcaniclastic rocks. Elsewhere, the Picture Gorge ranges in thickness to a maximum of 800 m. Thayer and Brown (1966a) reported more than 1,800 m along Flat Creek, although faulting may have duplicated part of this section.

Nathan and Fruchter (1974) described two reference localities for the formation, one along Girds Creek just southwest of Twickenham (Oles and Enlows, 1971; Swanson, 1969), the other along Highway 207 between Spray and Hardman; flows are well exposed in these two sections, but faulting obscures some stratigraphic relations (R. D. Bentley, unpub. mapping, 1973). An excellent unfaulted reference locality exposes more than 600 m of basalt on Monument Mountain, in the south half of sec. 19, T. 8 S., R. 28 E., Monument quadrangle. Another good unfaulted reference section is along the Holmes Creek road in secs. 4, 5, and 9, T. 10 S., R. 26 E., Picture Gorge quadrangle.

Reconnaissance mapping by R. D. Bentley (Bentley and Cockerham, 1973) suggests that the Picture Gorge Basalt can be subdivided into three mappable units, a sequence of aphyric flows underlain and overlain by plagioclase-phyric flows. The lower unit is here informally referred to as the basalt of Twickenham, for exposures along Kentucky Butte (sec. 13, 14, and 23, T. 9 S., R. 21 E., Kinzua quadrangle) near Twickenham, Oreg. Excellent reference sections occur along Highway 19 between Service Creek and Spray, in the cliffs above Foree Fossil Beds, and along the lower part of Monument Mountain north of Monument, Oreg. The basalt of Twickenham consists of two to six plagioclase-phyric flows varying in thickness from about 30 to 130 m; the thicker flows are in the lower part of the unit. The flows are normally magnetized, generally very coarse grained, and commonly contain pegmatoids and abundant zeolites (Lindsley, 1960; Lindsley and others, 1971). The unit is not exposed at the type locality of the Picture Gorge Basalt.

The middle unit, herein informally referred to as the basalt of Monument Mountain for exposures north of Monument, Oreg., occurs as the lower six flows in the type section of the Picture Gorge. Good reference sections are found along Holmes Creek just south of Kimberly, on Adler Butte near Service Creek, and on Kentucky Butte near Twickenham. The basalt of Monument Mountain consists of three to eight aphyric flows that are medium to coarse grained and have well formed colonnades and entablatures. Flow-top breccias and zeolite amygdules are common. A plagioclase-phyric flow is present near the top of the unit between Monument and Dale. The unit is normally magnetized (Watkins and Baksi, 1974; Nathan and Fruchter, 1974) and rests on the basalt of Twickenham everywhere except near the margins of the John Day basin, where it unconformably overlies the John Day Formation.

The upper unit, informally referred to as the basalt of Dayville for exposures near Dayville, Oreg., consists of 3 to 15 flows that are fine grained and generally plagioclase phyric. The upper 11 flows in the type section of the Picture Gorge belong to this unit. The flows have poorly formed colonnades but no entablatures. Thin flows of small areal extent are dominant, but some thick flows may extend long distances. The uppermost flows in the Monument-Picture Gorge area are magnetically reversed (Watkins and Baksi, 1974; Nathan and Fruchter, 1974), but elsewhere the unit is normally magnetized.

The three units within the Picture Gorge Basalt are used here in an informal sense, because we feel that more fieldwork must be done to confirm their lateral continuity. They can easily be elevated to member status if they prove to be valid discrete stratigraphic units.

The chemistry of the Picture Gorge Basalt varies gradationally within a rather well-defined compositional field termed the Picture Gorge chemical type by Wright and others (1973); two representative averages near the extremes of chemical variation are given in table 2. At the type locality, Mg and Cr decrease abruptly upward, and K, La, Th, Fe, Rb, and the rare-earth elements increase at the contact between the basalts of Monument Mountain and Dayville (Osawa and Goles, 1970; Wright and others, 1973; Bentley and Cockerham, 1973; Nathan and Fruchter, 1974).

Potassium-argon dating of samples from the type section suggests that the Picture Gorge Basalt is about 15.2 ± 0.6 m.y. old, with a range of dates from 14.6 to 15.8 m.y. (Watkins and Baksi, 1974).

The formation is known to crop out only in the John Day basin south of the Blue Mountains uplift, except for the lower part of Butte Creek canyon (Cockerham and Bentley, 1973; Nathan and Fruchter, 1974) and a small area near Lone Rock (Robinson, 1975; Fruchter and Baldwin, 1975). Most vents for the Picture Gorge likewise occur in the John Day basin, comprising the Monument dike swarm (Waters, 1961; Wilcox and Fisher, 1966), which contains numerous feeder dikes of appropriate chemistry and magnetic polarity (pl. 1, fig. *B*; Fruchter and Baldwin, 1975). Two feeder dikes occur north of the basin in the small area near Lone Rock (Robinson, 1975); others are present south of the basin about 8 km north and northeast of Izee (Dickinson and Vigrass, 1965).

A few dikes having major-element chemistry similar to that of Picture Gorge Basalt occur in northeast Oregon within the Chief Joseph dike swarm (Taubeneck, 1970; W. H. Taubeneck and T. L. Wright, unpub. data, 1977), and the lowermost flow at Dug Bar, the type locality of the Imnaha Basalt, has a similar compositon (Vallier and Hooper, 1976: Kleck, 1976). This flow is assigned to the Imnaha Basalt, and the dikes are considered as feeders for other similar Imnaha flows. The flow and dikes are not considered part of the Picture Gorge Basalt, as chemical similarity alone is not considered to be sufficient evidence on which to base such a long-range stratigraphic correlation. Moreover, stratigraphic and magnetic evidence indicates that the flow is considerably older than all known Picture Gorge Basalt in north-central Oregon.

Calc-alkaline andesitic and rhyolitic rocks belonging to the Strawberry Volcanics underlie, interfinger with, and overlie the Picture Gorge Basalt 20–30 km east-southeast of John Day (Robyn, 1977; Robyn and others, 1977). These rocks were erupted from at least two central-vent complexes along the margin of the John Day basin and have a relatively limited extent. Most eruptive activity took place between 12 and 15 m.y. ago, but some occurred as early as about 20 m.y., on the basis of K-Ar ages (Robyn, 1977); these older ages substantially pre-date the Picture Gorge. The Strawberry Volcanics is herein excluded from the Columbia River Basalt Group because of its local nature, its eruption from central vents rather than long fissures, its calc-alkaline chemistry, in part rhyolitic, and its earlier onset of eruptive activity. The Mascall Formation, probably "derived from high-standing volcanic centers represented by the *** Strawberry Volcanics" (Thayer and Brown, 1966b), is also specifically excluded from the Columbia River Basalt Group (Griggs, 1976). This treatment of the Mascall differs from that of Thayer and Brown (1966b), who assigned it to the Columbia River Group.

YAKIMA BASALT SUBGROUP

Wright and others (1973) divided the Yakima Basalt of Waters (1961) into three units informally designated the lower, middle, and upper Yakima basalt based on lithology and stratigraphic succession and showed that these units could be recognized across wide areas of the Columbia Plateau and in the Blue Mountains. The threefold subdivision has been accepted by most later workers, although the dual use of the name Yakima is improper according to the Code of Stratigraphic Nomenclature.

Wright and others (1973) found a very good correspondence between basalt chemistry and stratigraphic position. For example, the lower Yakima is characterized predominantly by flows of one particular chemical type (defined by a procedure outlined in Wright and Hamilton, 1978), the middle Yakima by flows of other chemical types, and the upper Yakima by flows of still other chemical types. Subsequent work has shown that the correlation between chemistry and stratigraphic position is at least as good as initially believed (fig. 2).

Wright and others (1973) showed that their three informally named units could be further subidvided into mappable flows or sequences of flows, some of which had previously been formally named. For example, the Frenchman Springs Member, a formally named sequence of flows, occurs in their middle Yakima basalt. Thus, a hierachy of mixed formal and informal terms is currently in use with the three basic subdivisions having only informal names but containing some formally named subdivisions.

In order to make this complicated hierachy compatible with the Code of Stratigraphic Nomenclature, we hereby propose that the Yakima Basalt be raised to subgroup status and designated the Yakima Basalt Subgroup. We further propose dividing the subgroup into three formations, reflecting the three basic subdivisions of Wright and others (1973). The three formations are, from oldest to youngest, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt (fig. 2). These three formations are not only distinct lithologic units but also reflect a succession of petrologic changes fundamental to the development of the flood basalt province. Several formal members, some previously named and some new, can be recognized in the Wanapum and Saddle Mountains Basalt (fig. 2). The Grande Ronde Basalt cannot yet be formally subdivided, but it can be broken into four easily mappable magnetostratigraphic units.

GRANDE RONDE BASALT

The Grande Ronde Basalt, a name suggested by Taubeneck (1970, footnote, p. 75) is herein formalized to replace the informal designation lower Yakima basalt of Wright and others (1973). Its type locality (pl. 1, fig. *C*) is the prominent west-trending spur ridge extending from the NW¼ sec. 23 across the N⅓ sec. 22 to the NE¼ sec. 21, T. 7 N., R. 46 E., Black Butte quadrangle, in the lower part of the Grande Ronde River valley, Asotin County, extreme southeast Washington. Camp, Price, and Reidel (1978) describe in detail a stratigraphic section at this locality, consisting of approximately 34 flows totaling about 830 m in thickness. Camp (1976), Price (1977), and Reidel (1978) give additional chemical and magnetic information for the type section. The type Grande Ronde conformably overlies the Imnaha Basalt in exposures a short distance downriver from the type locality and disconformably underlies the Weissenfels Ridge Member of the Saddle Mountains Basalt.

The Grande Ronde Basalt is essentially equivalent to the Yakima Basalt as defined by Waters (1961), except that his "late textural and mineralogic variant of the Yakima Basalt" (p. 600) is excluded and redefined as part of the Wanapum and Saddle Mountains Basalts. As Waters showed, the Grande Ronde Basalt is the most widespread formation in the Columbia River Basalt Group (pl. 1, fig. *C*). It underlies virtually all of the Columbia Plateau in Washington, although covered by younger rocks in much of this area, and extends south of the Blue Mountains uplift in northeast Oregon and southeast Washington. It is equivalent to most of Bond's "upper basalt" (1963) in the Clearwater embayment of Idaho. In north-central Oregon, the formation extends southward to the north flank of the Blue Mountains uplift but does not appear to cross the uplift into the John Day basin in the area west of Monument (Nathan and Fruchter, 1974; unpub. data of the authors), an interpretation contrary to that of some past workers (Waters, 1961; Lindsley, 1960; Thayer and Brown, 1966b). The Grande Ronde forms spectacular cliffs in the Columbia River Gorge and crops out west of the Cascade Range along the lower Columbia River valley and in adjacent parts of the Puget-Willamette Lowland.

The thickness of the Grande Ronde varies considerably depending on prebasalt topography and the amount of erosion. The thickest known section is about 1,000 m, with the base not found, in drill holes DH-4 and DH-5 in the Pasco Basin (Ledgerwood and others, 1973; Myers, 1973; Atlantic Richfield Hanford Co., 1976). Sections in the Blue Mountains (Swanson and others, 1977; 1979) are commonly more than 600 m thick; along the lower Salmon River, more than 450 m (Holden and Hooper, 1976); and in north-central Oregon along the lower John Day River, more than 450 m. The formation laps out against older rocks along its margins, but thick sections, to about 500 m in the Tieton River area (Swanson, 1967, 1978) along the east flank of the Cascade Range in south-central Washington, occur even near the margin wherever topographic basins permitted flows to accumulate.

A much thicker section of the Grande Ronde Basalt may exist, although another interpretation is preferred. The 3,248-m-deep Rattlesnake Hills No. 1 well, drilled by Standard Oil Co. of California in 1957–58 at an elevation of about 875 m along the west edge of the Pasco Basin in the central part of the Columbia Plateau (Raymond and Tillson, 1968), was at one time considered to contain only the Yakima Basalt. A chemical analysis of a section of core from the 2,464–2469-m depth interval (P. D. Snavely, written commun., 1973), the only core taken from the holes, is indistinguishable from the low-Mg Yakima chemical type of Wright and others (1973), consistent with assignment to the Grande Ronde Basalt. The upper contact with the Wanapum Basalt is readily identifiable at about

500-m depth on the basis of chemical analyses reported by Raymond and Tillson (1968). The Grande Ronde could therefore have a minimum thickness of 1,964 m, extending to at least 1,589 m below sea level. Evaluation of numerous spectrochemical analyses of sidewall cores and ditch samples (Raymond and Tillson, 1968), however, suggests that the base of the Grande Ronde Basalt is at about 1,280-m depth, nearly the same as the 1,265 m depth separating two district geoelectric intervals in the hole (Jackson, 1975). Most rocks at greater depths are chemically dissimilar to the Picture Gorge and Imnaha Basalts and are tentatively interpreted as Eocene to lower Miocene basalt and andesite on the basis of pollen (Newman, 1970; Raymond and Tillson, 1968). We prefer this interpretation, reached independently on chemical grounds by G. G. Goles (written commun., 1977), and thereby consider the drilled Grande Ronde Basalt to be only about 780 m thick, extending to about 405 m below sea level.

Several excellent reference localities can be designated for the Grande Ronde Basalt. Smith (1901) first used the term Yakima Basalt for flows exposed in cliffs along the Yakima River south of Ellensburg in south-central Washington, and this area, well described by Diery and McKee (1969), serves as a fine reference locality in the western part of the Columbia Plateau. Other good localities in this general area, for which published information is available, include Cresent Bar (McDougall, 1976) and Divide Ridge and Windy Point in the Tieton River area (Swanson, 1967). In the southwest part of the plateau, easily accessible sections include Cow Canyon (Waters, 1961; Watkins and Baksi, 1974) and Tygh Ridge (Waters, 1961; Nathan and Fruchter, 1974; Watkins and Baksi, 1974), although both have experienced minor faulting (R. D. Bentley, unpub. data, 1976). Structurally undisturbed reference sections in northeast Oregon include the Sherars Bridge section along the Deschutes River (T. 3 S., R. 14 and 15 E) and Beef Hollow (Waters, 1961; R. D. Bentley, D. A. Swanson, and T. L. Wright, unpub. data, 1977), as well as along Butte Creek (Cockerham and Bentley, 1973; Nathan and Fruchter, 1974), in which the interlayered contact of Grande Ronde and Picture Gorge Basalts is well exposed. The Ortley anticline exposes an excellent reference section in the Columbia River Gorge east of White Salmon, Washington (Hammond and others, 1977). Good sections of the Grande Ronde occur in the southeast part of the Columbia Plateau along most roads connecting ridgetops with canyon bottoms, as, for example, those listed by Waters (1961) and Patrick Grade (sec. 24, T. 9 N., R. 40 E.), on the north flank of the Blue Mountains of southeast Washington. The Snake River Canyon from the mouth of the Grande Ronde River downstream to Devils Canyon (T. 13 N., R. 34 E.) provides an excellent cross section of the Columbia Plateau, exposing an aggregate thickness of more than 1,000 m of the Grande Ronde Basalt.

The Grande Ronde consists overwhelmingly of aphyric to very sparsely phyric fine-grained tholeiitic basalt having a continuous range in chemical composition within a field defined as the Grande Ronde chemical type (a synonym for the Yakima chemical type of Wright and others, 1973); representative high- and low-MgO compositions and an unusually high MgO composition are given in table 2. Only rarely are flows highly plagioclase phyric, as near the base of the type locality and in the Lewiston Basin, lower Grande Ronde Valley, and lower Salmon River Canyon. A few sparsely plagioclase-phyric flows occur in north-central Oregon (R. D. Bentley, unpub. data, 1977), and one such flow was mapped southeast of Wenatchee, Wash. (Tabor and others, 1979). Most flows within the Grande Ronde Basalt contain rare plagioclase microphenocrysts and plagioclase-clinopyroxene clots visible in both hand specimen and thin section. Olivine is generally absent as phenocrysts but is commonly present in small amounts (less than 0.5 percent) in the groundmass of all but the least magnesian flows.

Flows within the Grande Ronde range in thickness from less than 1 m to more than 100 m. Generally flows are thinner and flow-top breccia more common near major vent areas. Thin, discontinuous interbeds of sedimentary detritus eroded from sources on and off the plateau occur commonly, particularly near prebasalt topographic highs. Calc-alkaline andesitic to rhyolitic tephra is mixed with epiclastic material between some flows near the Cascade Range.

Few flows are distinctive enough in the field to serve as regional stratigraphic markers, except in relatively limited areas. Criteria such as jointing habit and weathering color are unreliable for flow recognition over long distances, at least without independent documentation. The plagioclase-phyric flows found near the base of the type locality are some of the few flows in the Grande Ronde known to us whose lithology can be readily used for stratigraphic definition. Even this usage is limited, as these flows are found only in a relatively small area in extreme southeast Washington and adjacent Oregon and Idaho.

The only reliable means we have found for providing a regional stratigraphic breakdown of the Grande Ronde Basalt is by field mapping of magnetic polarities. The resulting magnetostratigraphy (fig. 2) has been shown to hold throughout southeast Washington (Swanson and Wright, 1976a; Camp, 1976; Swanson and others, 1977; 1979), and other workers are using it with success elsewhere on the plateau (Hooper, Camp, Kleck, Reidel, and Sundstrom, 1976).

Polarity determinations made rapidly and simply in the field with a portable fluxgate magnetometer compare favorably with laboratory data from several paleomagnetic sections and single flows studied in detail by Watkins and Baksi (1974), Choiniere and Swanson (1979), and Hooper and others (1979), except for transitional polarities, which cannot be reliably identified in the field. Four informal magnetostratigraphic units have been defined within the Grande Ronde, from bottom to top, R_1, N_1, R_2, and N_2, where R means reversed and N normal polarity. Transitional polarities make some contacts difficult to define precisely, although generally we find that the contacts can be determined to within one or two flows.

No stratigraphic section known to us contains all four magnetostratigraphic units. Only the three older units occur at the type locality. The well-exposed sequence of N_2 flows closest to the type locality is along Highway 12 at Alpowa Grade, between Clarkston and Pomeroy, Wash., in T. 11 N., R. 43 E. Thicker N_2 sections are exposed along the Snake River Canyon downstream from the Almota Creek area (T. 14 N., R. 41–42 E.) and in the Blue Mountains south of Pomeroy. The geologic maps by Swanson and others (1977; 1979) and Tabor and others (1979) show the distribution of the informal magnetostratigraphic units in southeast and north-central Washington, respectively.

Single flows or sequences of flows in the Grande Ronde Basalt can be correlated for several tens of kilometers in southeast Washington and adjacent Idaho on the basis of similar chemical composition (Camp, 1976; Reidel, 1978; T L. Wright and D. A. Swanson, unpub. data, 1977). In the western part of the Columbia Plateau, a sequence of flows of high-Mg Grande Ronde chemical type overlies flows of low-Mg Grande Ronde chemical type (Nathan and Fruchter, 1974; Taylor, 1976; Atlantic Richfield Hanford Co., 1976; M. H. Beeson and R. D. Bentley, unpub data, 1977). The contact between the two chemical types is consistently about three to five flows above the R_2–N_2 contact and appears to be a good stratigraphic marker, although one low MgO flow occurs higher in the section near Wenatchee (D. A. Swanson and G. R. Byerly, unpub. data, 1978). In the eastern Columbia Plateau, several such chemical breaks defined locally may eventually prove to be of regional significance.

Feeder dikes for some flows in the Grande Ronde Basalt are found in the Chief Joseph dike swarm of northeast Oregon and adjacent Washington and Idaho (pl. 1, fig. *C*; Waters, 1961; Gibson, 1969; Taubeneck, 1970; Price, 1974; Camp, 1976; Swanson and others, 1977; 1979) A few dikes in the Rocky Canyon area, western Idaho, east of the eastern margin that Taubeneck (1970) placed on the

Chief Joseph swarm, have been described by Price and others (1973). The western margin of Taubeneck's Chief Joseph swarm should be extended westward to include feeders for flows in and younger than the Grande Ronde in the drainage basin of the Walla Walla and Umatilla Rivers east and south of Milton-Freewater, Oreg. (Hogenson, 1964; Newcomb, 1965; Swanson and others, 1977; D. A. Swanson and T. L. Wright, unpub. mapping, 1977). No feeder dikes for the Columbia River Basalt Group have yet been found near the western margin of the plateau (Swanson, 1967, and subsequent unpub. data), although some had been previously suspected (Waters, 1961; Stout, 1961). Many dikes for the Grande Ronde Basalt may lie hidden by younger flows in the central part of the plateau.

Potassium-argon dates published by Holmgren (1970) and Baksi and Watkins (1973; Watkins and Baksi, 1974), as well as the geologically most reasonable dates in Gray and Kittleman (1967), indicate that the Grande Ronde Basalt is between about 14.0 and 16.5 m.y. old, consistent with an early and middle Miocene age for the Grande Ronde Basalt.

CONTACT RELATIONS

The contact of the Grande Ronde with the underlying Imnaha Basalt is well exposed in the tristate area of Washington, Oregon, and Idaho. Everywhere studied, this contact is conformable, with no evidence of a major time break (Kleck, 1973; Camp, 1976; Holden and Hooper, 1976). No interbedding of the two formations has been found, although we consider it likely that future mapping will find local examples of interbedding. Magnetostratigraphic mapping shows that the oldest known Grande Ronde flows overlie the Imnaha.

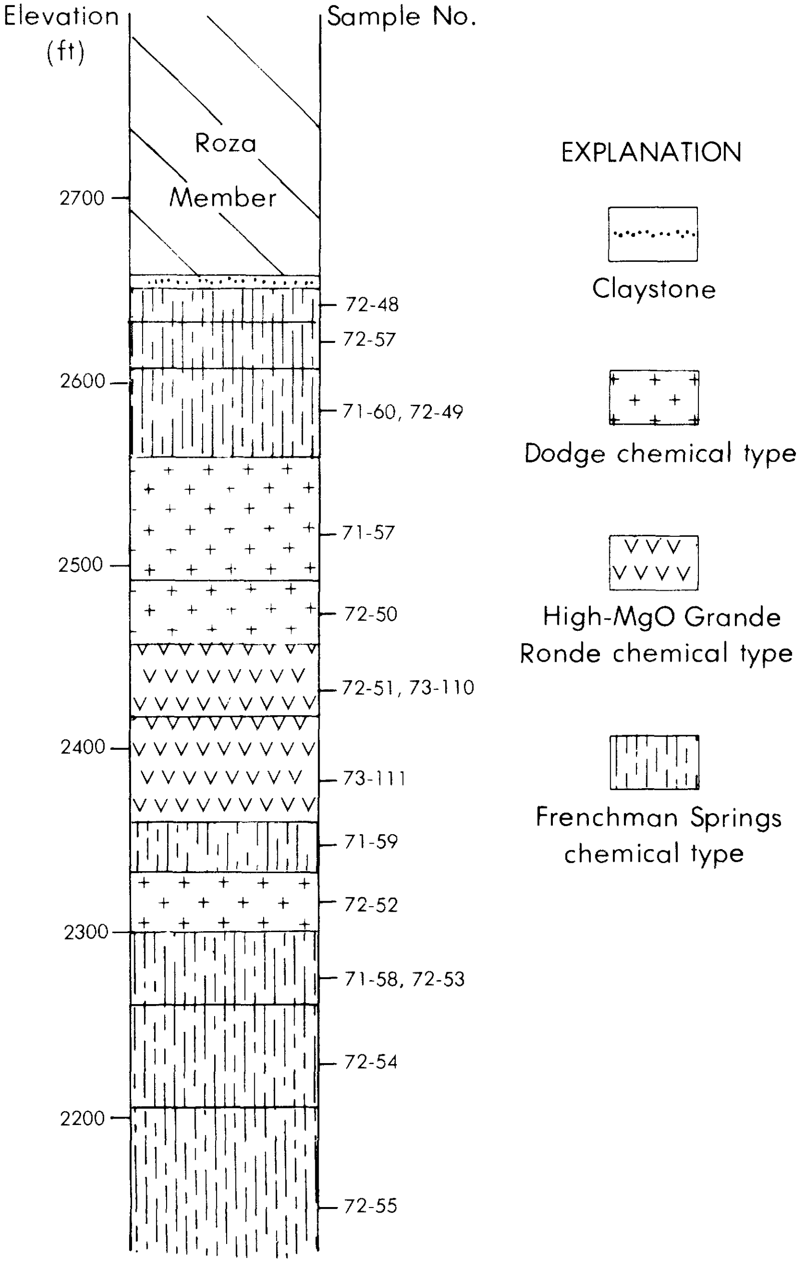
The Grande Ronde-Picture Gorge contact has been recognized in only three general areas in north-central Oregon. Along lower Butte Creek (Buckhorn Canyon and Chimney Springs quadrangles), the two formations intertongue (Cockerham and Bentley, 1973; Nathan and Fruchter, 1974), and magnetostratigraphy suggests that the interbedded flows are in the upper part of magnetostratigraphic unit N_1 (R. D. Bentley and D. A. Swanson, unpub. data, 1977). Along Camus Creek (Bridge Creek quadrangle), the contact appears conformable, although a 3-m-thick bed of siltstone and peat separates the two formations (Nathan and Fruchter, 1974). The contact is likewise conformable south of Dale (Dale quadrangle; R. D. Bentley, unpub. map, 1976). Elsewhere throughout north-central Oregon, a belt of older rocks along the Blue Mountains uplift appears to separate the Grande Ronde and Picture Gorge Basalts. This area is incompletely known, however, and other localities where the formations are in contact may eventually be found.

The observed contact relations of the Grande Ronde Basalt with the Imnaha and Picture Gorge Basalts differ from those suggested by Waters (1961), who believed that an angular unconformity separated the older and younger flows. Detailed and reconnaissance mapping in the years since publication of his classic paper has failed to demonstrate such an unconformity, and the interbedding of the Grande Ronde and Picture Gorge at Butte Creek clearly indicates that the two formations are, at least in part, coeval. The two formations have similar K-Ar ages within the error of measurement (Watkins and Baksi, 1974). On the basis of mangetostratigraphy, most or all of the Picture Gorge Basalt, the youngest flows of which are in the lower part of the R_2 magnetozone, is younger than the Imnaha Basalt.

The top of the Grande Ronde Basalt is generally well defined by a zone of weathering and (or) a sedimentary interbed separating the formation from the overlying Wanapum or Saddle Mountains Basalts. Absence of a saprolite or interbed makes field recognition of the top of the formation difficult if aphyric flows overlie it. However, the contact can be generally recognized by contrasting chemical compositions, particularly TiO_2 and FeO, of rocks above and below. This chemical change was labeled the "TiO_2 discontinuity" by Siems and others (1974), as rocks above the contact generally have markedly higher TiO_2 contents than those below. Chemical differences cannot be used to define lithostratigraphic units according to the Code of Stratigraphic Nomenclature, but we and many other workers have found them to be a reliable tool for distinguishing most of the stratigraphic units within the Columbia River Basalt Group.

Normally magnetized flows (unit N_2) of Grande Ronde, Dodge, and Frenchman Springs chemical types (table 2) are interbedded at one known locality, Benjamin Gulch, 3 km south of Pomeroy in southeast Washington (fig. 3). This is interpreted as indicating local interfingering of the Grande Ronde and Wanapum Basalts. A saprolite is missing, despite its presence as a thick unit between the Grande Ronde and Wanapum Basalts in nearby areas. These relations are

FIGURE 3.—Schematic stratigraphic section in Benjamin Gulch, showing chemical types of 13 basalt flows exposed in roadcuts along State Highway 128 in secs. 8, 9, and 16, T. 11 N., R. 42 E., Pomeroy quadrangle (Washington). Uncorrected for north dip of about 4°. Note interbedded nature of chemical types. In Pomeroy, 3 km to north, flow 72-55(?) overlies a continuous sequence of the Grande Ronde Basalt.


Elevation (ft)
Sample No.
Roza Member
2700
2600
2500
2400
2300
2200
72-48
72-57
71-60, 72-49
71-57
72-50
72-51, 73-110
73-111
71-59
72-52
71-58, 72-53
72-54
72-55
EXPLANATION
Claystone
Dodge chemical type
High-MgO Grande Ronde chemical type
Frenchman Springs chemical type

significant, as they indicate that magmas of greatly different compositons were available along local areas of the vent systems during a time in which weathering and sediment deposition prevailed across much of the rest of the Columbia Plateau.

FLOWS OF PRINEVILLE CHEMICAL TYPE

Thirteen flows of a distinct chemical composition (table 2, col 8), termed Prineville chemical type by Uppuluri (1974), form a 240-m-thick section near Prineville Dam, Crook County, north-central Oregon (fig. 1). They rest unconformably on the John Day Formation and are unconformably overlain by Pliocene basalt flows (Uppuluri, 1974; Waters, 1961, pl. 2*A*). These flows were considered part of the Columbia River Group by Swanson (1969), but they cannot be traced laterally into areas of known Yakima Basalt Subgroup or Picture Gorge Basalt. Nathan and Fruchter (1974) found flows of Prineville chemical type interlayered with flows of Grande Ronde chemical type along Butte Creek and at Tygh Ridge, and M. H. Beeson (oral commun., 1976) has found similar relations in the western Cascade Range. These observations suggest that at least some flows near Prineville Dam may be coeval with the middle part of the Grande Ronde Basalt. However, Uppuluri (1974) reported that 12 of 13 flows at the dam have reverse magnetic polarity, whereas the flows of Prineville type at Butte Creek and Tygh Ridge have normal polarity. We feel that too little is known about the stratigraphic relations to warrant assignment of the flows in the Prineville Dam section to any formal subdivision of the Columbia River Basalt Group. With further fieldwork, it may become advisable to elevate these flows to member or formational status in the Yakima Basalt Subgroup. At this time, we favor continuing to include in the Grande Ronde Basalt the Prineville-type flows that are interbedded with undoubted Grande Ronde Basalt along Butte Creek, at Tygh Ridge, and in the Western Cascades. The flows near Prineville Dam are not assigned herein to any formally named unit within the Columbia River Basalt Group.

REDEFINITION OF THE VANTAGE SANDSTONE MEMBER

The sedimentary interbed commonly present between the Grande Ronde and Wanapum Basalt in the western part of the Columbia Plateau was formally named the Vantage Sandstone Member of the Yakima Basalt by Bingham and Grolier (1966). This definition presents no problem at the type locality, but farther west, the Vantage merges laterally with and cannot be separated from sedimentary deposits of the Ellensburg Formation. In such places, the deposit must be mapped as belonging to the Ellensburg. Schmincke (1964) recognized this problem and suggested that the Vantage be made a part of the Ellensburg; he later (1967a) assigned it to the Yakima Basalt in order to conform to the then generally accepted classification but believed the observed evidence supported his earlier suggestion (H.-U. Schmincke, oral commun., 1965, 1976).

We agree that the evidence strongly supports Schmincke's (1964) earlier suggestion and reassign the Vantage Sandstone Member as a member of the Ellensburg Formation, for the name of a unit should not change laterally depending simply on whether it was or was not deposited between basalt flows. We also shorten the name to the Vantage Member, because it commonly contains only siltstone, claystone, or tuffaceous rocks.

All major sedimentary interbeds between basalt flows along the edges of the Columbia Plateau are likewise excluded from the Columbia River Basalt Group, following the procedure of Griggs (1976). Those major interbeds in the western part of the plateau in Washington are assigned to the Ellensburg Formation, and those in the northwestern part of the plateau, to the Latah Formation. Interbeds elsewhere are left unassigned, as existing nomenclature is unsatisfactory and we wish to propose no new names for these deposits at this time.

WANAPUM BASALT

The name Wanapum was used by J. Hoover Mackin (P. E. Hammond, oral commun., 1976) in classroom lectures during the 1950's and 1960's for basalt above the Vantage Member and below the Saddle Mountains Basalt in the Vantage-Priest Rapids area of central Washington. These rocks were called the middle Yakima basalt by Wright and others (1973).

We hereby adopt Mackin's usage and formally assign the Wanapum Basalt to formational status. The Wanapum Basalt includes all of the flows previously included in the middle Yakima basalt except for the Umatilla Member, now defined as the basal part of the Saddle Mountains Basalt. The type locality of the Wanapum is designated as the area of nearly continuous exposure along the east side of the Columbia River near Wanapum Dam, from Sand Hollow in sec. 28, T. 17 N., R. 23 E., south to the top of the section near the Vantage Substation above Wanapum Dam in sec. 16, T. 16 N., R. 23 E., Vantage and Beverly quadrangles, Grant County, Washington. Most of the section is also exposed in roadcuts along Highway 243 south of the intersection with Highway 26. This 120-m-thick section consists of three flows of the Frenchman Springs Member overlain by one flow of each of the Roza and Priest Rapids Members.

The Wanapum Basalt contains a sequence of generally medium-grained olivine-bearing commonly slightly to moderately plagioclase-phyric flows, most of which have high Fe and Ti contents (table 2). Many of the flows recognized as a "late textural and mineralogical variant of the Yakima Basalt" by Waters (1961) are in the Wanapum. The generally high Fe and Ti nature of the formation is known to be broken only by flows in the Eckler Mountain Member in southeast Washington (table 2, Nos. 12–14).

The Wanapum Basalt is divided into four members on the basis of petrography and magnetic polarity, from oldest to youngest, the Eckler Mountain Member, Frenchman Springs Member, Roza Member, and Priest Rapids Member. All terms except Eckler Mountain Member, a new name, are used in the same sense as originally defined (Mackin, 1961; Bingham and Grolier, 1966). The Eckler Mountain Member contains flows of three different petrographic and chemical types, all of which have normal magnetic polarity. The dominant type of flow in the Eckler Mountain is coarse-grained, commonly grusy weathering, and plagioclase phyric; another type of flow, the oldest in the member, is diktytaxitic, aphyric, and olivine rich; a third, the youngest type of flow, is fine grained and aphyric. The Frenchman Springs Member contains several flows, some with moderately abundant large plagioclase glomerocrysts, and has normal magnetic polarity. The Roza Member is moderately plagioclase phyric, with single crystals greatly predominating over glomerocrysts, and has either a transitional or reversed magnetic polarity. The Priest Rapids Member commonly carries small plagioclase and olivine phenocrysts, although most local flows near the type locality are aphyric and coarse grained, and has a reversed magnetic polarity. The youngest Priest Rapids flow is notably more magnesian than most other high Fe and Ti flows in the Wanapum. Contacts between the four members are conformable, although sedimentary interbeds separate them in places.

On a local scale, the Wanapum Basalt overlies the Grande Ronde conformably or with local erosional disconformities, except for the interbedded relation in Benjamin Gulch south of Pomeroy, Wash. On a regional scale, however, the Wanapum disconformably overlies progressively older parts of the Grande Ronde Basalt eastward from the center of the plateau (Swanson and Wright, 1976b; Swanson and others, 1977; 1979). This relation is interpreted as indicating subsidence of the central plateau prior to Wanapum time. The regional unconformity between the two formations is caused by confinement of younger Grande Ronde flows to the deeper part of the subsidence basin, not by their erosion from the eastern limb of the plateau (Swanson and Wright, unpub. data, 1977). Such subsidence continued through Wanapum time and into late Saddle Mountains time.

A prominent saprolite mantles the surface of the Grande Ronde Basalt in southeast Washington and adjacent Oregon and Idaho, progressively thickening eastward from the Devils Canyon area. Local basins in which arkosic and subarkosic sediments were deposited occur above the saprolite in places, such as the Spokane and Pullman areas. The saprolite is an excellent guide to recognizing the Grande Ronde-Wanapum contact.

The Vantage Member of the Ellensburg Formation separates the Grande Ronde and Wanapum across much of the western part of the Columbia Plateau. Where it is missing, a thin saprolite commonly marks the contact. Where both the Vantage and the saprolite are missing or very thin, such as in the Blue Mountains east of Milton-Freewater, Oreg., the Grande Ronde-Wanapum contact may be hard to map except where the lowermost flow in the Wanapum is porphyritic.

The contact between the Wanapum and the overlying Saddle Mountains Basalt is generally conformable, although local angular unconformities occur along Yakima Ridge near Yakima (Holmgren, 1967, Bentley, 1977) and on Umtanum Ridge near Priest Rapids (Bentley, 1977), and erosional unconformities are known from a few areas in south-central Washington and in the Spokane River drainage basin. A saprolite or thin deposit of tuffaceous rocks belonging to the Ellensburg Formation commonly occurs along the Wanapum-Saddle Mountains contact in the western part of the Columbia Plateau.

Dikes and vent areas for Wanapum flows are known from many places in southeast Washington, western Idaho, and northeast Oregon (fig. 1; Swanson and others, 1975; Swanson and others, 1977; 1979). Probably other vents are hidden beneath younger flows in the central part of the Columbia Plateau, as some Wanapum flows are known to occur there and nowhere else.

ECKLER MOUNTAIN MEMBER

In and adjacent to the Blue Mountains in southeast Washington, petrographically and chemically distinctive flows, informally named the basalt of Dodge (Swanson and others, 1975) and the underlying basalt of Robinette Mountain, occur between typical flows of the Grande Ronde Basalt and Frenchman Springs Member. These distinctive flows overlie a well-developed saprolite in most places but are themselves somewhat weathered and locally overlain by a saprolite. They most likely were erupted during the period of time that produced the extensive soil on top of the Grande Ronde Basalt elsewhere in southeast Washington. Field relations at Benjamin Gulch south of Pomeroy, where three flows of Dodge type are interbedded with Grande Ronde and Frenchman Springs flows (fig. 3), support this timing.

The name Eckler Mountain Member is here introduced for the flows between the underlying Grande Ronde Basalt and the overlying Frenchman Springs Member. The Eckler Mountain is designated a member of the Wanapum rather than the Grande Ronde Basalt, because the underlying saprolite, which represents a significant period of time following Grande Ronde volcanism, is more common and generally thicker than the overlying saprolite. The Eckler Mountain bears more resemblance chemically to the Grande Ronde than to the Wanapum, however. It may be desirable at some later time to raise the Eckler Mountain to formational status, but that is not done here because of its comparatively restricted occurrence.

The type locality is on the south and southeast side of Eckler Mountain (misspelled Echler Mountain on the Pullman 1° by 2° quadrangle), about 17 km southeast of Dayton, Columbia County, Wash. in the north halves of secs. 26 and 27, T. 9 N., R. 40 E., Eckler Mountain quadrangle (pl. 1, fig. *D*). This is the only known area in which flows of both the Dodge and Robinette Mountain chemical types (table 2, col. 12–13) occur in the same section. Two sites in the type locality where a Dodge-type flow overlies a Robinette Mountain flow are (1) roadcut and cliff below road in the NW¼NW¼NE¼ sec. 26, T. 9 N., R. 40 E. and (2) roadcut and cliff below road along the border of the SW¼NE¼ and SE¼NW¼ sec. 27, T. 9 N., R. 40 E. The total thickness of the member in this area is 20 to 25 m.

All known flows in the Eckler Mountain Member have normal magnetic polarity (Choiniere and Swanson, 1979; Swanson and Wright, unpub. data, 1977).

The basalt of Robinette Mountain is named for a single flow in roadcuts on Robinette Mountain near a powerline crossing in the NE¼NW¼ sec. 22, T. 9 N., R. 39 E., Robinette Mountain quadrangle, Columbia County, Wash. Other excellent accessible exposures in this general area are (1) the Dayton city dump in Crall Hollow, SW¼SW¼ sec. 34, T. 10 N., R. 39 E., Dayton quadrangle, and (2) the prominent cliff along the upper part of Rodgers Gulch near Pioneer Memorial Park, NE¼SW¼ sec. 4, T. 9 N., R. 40 E., Cahill Mountain quadrangle. Nowhere have two or more Robinette Mountain flows been found in contact, and it is possible that only one such flow was erupted. The maximum exposed thickness of the basalt of Robinette Mountain is about 20 m.

The basalt of Robinette Mountain is coarse grained, has a distinctive coarsely diktytaxitic texture, and contains abundant olivine (commonly rimmed or replaced by iridescent iddingsite) but only very rare, small plagioclase phenocrysts. It is a prominent cliff former throughout much of its outcrop area, inferred to be a minimum of 180 km^2 (pl. 1, fig. *D*; Swanson and others, 1977). It has a distinctive chemical composition, with the highest Al_2O_3 and lowest K_2O and TiO_2 contents of any known flow in the Yakima Basalt Subgroup (table 2, No. 12). A north-northwest-trending feeder dike for the basalt of Robinette Mountain extends for at least 3 km through the center of secs. 5 and 8, T. 7 N., R. 40 E., Godman Spring quadrangle (pl. 1, fig. *D*: Swanson and others, 1977; 1979).

The basalt of Dodge is named from a flow exposed in a roadcut along Highway 127, in the SW¼NE¼ sec. 16, T. 12 N., R. 40 E., Hay quadrangle, 1.5 km by road from the intersection of Highways 127 and 12 at Dodge, Garfield County, Wash. The roadcut displays a grussy flow containing weathering spheroids whose cores are fresh. This type of weathering, typical of Dodge flows at relatively low elevations below about 1,200 m, is well shown at the following reference localities: (1) switchback in road at 597 m (1,960 ft) elevation 1 km north-northeast of Marengo, Columbia County, Zumwalt quadrangle, Wash.; (2) roadcut along Highway 128 in SE¼SE¼ sec. 4, T 10 N., R. 42 E., Rose Springs quadrangle, Wash.; (3) roadcut at head of Shumaker Creek, extreme southeast corner of sec. 11, T. 7 N., R. 45 E., Black Butte quadrangle, Wash.; (4) roadcut along the boundary of the SE¼NE¼ sec. 31 and SW¼NW¼ sec. 32, T. 7 N., R. 43 E., Saddle Butte quadrangle, Wash.; and (5) roadcut along Highway 3 at 1,000 m (3,280 ft) elevation, NE¼NE¼ sec. 26, T. 6 N., R. 44 E., Flora quadrangle, Oreg.

At higher elevations, the basalt of Dodge tends to lose its grusy aspect and is more resistant to weathering. Examples are: (1) roadcut near the base of the knoll at Wenatchee Guard Station, extreme northeast corner of sec. 2, T. 7 N., R. 43 E., Saddle Butte quadrangle, Wash.; (2) cliffs west of Abels triangulation station, NE¼ SW¼ sec. 7, T. 9 N., R. 42 E., Rose Springs quadrangle, Wash.; and (3) roadcut at about 1,355 m (4,450 ft) elevation in NE¼SW¼ sec. 18, T. 7 N., R. 39 E., Deadman Peak quadrangle, Wash.

The basalt of Dodge is characterized by coarse grain size and moderately abundant large phenocrysts and glomerocrysts of plagioclase as much as 2 cm across. Smectitic alteration is common. Olivine originally constituted more than 5 percent of the rock, but most has been altered to clay minerals. The basalt of Dodge can be confused with some plagioclase-phyric Frenchman Springs flows, but its grain size and average glomerocryst size are both greater than in most Frenchman Springs flows. The chemical composition of the Dodge is similar to that of some very high MgO flows in the Grande Ronde Basalt (table 2, Nos. 11 and 13), but the coarse grain size and glomerophyric nature of the Dodge allows ready identification.

The basalt of Dodge generally consists of one flow in a single exposure but locally comprises as many as four flows. Its maximum thickness is about 40 m. The Dodge is the most widespread unit in the Eckler Mountain Member. It occurs principally in two major areas of outcrop (pl. 1, fig. *D*): the Blue Mountains east and south of Walla Walla, Wash., and a belt extending more than 80 km northwest from Buford Creek, Oreg., to the Snake River near the mouth of New York Gulch, Wash. (Swanson and others, 1977, 1979; Swanson and others, 1975; Price, 1977; and Ross, 1978). Flows of Dodge type also occur in the Shumaker Canyon area in extreme southeast Washington and in a small area near Walker grain elevator along the lower Snake River (Swanson and others, 1977, 1979; Price, 1977). Griggs (1976) reported one or more chemically similar flows along the lower St. Joe and St. Maries Rivers south of Coeur d'Alene Lake, Idaho; we feel that these flows may correlate with the basalt of Dodge, although they lack the large plagioclase phenocrysts typical of Dodge-type flows elsewhere. The Dodge is locally interbedded with the Frenchman Springs Member in Benjamin Gulch south of Pomeroy, Wash., and in the Blue Mountains southeast of Walla Walla (D. A. Swanson and T. L. Wright, unpub. data, 1978).

Dikes of Dodge chemical type, presumably feeders of the basalt of Dodge, occur at several locations in the Blue Mountains in Washington (pl. 1, fig *D*; Swanson and others, 1977, 1979; Ross, 1978), and a similar dike crops out along Little Sheep Creek east of Enterprise, Oreg. (Swanson and others, 1975; Kleck, 1976, table 29, no. I 148).

In extreme southeast Washington, the basalt of Dodge is locally overlain by one or two aphyric flows that are also low in Fe and Ti but considerably higher in alkalis and lower in Mg than the Dodge. These flows are informally named the basalt of Shumaker Creek for a flow prominently exposed in roadcuts above the basalt of Dodge at the head of Shumaker Creek, in the extreme southeast corner of sec. 11, T. 7 N., R. 45 E., Black Butte quadrangle, Asotin County, Wash. Another good locality is at Wenatchee Guard Station, Wash. (fig. 1), where the capping flow is the basalt of Shumaker Creek. These flows are overlain by the Roza Member between Wenatchee Guard Station and Anatone Butte but are nowhere known to occur in a section with flows of the Frenchman Springs Member. Consequently, we know little about the precise age relation of the basalt of Shumaker Creek to the Frenchman Springs Member, although we tentatively consider the Shumaker Creek to be older and assign it to the Eckler Mountain Member. The distribution of the basalt of Shumaker Creek is poorly known and not shown on plate 1.

The basalt of Shumaker Creek is fine grained and similar in appearance to many flows of the Grande Ronde Basalt. Its chemical composition, however, is distinctly lower in MgO and higher in P_2O_5 than the low-MgO Grande Ronde chemical type (table 2, No. 14).

Camp (1976) described a similar flow, the George Creek flow, at Cloverland Grade, Wash. (fig. 1) and assigned it to a magnetically reversed part of the Grande Ronde Basalt. Field relations are somewhat obscure in the Cloverland Grade area, however, as the basalt of Dodge is absent. We suggest, on the basis of chemical similarity, that the George Creek flow correlates with the basalt of Shumaker Creek and should be assigned to the Eckler Mountain Member.

FRENCHMAN SPRINGS MEMBER

The Frenchman Springs Member (Bingham and Grolier, 1966) was named and described by Mackin (1961) for flows exposed at its type locality in Frenchman Springs Coulee (named Frenchman Coulee on the Evergreen Ridge quadrangle), in secs. 19–21 and 29–30, T. 18 N., R. 23 E., Grant County, south-central Washington (pl. 1, fig. *E*). Mackin considered that two informally named cooling units, the Ginkgo and overlying multiple-flow Sand Hollow, compose the 75-m-thick member at its type locality; a third cooling unit, the Sentinel Gap flow, overlies the Sand Hollow several kilometers farther south. Work in progress by R. D. Bentley may result in modification of this scheme. A thin bed of diatomite overlies the member at its type locality and has been designated the Squaw Creek Diatomite Bed (Bingham and Grolier, 1966; see later discussion in this paper). Elsewhere in south-central Washington, the Frenchman Springs consists of as many as nine flows, generally three to six, and is the most extensive member of the Wanapum Basalt. The reader is referred to Mackin (1961), Bingham and Grolier (1966), and Bentley (1977) for more information about the Frenchman Springs Member in south-central Washington.

A good reference locality for the Frenchman Springs Member is in roadcuts and natural exposures in Devils Canyon, south of Kahlotus in the Kahlotus and Lower Monumental Dam quadrangles, Wash. (fig. 1). At least nine flows totaling about 190 m in thickness are exposed here. The member overlies the reddened top of a slightly weathered flow of the Grande Ronde Basalt at the mouth of the canyon near the north end of Lower Monumental Dam (Swanson and Wright, 1976b; Siems and others, 1974) and underlies the Roza Member, exposed in roadcuts along the Pasco-Kahlotus highway at the head of Devils Canyon (Bingham and Walters, 1965; Swanson and Wright, 1976b).

Other easily accessible reference localities where the Frenchman

Springs is well exposed are on both sides of Wallula Gap, Wash. (Atlantic Richfield Hanford Company, 1976, v. 2, p. B 24–B 26); on the Maryhill grade along Highway 97 north of Biggs, Oreg. (Hammond and others, 1977); along the Deschutes River just north of Maupin, Oreg. (R. D. Bentley, unpub. map, 1977); roadcuts and railroad cuts in Palouse Falls State Park, Wash. (Swanson and Wright, 1976b); and at Rattlesnake Springs in Moses Coulee, Wash. (Siems and others, 1974).

The Frenchman Springs Member rests on the Grande Ronde Basalt, except in parts of southeast Washington and northeast Oregon, where it overlies and is locally interbedded with the Eckler Mountain Member. A saprolite or, less commonly, arkosic to subarkosic siltstone and sandstone, occurs on the pre-Frenchman Springs surface in many places. Thin discontinuous subarkosic and tuffaceous interbeds occur between some flows of the Frenchman Springs Member in the central and western part of the Columbia Plateau. Examples can be seen at Palouse Falls (Swanson and Wright, 1976b, p. 17; Siems and others, 1974, p. 1063), in the Yakima area (Bentley, 1977), and near Maupin, Oreg. (R. D. Bentley, unpub. map, 1977).

Most flows in the member contain scattered glomerophyric clots of plagioclase a centimeter or more in diameter, generally unequally distributed through a flow. Large phenocrysts of olivine are very sparse in most flows but are notable in a few flows, such as the one atop Pikes Peak, Oreg. (sec. 22, T. 6 N., R. 37 E., Peterson Ridge quadrangle). In our experience, post-Eckler Mountain flows in the Yakima Basalt Subgroup containing numerous large plagioclase glomerocrysts almost certainly belong to the Frenchman Springs Member. However, flows containing very sparse glomerocrysts (perhaps one per 20 m^2 or fewer) are not necessarily in the member, as such flows have been found in definite Grande Ronde Basalt. On the other hand, not all Frenchman Springs flows contain glomerocrysts. Such aphyric flows, particularly common in the eastern part of the Columbia Plateau, cannot be distinguished in the field from the Grande Ronde Basalt. Their assignment to the Frenchman Springs is clearcut if they are interbedded with glomerophyric flows, but rather tenuous otherwise. Mapping in adjacent areas or chemical analysis of the suspect flows generally results in firm assignment.

All known flows within the Frenchman Springs, whether glomerophyric or not, are characterized by a chemical composition defined by Wright and others (1973) as Frenchman Springs chemical type; the average composition of one flow of this chemical type is given in table 2 (No. 15). Nearly all flows of this chemical type are in the Frenchman Springs Member.

All flows in the member that have been tested have normal magnetic polarity (Rietman, 1966; Kienle and others, 1978).

The Frenchman Springs Member has been recognized over wide areas of the Columbia Plateau in eastern Washington and northeast Oregon, and Beeson and others (1976) found that flows of Frenchman Springs petrographic and chemical type and stratigraphic position occur in the Bull Run area and the lower Willamette Valley of western Oregon (pl. 1, fig. *E*). In most places, the "TiO_2 discontinuity" (Siems and others, 1974) marks the contact between the Grande Ronde Basalt and the Frenchman Springs Member. The member generally thins away from the central Columbia Plateau; its eastern limit, mapped by Swanson and others (1977; 1979), is at about long 117° 25′ W. in southeast Washington.

Dikes having appropriate chemistry, lithology, and paleomagnetic polarity for the member occur in the Blue Mountains southeast of Walla Walla and along the Snake River slightly upstream from Walker, Wash. (pl. 1, fig. *E*; Swanson and others, 1975; Swanson and others, 1977; 1979). These dikes served as feeders for some of the flows; a good example of a dike merging with the flow it fed occurs along the Snake River downstream from Devils Canyon (Swanson and others, 1975, fig. 1). Most of the feeder dikes are nearly vertical, but some east of Milton-Freewater, Oreg., have dips as low as 20°.

ROZA MEMBER

The Roza Member (Bingham and Grolier, 1966) was named by Mackin (1961) for exposures of a plagioclase-phyric flow at the type locality, "a scarp on the east side of the Yakima River opposite Roza Station" (a railroad siding in Yakima Canyon between Ellensburg and Yakima), at about 460 m (1,500 ft) elevation in the SE¼ sec. 16, T. 15 N., R. 19 E., Wymer quadrangle, south-central Washington (pl. 1, fig. *F*). For years a more accessible outcrop and roadcut 8 km to the south, just above and south of an abandoned tunnel on old Highway 97 in the W½ sec. 9, T. 14 N., R. 19 E., Pomona quadrangle, has served as a principal reference locality. Mapping by Diery and McKee (1969) established stratigraphic continuity between the two localities. At both, the Roza occurs as a single flow overlying diatomite and underlying volcaniclastic rocks of the Ellensburg Formation.

Elsewhere, more than one flow may be present between the Frenchman Springs and Priest Rapids Members. This was recognized by Bingham and Grolier (1966), who assigned all such flows to the Roza Member. We follow this procedure, as all these flows have similar petrographic and chemical characteristics and appear to share a common vent system (Swanson and others, 1975).

The Roza occurs across much of the Columbia Plateau (pl. 1, fig. *F*) and was erupted from a narrow linear vent system more than 150 km long in southeast Washington and northeast Oregon. Each of its flows is characterized by numerous (about 5–8 percent) plagioclase phenocrysts, mostly single crystals averaging more than 5 mm in length, that are evenly distributed throughout the flow. The nature and distribution of the phenocrysts distinguish the Roza from the Frenchman Springs Member. The Roza generally consists of no more than two flows whose total thickness is about 50 m at any site. Most of the Roza has a transitional magnetic polarity (Rietman, 1966), but at least one cooling unit along the vent system in extreme southeast Washington has reversed polarity (Choiniere and Swanson, 1979); this reversed unit is considered to be the youngest flow in the Roza Member. A more complete description of the member is given by Swanson and others (1975), Lefebvre (1970), and Bingham and Grolier (1966).

Good reference localities showing characteristics of the member on a regional scale are along several roadcuts: (1) the head of Frenchman Springs Coulee (Mackin, 1961, pls. 5B and 6); (2) head of Devils Canyon (Bingham and Walters, 1965, Swanson and Wright, 1976b); (3) head of Horton Grade (sec. 11, T. 14 N., R. 40 E., near Penawawa); (4) north part of Colfax, along Highway 195; (5) Highway 12 at Alpowa Summit, 15 km southeast of Pomeroy; (6) Anatone Butte along the vent system (Swanson and others, 1975, table 1, No. 17); and (7) the lower Grand Coulee area, in which Lefebvre (1970) conducted a detailed investigation of the Roza. The member occurs in scattered outcrops along its vent system in northeast Oregon; it does not occur in Idaho.

Regional stratigraphic relations mapped by Swanson and others (1977) indicate that the Roza overlies progressively older flows eastward from the central Columbia Plateau. The underlying Frenchman Springs Member thins and pinches out eastward, and the Roza near its eastern margin overlies magnetically reversed Grande Ronde Basalt belonging to the informal R_2 magnetostratigraphic unit. The member has not been found east of about long 177° 10′ W. The westernmost known exposure is in the Mosier syncline west of Mosier, Oreg., in the Columbia River Gorge, according to R. D. Bentley (unpub. data, 1977).

The Roza Member is slightly richer in MgO but otherwise chemically similar to most flows of Frenchman Springs chemical type (table 2, No. 16).

SQUAW CREEK DIATOMITE BED AND QUINCY DIATOMITE BED

Bingham and Grolier (1966) used the formal names Squaw Creek Diatomite Bed and Quincy Diatomite Bed to designate units beneath and above, respectively, the Roza Member. The Squaw Creek was assigned to the Frenchman Springs Member, the Quincy to the Priest Rapids Member. These beds are only locally developed in the west-central Columbia Plateau; little if any sedimentary material occurs at these stratigraphic intervals over most of the plateau.

There has been confusion as to the number of diatomites present at the type area for the Quincy Diatomite Bed in the southwestern part of the Quincy Basin, Wash. The Roza Member here forms a peperite intermixed with diatomite and hence is, at least in part, younger than the diatomite. Excellent exposures in many quarries in the Frenchman Hills and the Quincy basin, for example those in sec. 17, T. 18 N, R. 23 E., Evergreen Ridge quadrangle, reveal the chilled nature of tongues, "dikes" and "sills," and irregular masses of the Roza invading this diatomite. These relations, apparently recognized by M. J. Grolier (Mackin, 1961, p. 26, footnote), were overlooked by Bingham and Grolier (1966), who, incorrectly considering the diatomite to be younger than the Roza, assigned it to the type Quincy. We do not believe that the diatomite was deposited on top of one Roza flow and invaded by a younger Roza flow, as we have found no independent indication of two flows. Instead, the evidence suggests that only one Roza flow is present and that this flow invades the Squaw Creek Diatomite Bed. In these quarries, a thin reworked tuff overlies the peperite disconformably and probably is the only post-Roza sedimentary deposit below the Priest Rapids Member in this area. Nowhere do we know of clear evidence of a diatomite younger than or interbedded with Roza and older than Priest Rapids.

The name Quincy Diatomite Bed is here abandoned because it is apparently equivalent to the Squaw Creek Diatomite Bed and because its presumed stratigraphic position above the Roza and within the Priest Rapids is incorrect. The Squaw Creek thickens westward, becomes chiefly a sandstone, tuffaceous sandstone, and siltstone, and merges with the Ellensburg Formation (Bentley, 1977). Consequently, the Squaw Creek is renamed the Squaw Creek Member and reassigned to the Ellensburg Formation.

PRIEST RAPIDS MEMBER

The Priest Rapids Member (Bingham and Grolier, 1966) includes all basalt flows above the Roza Member and below the Umatilla Member of the Saddle Mountains Basalt. Mackin (1961) named the member for four basalt flows exposed along the Columbia River in the "area upstream from the Priest Rapids Dam," in central Washington (pl. 1, fig. *G*). The member here is about 65 m thick. The type locality is now mostly covered by water impounded behind the dam, but the member is poorly exposed in a south-dipping homocline west of the dam. Nowhere in the vicinity, however, are all four flows well exposed. Cores from two holes, PRE–1 and PRK–3, below either end of the dam provide samples of the four flows; these cores, thoroughly studied by personnel of Atlantic Richfield Hanford Co. (1976, v. 2, p. A 35–A 41) and stored at Rockwell Hanford Operations, Richland, Wash., constitute the principal reference material for the member.

The Priest Rapids overlies the Roza Member and underlies the Beverly Member of the Ellensburg Formation at the type locality (Bentley, 1977); the Umatilla Member is not present. The relation of the Priest Rapids to the Umatilla can be seen in core from drill holes DDH–1 and DDH–3 in the Pasco Basin (fig. 1; Atlantic Richfield Hanford Co., 1976) and in outcrops along the east end of Yakima Ridge, such as along Highway 11 in SE¼SE¼ sec. 12, T. 12 N., R. 23 E., Emerson Nipple and Cairn Hope Peak quadrangles, Washington (Schmincke, 1967a). Farther south, the Priest Rapids and overlying Umatilla are separated by an interbed belonging to the Ellensburg Formation (the Mabton bed of Laval, 1956), well exposed in many parts of the Horse Heaven Hills south of Mabton (Schmincke, 1967a).

The Priest Rapids Member extends for long distances away from the type locality (pl. 1, fig. *G*). Only one flow is commonly present, although two or more flows occur in northeastern Washington, northern Idaho, and in the Clearwater embayment of western Idaho. At least one of the flows thought to be the single Lolo Creek flow by Bond (1963) belongs to the Priest Rapids Member. The member has not been found south of the Blue Mountains uplift and is not known to occur in northern Oregon except along the Columbia River valley. Reconnaissance mapping shows that it extends into the Spokane area of the northeast Columbia Plateau, far up the St. Joe and St. Maries Rivers in northern Idaho, and into the northern Grand Coulee area in the northern part of the plateau. One or two flows extend west in northern Oregon as far as Mosier (R. D. Bentley, unpub. data, 1977).

Several reference localities are given because of the wide extent of the member. Localities in the eastern part of the plateau include (1) the roadcut along the Pasco-Kahlotus highway at the head of Devils Canyon, Wash., described by Bingham and Walters (1965); (2) the Whitlow quarry along the Pullman-Moscow highway in the SE¼SW¼ sec. 4, T. 14 N., R. 45 E., Pullman, Wash. quadrangle; the Priest Rapids in this general area was described in a study by Brown (1976); (3) a foreset-bedded lava delta in a roadcut 1.5 km southwest of Malden, Wash. (the basal flow in the Priest Rapids Member is pillowed over a wide area southwest of Malden) (Griggs, 1976, fig. 3); (4) a columnar outcrop about 3 km south of Cavendish, Idaho, along the highway to Ahsahka, in the NE¼SW¼ sec. 22, T. 37 N., R. 1 W., Ahsahka quadrangle (Bond, 1963); and (5) roadcuts along Highway 95A above an elevation of 741 m (2,430 ft) 8–13 km southeast of St. Maries, Idaho, in secs. 6–8 and 18, T. 45 N., R. 1 W., St. Maries, St. Joe, and Emida quadrangles (Griggs, 1976, p. 25; D. A. Swanson and T. L. Wright, unpub. data). The member includes the "rim rock" flows of Pardee and Bryan (1926) in the Spokane area.

Reference localities in the western part of the plateau are (1) the southeast side of Sentinel Gap, 15 km north of the type locality, where two flows in the member overlie the Roza Member and underlie a thick conglomerate of the Ellensburg Formation; (2) south end of Union Gap, Wash., along Thorpe Road (fig. 1); (3) roadcuts along Interstate Highway 80 just west of Arlington, Oreg.; and (4) roadcuts along Highway 14 about 7 km east of Bingen, Wash. (Hammond and others, 1977).

The upper flow of the Priest Rapids at the type locality, at the reference locality at Sentinel Gap, in drill cores from the Pasco Basin (Myers, 1973; Atlantic Richfield Hanford Co., 1976), and across all of the southeastern part of the plateau has a relatively high magnesium composition (table 2, No. 18) termed the Lolo chemical type by Wright and others (1973). Flows of this chemistry are distinctive, as they invariably contain small olivine phenocrysts (a hand lens is generally needed for identification) and commonly small plagioclase phenocrysts or glomerophyric clots of plagioclase and olivine. Older flows in the northern and northeastern parts of the plateau have a high TiO_2-low MgO composition (Griggs, 1976), chemically resembling the Elephant Mountain Member except for higher P_2O_5 (table 2, No. 17); this composition is designated the Rosalia chemical type.

All flows in the Priest Rapids Member have reversed magnetic polarity and by this can be distinguished from sparsely phyric or aphyric flows in the Frenchman Springs in areas where the intervening Roza is missing or poorly exposed.

Several dikes of Lolo chemical type and reversed magnetic polarity and one dike of Rosalia chemical type occur along the Clearwater River south of Orofino, Idaho (pl. 1, fig. *G*; W. H. Taubeneck, T. L. Wright, and D. A. Swanson, unpub. data, 1977) and apparently fed much of the Priest Rapids Member on the Columbia Plateau.

SADDLE MOUNTAINS BASALT

Bingham and Grolier (1966) applied the name Saddle Mountains Member "to all the basalt flows overlying the Priest Rapids Member in the Sentinel Gap area *** [and] *** in the Yakima Valley," in the west-central part of the Columbia Plateau, Wash. In these two areas, the Pomona is the oldest unit in the Saddle Mountains. Elsewhere, however, flows older than the Pomona but younger than the Priest Rapids have been found. We hereby include all flows younger than the Priest Rapids Member in the Saddle Mountains, which we raise to formational rank as the Saddle Mountains Basalt and subdivide into 10 members and several informal units of differing chemical composition, source regions, and geographic distribution. The Saddle Mountains Basalt as so defined is equivalent to the upper Yakima basalt of Wright and others (1973), except that it includes the Umatilla Member previously considered as a part of the middle Yakima. This change is made on the basis of geochemistry (McDougall, 1976), the presence of the Mabton bed of Laval (1956) below the Umatilla over a relatively wide area, and the discovery that the Umatilla locally fills valleys cut in older rocks, a characteristic shared by the flows in the Saddle Mountains and described later in the paper.

Bingham and Grolier (1966) designated the area "southeast of Sentinel Gap," in the Beverly quadrangle, as the type locality of the Saddle Mountains Basalt. Only one member, the Elephant Mountain, is present at this locality, although the Pomona Member occurs nearby. The formation is nowhere represented by all its members, but more complete reference localities, all in Washington, can be designated as:

(1) Exposures of the Esquatzel, Pomona, and Elephant Mountain Members in roadcuts along Highway 17 in and just north of the village of Mesa, 40 km north of Pasco in Esquatzel Coulee (Swanson and others, 1977; 1979);

(2) Upper part of the bluffs on west side of Wallula Gap. Here the Umatilla Member directly overlies the Frenchman Springs Member, and the Pomona, Elephant Mountain, and Ice Harbor Members occur in scattered outcrops (see map of Swanson and others, 1977, 1979, and Atlantic Richfield Hanford Co., 1976).

(3) Exposures of the Pomona and Elephant Mountain Members in roadcuts along the Mabton-Bickleton road, in SE¼SE¼ sec. 27, T. 8 N., R. 22 E., and of the Umatilla Member in the W½ sec. 35, T. 8 N., R. 22 E. (Schmincke, 1967a, b);

(4) In Devils Canyon (SE¼ sec. 21, T. 13 N., R. 34 E.), natural exposures on the canyon wall show a cross section of four paleovalleys eroded into the Wanapum Basalt and filled successively by an unnamed and unassigned Saddle Mountains flow and the Esquatzel, Pomona, and Elephant Mountain Members. About 5 km to the

south, a roadcut across the Snake River from the mouth of Devils Canyon (in SE¼ sec. 3, T. 12 N., R. 34 E.) is the type locality of the Lower Monumental Member (Swanson and Wright, 1976b, p. 13–16; Swanson and others, 1977; 1979);

(5) Exposures of the Umatilla, Wilbur Creek, Asotin, Weissenfels Ridge, and Elephant Mountain Members in the Cloverland Grade, 6 km west of Asotin, secs. 25 and 26, T. 10 N., R. 45 E. (Camp, 1976; Swanson and others, 1977; 1979);

(6) Exposures of the Pomona and Elephant Mountain Members and feeder dikes of the Ice Harbor Member in railroad cuts about 2 km northeast of Ice Harbor Dam, in sec. 18, T. 9 N., R. 32 E. A flow of Martindale chemical type in the Ice Harbor Member occurs on the hillslope above the Elephant Mountain (Swanson and others, 1975; Swanson and others, 1977; 1979).

Several flows within the Saddle Mountains Basalt are not assigned formal member status because of limited areal extent or lack of information. Among these are the Bear Creek and Eden flows of Ross (1978), the oldest known intracanyon flow along the ancestral Snake River (Swanson and others, 1977), and andesite at several localities in northeast Oregon (Walker, 1973; W. H. Taubeneck, oral commun., 1978). Future work may result in elevation of such flows to formal member rank.

The Saddle Mountains Basalt contains flows of diverse chemistry, petrography, age, and paleomagnetic polarity. It was erupted between about 13.5 ± 0.5 m.y. and 6 m.y. ago (McKee and others, 1977; Atlantic Richfield Hanford Co., 1976), during a period of deformation, canyon cutting, waning volcanism, and development of thick but local sedimentary deposits between flows. The Saddle Mountains Basalt constitutes much less than 1 percent of the total volume of the Columbia River Basalt Group, yet contains by far the greatest chemical diversity, including major and trace element and isotopic abundances, of any formation in the group.

Four of the newly defined members of the Saddle Mountains Basalt occur principally in the Lewiston Basin of extreme southeast Washington: the Wilbur Creek, Asotin, Weissenfels Ridge, and Buford Members (pl. 1, figs. *I–K*, *O*). The Wilbur Creek and Asotin are also found as intracanyon flows toward the center of the Columbia Plateau (Swanson and others, 1977; 1979), channeled westward by ancestral valleys heading on the Uniontown Plateau. Two members, the Esquatzel and Lower Monumental, occur chiefly as intracanyon flows along the ancestral Snake (pl. 1, figs. *L*, *Q*). They therefore cover only a very small total area but extend for tens of kilometers along the canyon. The other four members, the Umatilla, Pomona, Elephant Mountain, and Ice Harbor, cover relatively wide areas and also occur, at least locally, as canyon fills (pl. 1, figs. *H, M, N, P*).

Direct evidence (dikes and vent areas) and interpretation based on distribution and field relations suggest that 9 of the 10 members were erupted wholly or in part from fissures near the eastern margin of the Columbia Plateau in southeast Washington and adjacent Idaho and Oregon. This evidence is given in the descriptions of the individual members. The exception, the Ice Harbor Member, was erupted from the central part of the plateau (Swanson and others, 1975; 1977; 1979; Helz, 1978).

UMATILLA MEMBER

Laval (1956) described two similar flows, which he named the Umatilla and Sillusi, in exposures near McNary Dam, in Washington across the Columbia River from Umatilla, Oreg. Schmincke (1964; 1967a; oral commun., 1964) interpreted these to be flow units of the Umatilla, and he mistakenly thought that Laval had done likewise. Schmincke further incorrectly thought that Laval had applied the name Sillusi to a distinctly different flow that Schmincke termed the Pomona. These mistakes have led to confusion as to Schmincke's (1967a) usage of the term Umatilla Basalt.

We hereby define the Umatilla as a member, the Umatilla Member, to include the two flows or flow units described by Laval (1956) and designate its type locality as natural exposures and cuts along an abandoned railroad 1 km west of the north abutment of McNary Dam, in the extreme SE¼SE¼SE¼ sec. 4, T. 5 N., R. 28 E., Umatilla quadrangle, Benton County, Wash. (pl. 1, fig *H*). This corresponds to the suggestion of Atlantic Richfield Hanford Co. (1976). The base of the member is not exposed here, although core holes at the damsite show that it is about 100 m thick and overlies sedimentary deposits (the Mabton bed of Laval, 1956). The Umatilla underlies the Pomona Member on Sillusi Butte overlooking the type locality.

Schmincke (1967a) found the Umatilla to occur throughout much of extreme south-central Washington (pl. 1, fig *H*) and further work shows it extending as far west as about 14 km west of Bickleton (Steven Strait, oral commun., 1978). The unit has been recognized in drill cores from the Pasco and Walla Walla Basins (Myers, 1973; Ledgerwood and others, 1973; Bush and others, 1973; Atlantic Richfield Hanford Co., 1976), and it occurs on the plateau surface south of Milton-Freewater, Oreg. (D. A. Swanson and T. L. Wright, unpub. data). It occurs as an intracanyon flow along Yakima Ridge to a point 2 km east of Selah Gap (fig. 1), where it is pillowed in cuts along the Resthaven Road (D. A. Swanson and G. R. Byerly, unpub. chemical analyses, 1978). Flows of similar characteristics, chemistry, and stratigraphic position on and just west of the Uniontown Plateau, in and south of the Lewiston Basin (Camp, 1976; Price, 1977), and in the Troy, Oreg., area (Ross, 1978) are also assigned to the Umatilla (pl. 1, fig. *H*).

Reference localities are (1) the thickest and best exposed flow near the top of the bluff on the west side of Wallula Gap, Wash. (Atlantic Richfield Hanford Co., 1976) and (2) Puffer Butte, in extreme southeast Washington, which includes both flows and tephra related to a Umatilla vent area (Price, 1974, 1977; Swanson and others, 1977, 1979).

The Umatilla is very fine grained, consistently finer than other Columbia River flows, and in places has an almost "porcellanite" appearance. Small plagioclase and olivine phenocrysts are rare. Both flows or flow units at and near the type locality have upper zones of flow breccia, ramp joints, and some flow banding; as a result, the flows bear some physical resemblance to andesite flows.

The Umatilla has a distinct chemistry (table 2, No. 19) characterized by lower CaO and higher K_2O and total alkalies than most other flows in the Columbia River Basalt Group. The content of Ba is very high, about 3,000 ppm or more (Ledgerwood and others, 1973; Price, 1974, 1977; Atlantic Richfield Hanford Co., 1976); the member can be identified by Ba content alone. Also, the Umatilla Member has a normal magnetic polarity (Rietman, 1966).

Puffer Butte (fig. 1) is a vent area for the Umatilla Member; a dike[3] exposed south of the butte in the NW¼ sec. 3, T. 6 N., R. 45 E., Fields Springs quadrangle, along the north wall of the Grande Ronde Valley near Shumaker Canyon supplied magma to the vent (pl. 1, fig. *H*; Waters, 1961, pl. 2B; Price, 1974, 1977). No other Umatilla sources have been found. It is probable that the type Umatilla in the central plateau flowed there along a valley draining westward from the Puffer Butte area (D. A. Swanson and T. L. Wright, unpub. map, 1978).

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[3] This dike, in which Peacock and Fuller (1928) described the first occurrence of chlorophaeite on the Columbia Plateau (A. C. Waters, oral commun., 1971), is cut by a tunnel on the old Anatone-Enterprise stage road.

WILBUR CREEK MEMBER

The Wilbur Creek Member is here named for basalt flows between the Umatilla and Asotin Members on the Uniontown Plateau and in the Lewiston Basin of southeast Washington. The member is poorly exposed, and its type locality is designated as a series of roadcuts along Wilbur Creek (sec. 9 and the SW¼SW¼ sec. 4, T. 14 N., R. 44 E., Ewartsville quadrangle), about 7 km west of Pullman, Whitman County, Wash. (pl. 1, fig *I*). Here the member consists of at least two flows that overlie the Priest Rapids Member along an erosional unconformity exposed in a roadcut on the northeast side of Wilbur Creek at 725 m (2,380 ft) elevation. The top of the member is not exposed at the type locality, but scattered outcrops show that the Wilbur Creek is at least 45 m thick. Elsewhere on the Uniontown Plateau, and in the Lewiston Basin, the Wilbur Creek can be seen to overlie the Umatilla Member and underlie, locally with erosional unconformity, the Asotin Member. A good reference locality where this relation is evident is in roadcuts in the Cloverland Grade section between 506 m (1,660 ft) and 540 m (1,770 ft) elevation in the NW¼SW¼ sec. 25 and NE¼SE¼ sec. 26, T. 10 N., R. 45 E., Asotin quadrangle (Camp, 1976), in the Lewiston Basin. The member is generally less than 20 m thick and has normal magnetic polarity, based on field determinations only.

The Wilbur Creek Member is sparsely plagioclase-phyric (phenocrysts less than 5 mm across) and fine grained. In the field, it is distinguished from the underlying Umatilla Member by its somewhat coarser grain size and from the overlying Asotin Member by its near lack of olivine phenocrysts. The Wilbur Creek is compositionally similar to but contains more P_2O_5 than the Grande Ronde chemical type (table 2, No. 20). By its petrography, chemistry, and magnetic polarity, the Wilbur Creek Member is tentatively correlated with remnants of a canyon-filling flow 5 km west of Cow Creek (T. 16 N., R. 36 and 37 E.), on Rattlesnake Flat and in the Warden-Othello area (the Warden-Othello flow tongue of Grolier, 1965, p. 106–107; Swanson and others, 1977; 1979) in the central part of the Columbia Plateau; this intracanyon flow has been recognized on the eastern parts of Umtanum and Yakima Ridges west of the Pasco Basin by F. E. Goff (1977; oral commun., 1978).

The Wilbur Creek Member correlates with the Wahluke flow of Atlantic Richfield Hanford Co. (1976), as judged by stratigraphic position, chemistry, and magnetic polarity.

A source for the Wilbur Creek has not been found but is assumed to be near the Lewiston Basin-Uniontown Plateau area, as the flows moved from there down a canyon draining westward.

ASOTIN MEMBER

A single thick hackly jointed basalt flow occurring between the Wilbur Creek and Weissenfels Ridge Members in the Lewiston Basin of Washington and Idaho is defined as the Asotin Member (Camp, 1976). The member crops out particularly well near Asotin, Wash., and the type locality is designated as roadcuts along Cloverland Grade in the NE¼SE¼ sec. 26 and the NW¼ and SW¼ of the SW¼ sec. 25, T. 10 N., R. 45 E., Asotin quadrangle, 5 km west-southwest of Asotin, Asotin County, extreme southeast Washington (pl. 1, fig. *J*). The base of the member is at about 543 m (1,780 ft), the top at about 585 m (1,920 ft) (Camp, 1976, fig. 14). Sedimentary deposits lie above and below the Asotin Member at the type locality and elsewhere in the Lewiston Basin. These deposits are easily erodible, leading to the development of a prominent cliff 40 to 50 m high that characterizes the member in many places.

The flow occurs as an invasive flow (Byerly and Swanson, 1978), a flow that has an invasive sill-like relation to the enclosing sedimentary rocks, at the type locality and many other places in the Lewiston Basin. The top of the flow is peperitic and chilled against the siltstone, predominantly subarkosic, which at the time of eruption was nonindurated and quite thin, as indicated by the presence of aerodynamically shaped ejecta sprinkled throughout the peperite (Camp, 1976). Other good exposures of the peperite at the top of the Asotin are at about 884 m (2,900 ft) on Montgomery Ridge, Wash. (SW¼NE¼ sec. 24, T. 8 N., R. 46 E., Captain John Rapids quadrangle) and at about 750 m (2,470 ft) on Weissenfels Ridge (NW¼NW¼ sec. 24, T. 9 N., R. 46 E., Lewiston Orchards South quadrangle).

The Asotin Member is sparsely olivine and plagioclase phyric. It contains more olivine than the underlying Wilbur Creek Member and less olivine than many flows of the overlying Weissenfels Ridge Member. The Asotin has a major-element composition similar to that of the basalt of Robinette Mountain (Eckler Mountain Member) (table 2, Nos. 12 and 21) but has higher concentrations of most minor and trace elements. It differs also by lacking a coarse-grained diktytaxitic texture and by having no iddingsite after olivine. It contains more MgO and Al_2O_3 and less FeO than the Pomona Member, with which it might otherwise be confused, and has normal magnetic polarity.

The Asotin Member occurs on the Uniontown Plateau, where it fills a valley eroded into the underlying Wilbur Creek, Umatilla, and possibly Priest Rapids Members (Swanson and others, 1977, 1979). A chemically similar flow occurs near Lind in the central

Columbia Plateau and may be a remnant of the member that flowed down a valley from the Uniontown Plateau (pl. 1, fig *J*; Swanson and others, 1977, 1979).

A source for the Asotin has not been found, but distribution patterns suggest a vent southeast of the Uniontown Plateau.

A normally magnetized basalt flow occurs between probable correlatives of the Wilbur Creek and Esquatzel Members in core holes in the Pasco Basin. This was recognized by workers of the Atlantic Richfield Hanford Co. (Myers, 1973; Ledgerwood and others, 1973; Ward, 1976; Atlantic Richfield Hanford Co., 1976), who correlated the flow with the Huntzinger flow of Mackin (1961) on the basis of chemistry and magnetic polarity. The Huntzinger flow fills a channel, and its stratigraphic relations are obscure. Ward (1976) found a possible correlative of the Huntzinger overlying probable Wilbur Creek Member on Wahatis Peak in the Saddle Mountains (fig. 1); the attitude of columnar jointing suggests that this possible correlative is filling a shallow valley (Ward, 1976, fig. 4d and p. 17). Chemical correlations are not convincing, as the unit shows wide variation in composition for reasons not yet well understood (Ward, 1976). Nonetheless, several analyses in Ward (1976, tables 4 and 5) are similar in major and trace elements to the Asotin (table 2, No. 21; J. S. Fruchter, written commun., 1976). We tentatively suggest that the Huntzinger and Asotin are the same flow but favor retaining the informal name, Huntzinger, until such time as the postulated correlation can be better documented.

WEISSENFELS RIDGE MEMBER

The name Weissenfels Ridge Member is here introduced for the three or more basalt flows between the underlying Asotin Member and the overlying Elephant Mountain Member in the Lewiston Basin of Washington and Idaho. The type locality is in roadcuts along Weissenfels Ridge, Asotin County, Wash., in the NW¼ sec. 24 (projected) and the NE¼ sec. 23 (projected), T. 9 N., R. 46 E., Captain John Rapids quadrangle (pl. 1, fig. *K*). The base of the member, exposed at about 756 m (2,480 ft) elevation, rests on micaceous sandstone and basaltic conglomerate overlying a peperite at the top of the Asotin Member. The member extends to the top of the ridge and is at least 34 m thick.

The Weissenfels Ridge Member is informally subdivided into two units, the basalt of Slippery Creek and the older basalt of Lewiston Orchards. Only the basalt of Lewiston Orchards occurs at the type locality. Both units have normal magnetic polarity.

The basalt of Lewiston Orchards (Camp, 1976) occurs chiefly in that part of the Lewiston Basin in western Idaho. It underlies the plateau surface on which the town of Lewiston Orchards, Idaho, is built and is particularly well exposed above a sedimentary interbed in roadcuts at 380 m (1,250 ft) along Thain Road, near the center of sec. 8, T. 35 N., R. 5 W., Lewiston Orchards North quadrangle. Here the unit, consisting of one flow, is 37 m thick; elsewhere it averages 10 to 15 m thick. Most of the basalt of Lewiston Orchards is rather coarse grained and sparsely plagioclase-phyric, with phenocrysts rarely as large as 1 cm. Olivine is visible in hand specimen. A chemical analysis of the Lewiston Orchards (table 2, No. 23) shows it to be relatively rich in MgO and poor in K_2O. Definite feeder dikes have not yet been recognized, although possible feeders occur in the Lewiston Basin (Camp, 1976).

The basalt of Slippery Creek, a name suggested by S. M. Price (oral commun., 1976), is well exposed at the head of Slippery Creek (NE¼ sec. 21, T. 7 N., R. 46 E., Black Butte quadrangle, Wash.) and is the upper flow along the southern part of Weissenfels Ridge, particularly in sec. 32, T. 8 N., R. 46 E., Weissenfels Ridge and Black Butte quadrangles. It covers most of the plateau surface in extreme southeast Washington south of Asotin Creek and north of Anatone, averaging about 10 m thick. It includes the Uniontown-3 flow of Camp (1976). The Slippery Creek contains moderately abundant plagioclase phenocrysts 3 mm or less in length. At least one flow has much groundmass olivine visible with a hand lens, probably more than any other flow in the Columbia River Basalt Group that we have seen. The Slippery Creek has a chemical composition that differs from other flows in the Saddle Mountains Basalt (table 2, No. 22). Feeder dikes have not been found.

One or more flows near Anatone, Wash., are poorer in olivine than typical basalts of Lewiston Orchards or Slippery Creek but occur at a similar stratigraphic position; they are here included within the Weissenfels Ridge Member. These flows are of the Lolo chemical type (table 2, No. 18). A possible feeder dike occurs on a hillside near the mouth of Hackberry Gulch, in the NE¼SE¼ sec. 30, T. 7 N., R. 46 E., Black Butte quadrangle (S. M. Price, written commun., 1977).

ESQUATZEL MEMBER

The name Esquatzel Member is here applied to a phyric basalt flow occurring in Esquatzel Coulee near the community of Mesa, 40 km north of Pasco, Wash. The type locality is 1 km north of Mesa, on a hillslope on the north side of Esquatzel Coulee, at an elevation between 223 and 241 m (730–790 ft) in the NW¼NW¼ sec. 25, T. 13 N., R. 30 E., Mesa quadrangle, Franklin County, south-central Washington (pl. 1, fig. *L*). Here the Esquatzel rests with erosional unconformity on the Priest Rapids Member and is overlain by the

Pomona Member. A more accessible reference locality that better exposes lithology but lacks definitive contact relations is a prominent roadcut on the south side of Esquatzel Coulee in Mesa, in the SW¼NW¼ sec. 25, T. 13 N., R. 30 E. The Esquatzel Member fills a shallow valley eroded into the Priest Rapids Member throughout the Mesa area.

Remnants of one or more intracanyon flows correlated petrographically and chemically with the type Esquatzel occur along an ancestral Snake River canyon from Devils Canyon upstream to the mouth of New York Gulch (Swanson and others, 1977; 1979), a distance of about 52 km (pl. 1, fig. *L*).

The Esquatzel Member contains phenocrysts and glomerophyric clots of strongly zoned plagioclase and clinopyroxene less than 5 mm in diameter. The distribution of phenocrysts is quite irregular; some hand samples are highly phyric and others are nearly aphyric, as is well shown at the reference locality in Mesa. The member has a distinctive chemical composition (table 2, No. 24).

The Esquatzel averages 10 m in thickness but reaches 50 m in some canyon-filling remnants. It has normal magnetic polarity (Choiniere and Swanson, 1979).

A source for the Esquatzel Member has not been found with certainty. Its occurrence far up the ancestral Snake River canyon suggests the probability of a source in the eastern part of the Columbia Plateau. On the other hand, three small (less than a 5-m diameter) columnar-jointed knobs surrounded by Holocene sand south of Eltopia in T. 11 N., R. 30 E. (Swanson and others, 1977, 1979) have Esquatzel-type petrography and chemistry. The knobs are alined in a northwest direction, similar to the trend of known dikes in the area, suggesting the remote possibility that they are eroded pluglike bodies protruding above the neighboring Elephant Mountain Member. Alternatively, they may be glacial erratics deposited during the Missoula floods in late Pleistocene time. Paleomagnetic studies could determine if the blocks have been rotated after cooling. The largest (northernmost) of these knobs was destroyed by blasting during preparation of new farmland in 1975.

The Esquatzel Member is probably equivalent to the informal Gable Mountain member of Atlantic Richfield Hanford Co. (1976), as judged by stratigraphic position, chemical composition, and magnetic polarity.

POMONA MEMBER

Schmincke (1967a) gave the name Pomona Basalt to a prominent, easily recognized flow that is widespread in south-central Washington and adjacent Oregon. We hereby formalize the name as the Pomona Member and designate the type locality as that from which Schmincke named the unit, specifically, roadcuts along Canyon Road (old Highway 97) and a nearby quarry in the NE¼ sec. 17, T. 14 N., R. 19 E., Pomona quadrangle, near the community of Pomona, Yakima County, south-central Washington (pl. 1, fig. *M*). Neither the base nor the top of the member is exposed at the type locality, but many exposures in adjacent areas show that the Pomona is interbedded with volcaniclastic sedimentary rocks of the Ellensburg Formation (Waters, 1955, pl. 1 [his Wenas flow is the Pomona]). The Esquatzel Member contains the youngest flow known to underlie the Pomona; this relation is exposed at the type locality of the Esquatzel. The Elephant Mountain Member contains the oldest flow known to overlie the Pomona, as indicated by relations along Rattlesnake Ridge east of Donald Pass (secs. 19–22, T. 12 N., R. 20 E., Elephant Mountain quadrangle) and at many other places in south-central Washington.

The member covers much of the southwestern part of the Columbia Plateau from the Saddle Mountains in south-central Washington (fig. 1; pl. 1, fig. *M*) to northernmost Oregon. It extends west along the Columbia River at least as far as Mosier, Oreg. (pl. 1) (Schmincke, 1967a) and may have reached nearly to the Pacific Ocean, as it is similar in all respects to the basalt of Pack Sack Lookout in southwest Washington (Snavely and others, 1973). Recent work indicates its presence in nearly 50 remnants of an intracanyon flow along an ancestral Snake River canyon from Asotin in extreme southeast Washington to the Pasco Basin in the central Columbia Plateau (pl. 1, fig. *M*; Swanson and Wright, 1976b; Swanson and others, 1977, 1979). The flow presumably advanced down the canyon from a source in western Idaho, emptying from the mouth of the canyon in the lower part of what is now Old Maid Coulee (Tps. 12 and 13 N., Rs. 30 and 31 E., Mesa East quadrangle) into a broad basin across which the flow moved as a sheetflood. A peperite is commonly developed where the Pomona ploughed into unconsolidated vitric ash near the margin of the flow (Schmincke, 1967a).

Good reference localities for the Pomona Member in Washington, in addition to those given by Schmincke (1967a, b), include (1) two cooling units overlain by the Elephant Mountain Member in roadcuts along Highway 17, 1 km north of Mesa, (2) peperite and invasive relations into a vitric tuff in the Ellensburg Formation in railroad cuts and natural exposures 3 to 6 km upstream from Ice Harbor Dam on the north side of the Snake River from the center of sec. 18 upriver to the west half of sec. 4, T. 9 N., R. 32 E., Levey SE quadrangle, (3) spectacular columnar jointing in a remnant of intracanyon flow in roadcut and roadside quarry along Hastings Hill Road

NE¼NE¼ sec. 3, T. 13 N., R. 40 E., Hay quadrangle, and (4) columnar remnant of intracanyon flow in quarry just east of Silcott, SW¼ sec. 21, T. 11 N., R. 45 E., Silcott quadrangle.

The Pomona Member consists in most places of a single sparsely phyric flow of Pomona chemical type (table 2, No. 25; Wright and others, 1973). The flow can be subdivided into two units in a few places, as 6 km upstream from Ice Harbor Dam and 1 km north of Mesa, but these units are not traceable far, are commonly associated with peperites and invasive flows (Schmincke, 1967a), and presumably represent gushes of one major eruptive event.

The member is characterized petrographically by small commonly wedge-shaped phenocrysts of plagioclase (generally less than 5 mm long), together with scattered clinopyroxene and olivine. Some plagioclase phenocrysts are riddled with clinopyroxene inclusions. Modal analyses show low plagioclase-pyroxene ratios, generally less than 1 (Schmincke, 1967a). Locally, the flow contains large clots (to 10 cm or more across) of plagioclase, pyroxene (including very rare hypersthene), and olivine; the best locality for observing such clots is in a quarry on the east side of Devils Canyon (SW¼SW¼ sec. 22, T. 13 N., R. 34 E., Lower Monumental Dam quadrangle).

The Pomona averages about 30 m thick outside the ancestral Snake River canyon. Its maximum preserved thickness in the ancient canyon is 110 m near the mouth of the Tucannon River (fig. 1). It has reversed magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979) and is about 12 m.y. old (McKee and others, 1977). A definite feeder dike has not been found, although a dike matching many of the Pomona's characteristics cuts Grande Ronde Basalt along Wapshilla Creek, a tributary of the lower Salmon River draining Craig Mountain, western Idaho (pl. 1, fig. *M*; S. P. Reidel, oral commun., 1976, 1978).

Schmincke (1967a) studied the Pomona in detail, and his paper is the best source of additional information.

ELEPHANT MOUNTAIN MEMBER

Waters (1955) named the Elephant Mountain flow from exposures near Elephant Mountain (chiefly in secs. 22 and 27, T. 12 N., R. 20 E., Elephant Mountain quadrangle), on Rattlesnake Ridge about 16 km southeast of Yakima, Yakima County, south-central Washington. Schmincke (1967a) considered this flow to be regionally extensive throughout south-central Washington and redesignated it the Elephant Mountain Basalt Member. He recognized an overlying but otherwise similar flow at several places in south-central Washington from the eastern Horse Heaven Hills north to Sentinel Gap and named it the Ward Gap Basalt Member from outcrops at

Ward Gap (NE¼SE¼ sec. 20, T. 8 N., R. 24 E., Prosser quadrangle), 6.5 km west of Prosser, Wash.

We here assign both Schmincke's Elephant Mountain and Ward Gap Basalt Members to the Elephant Mountain Member, the procedure followed by Atlantic Richfield Hanford Co. (1976). The type locality (pl. 1, fig. *N*) is that designated by Waters (1955) on Elephant Mountain. The name Ward Gap is abandoned and the flow is included in the Elephant Mountain because of its similarity to the type Elephant Mountain. Ward Gap is designated a reference locality for the member.

Only two flows are known to occur in the Elephant Mountain Member west of the Columbia River, but three or more flows of similar characteristics occur in the same stratigraphic position at several localities east of the river in Washington and are assigned to the member. Such flows crop out in the area 5 km south of Eltopia (NE¼ sec. 23, T. 11 N., R. 30 E., Eltopia quadrangle) and just south of Scooteny Reservoir (secs. 26 and 27, T. 14 N., R. 30 E., Mesa quadrangle).

The member occurs as a sheetlike flow in the Lewiston Basin south of Clarkston, Wash. (Camp, 1976; Swanson and others, 1977, 1979) and appears to spill into an ancestral Snake River channel in the basin about 7 km west of Clarkston (sec. 22, T. 11 N., R. 45 E., Silcott quadrangle). Remnants of one or more intracanyon flows occur along an ancestral Snake River canyon from a point about 20 km upriver from Clarkston across the Lewiston Basin to a point 5 km north-northwest of Silcott, and between the mouth of the Palouse River and Devils Canyon (fig. 1; Swanson and others, 1977, 1979). The Wenaha flow of Walker (1973), in the Grande Ronde River valley near Troy, Oreg. (fig. 1; Ross, 1978), is tentatively correlated with the Elephant Mountain on the basis of chemistry, magnetic polarity, and gross stratigraphic position, and because a series of intracanyon flow remnants of the member in the drainage of Asotin Creek nearly connect the Grande Ronde and Lewiston Basin areas (Swanson and others, 1977, 1979).

The member is composed of nearly aphyric generally fine-grained flows of Elephant Mountain chemical type (table 2, No. 26: Wright and others, 1973). Its thickness averages about 30 m; it reaches 150 m in intracanyon remnants along Asotin Creek (sec. 26 and 34, T. 10 N., R. 44 E., Potter Hill quadrangle) and 100 m along the Snake River near Skookum Canyon (secs. 20 and 21, T. 13 N., R. 35 E., Haas quadrangle). The member has transitional and normal magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979) and is about 10.5 m.y. old (McKee and others, 1977).

The Elephant Mountain is only slightly less extensive than the

Pomona in south-central Washington and adjacent Oregon (Schmincke 1967a, fig. 20; Shannon and Wilson, Inc., 1973), but there is no evidence that it extended westward through the Columbia River Gorge (pl. 1, fig *N*).

All flows in the member are thought to have been erupted in extreme southeast Washington and adjacent Oregon and (or) Idaho (pl. 1, fig. *N*). A feeder dike occurs discontinuously from sec. 4, T. 6 N., R. 42 E., Diamond Peak quadrangle, southeast Washington, to at least as far south as sec. 19, T. 5 N., R. 43 E., Troy quadrangle, northeast Oregon (Ross, 1978; Swanson and others, 1977, 1979). Another dike of Elephant Mountain chemical type occurs in the headwaters of Cache Creek, extreme northeast Oregon (S. P. Reidel, oral commun., 1976, 1978).

BUFORD MEMBER

Walker (1973) gave the informal name Buford flow to a fine- to medium-grained very sparsely plagioclase- and olivine-phyric flow overlying sedimentary deposits in the Buford Creek area of extreme northeast Oregon. Subsequent work (Ross, 1978; Price, 1977; Swanson and others, 1977, 1979) showed that this flow extends north and west from Buford Creek and that it is of post-Elephant Mountain age, judged by stratigraphic relations in the Grande Ronde Valley.

The Buford flow is hereby raised to member status, with its type locality as designated by Walker (1973) about 7.5 km north-northeast of Flora, Oreg. (fig. 1), in a small quarry on the east side of Highway 3 at 1,225 m (4,020 ft) elevation in the NE¼NE¼ sec. 2, T. 5 N., R. 44 E., Flora quadrangle, Wallowa County, extreme northeast Oregon (pl. 1, fig. *O*). A good reference locality is above a white tuff in a roadcut along Highway 129, 8 km northeast of Anatone, Wash. (fig. 1), in the SE¼NW¼ sec. 5, T. 8 N., R. 46 E., Weissenfels Ridge quadrangle, southeast Washington.

The Buford Member everywhere consists of one basalt flow, generally 20 to 30 m thick, with reversed magnetic polarity (Price, 1977; Ross, 1978; Swanson and Wright, unpub. data, 1977). The Buford has a major-element chemical composition (table 2, No. 27) similar to some flows in the Grande Ronde Basalt except that it has generally lower Na_2O for a given MgO content.

The Buford Member is the youngest known basalt on the plateau surface of extreme southeast Washington and northeast Oregon. The age relation of the Buford to the Ice Harbor and Lower Monumental Members is not clear. We believe that it is older than both, as it does not appear to have filled canyons eroded into the Elephant Mountain Member, as do the Ice Harbor and Lower Monumental Members. This implies that the Buford was erupted relatively soon after the

Elephant Mountain. The source for the Buford is unknown, but its distribution (pl. 1, fig. *O*) suggests extreme southeast Washington or adjacent parts of Idaho or Oregon.

ICE HARBOR MEMBER

Flows and minor tephra younger than the Elephant Mountain Member crop out along the lower Snake River in the Ice Harbor Dam area and were termed the flows at Ice Harbor Dam by Wright and others (1973). This name is here formalized as the Ice Harbor Member, and the type locality is designated as an abandoned quarry on the south side of the Snake River 2.6 km west of Ice Harbor Dam, in SE¼SE¼ sec. 22, T. 9 N., R. 31 E., Humorist quadrangle, Walla Walla County, southeast Washington (pl. 1, fig. *P*).

Two thick flows, separated by a deposit of tephra associated with several thin, discontinuous flows, occur above the Elephant Mountain Member in a shallow syncline at the type locality. The lower flow, about 15 m thick and markedly columnar, contains single phenocrysts and glomerocrysts of clinopyroxene, plagioclase, and olivine and has reversed magnetic polarity (Helz, 1978; Helz and others, 1976; Choiniere and Swanson, 1979). We informally designate this flow as the basalt of Martindale, a railroad siding on the north side of the Snake River in Franklin County about 3.5 km downstream from the type locality of the Ice Harbor Member. Reference localities, all in Washington, for the basalt of Martindale include (1) the highest cliffs along both sides of the Walla Walla River about 3 km west of Reese (fig. 1), in sec. 21, T. 7 N., R. 32 E., Zangar Junction quadrangle, (2) a quarry about 12 km west of Kennewick, in the SW¼NE¼ sec. 14, T. 8 N., R. 28 E., Badger Mountain quadrangle, and (3) exposures 5.5 km southwest of Eltopia along the east side of Highway 395, NW¼ sec. 27, T. 11 N., R. 30 E., Eltopia quadrangle. The basalt of Martindale is the most extensive of the informally named units in the Ice Harbor Member (Swanson and others, 1977, 1979).

The tephra, associated thin flows, and the overlying thick flow, totaling about 15 m in thickness above the Martindale flow, are sparsely phyric with respect to plagioclase, magnetite, and rarely olivine and have transitional to normal magnetic polarity (Helz, 1978; Helz and others, 1976; Choiniere and Swanson, 1979). These rocks are assigned to the informally named unit, basalt of Goose Island, named for a small island in the Snake River at the type locality of the member. A good reference locality for the basalt of Goose Island is a quarry 9.5 km northwest of Ice Harbor Dam, in the SW¼SE¼ sec. 29, T. 10 N., R. 31 E., Levey SW quadrangle; drifting sand sometimes makes roads to this quarry impassable to all but four-wheel-drive vehicles.

The basalts of Martindale and Goose Island have distinctly different chemistries (Helz, 1978; table 2, No. 29–30), designated Ice Harbor 1 chemical type and Ice Harbor 2 chemical type, respectively, by Wright and others (1973). The names of these chemical types are hereby changed to Martindale and Goose Island chemical types, respectively, to agree with the informal stratigraphic terminology.

North of the Ice Harbor area, sparsely phyric flows with olivine and plagioclase phenocrysts and glomerocrysts to 2 cm in diameter and normal magnetic polarity (Helz, 1978; Helz and others, 1976; Choiniere and Swanson, 1979) occur stratigraphically above the Elephant Mountain Member and below the basalt of Goose Island. The relation of these flows, which have a chemistry termed the Basin City chemical type by Helz and others (1976) (table 2, No. 28), to the basalt of Martindale is uncertain; field relations suggest that the basalt of Basin City is older (Helz and others, 1976; Helz, 1978). These olivine and plagioclase-phyric flows are considered to be part of the Ice Harbor Member and are here assigned to the informal unit, the basalt of Basin City, named for a small community 11 km west of Mesa, Franklin County. Reference localities for the basalt of Basin City include (1) the area just northwest of two small lakes in the SW¼NE¼ sec. 20, T. 12 N., R. 30 E., Mesa quadrangle, 7 km northwest of Eltopia, and (2) the area 1.5 km north of Basin City in secs. 14 and 24, T. 13 N., R. 29 E., Mesa quadrangle. The Basin City occupies a narrow graben cutting the Elephant Mountain Member at both of these localities (Swanson and others, 1975).

The Ice Harbor Member is generally about 15 m, nowhere more than 30 m, thick. It occurs as a narrow belt of outcrops separated by younger alluvial deposits extending about 90 km north-northwest from near the Washington-Oregon border south of Reese (fig. 1; Swanson and others, 1977, 1979). The member caps the highest bluff on the west side of Wallula Gap (Ledgerwood and others, 1973; Swanson and others, 1975) and occurs along the Red Mountain-Badger Mountain line of plunging anticlines between Benton City and Wallula Gap and in a core hole (DDH–3) in north Richland (Myers, 1973; Atlantic Richfield Hanford Co., 1976); only the basalt of Martindale has been identified at these three localities.

Many dikes and vent areas for flows in the Ice Harbor Member have been located along the elongate, north-northwest belt of major outcrops (pl. 1, fig. *P*; Swanson and others, 1975; 1977, 1979). The member is about 8.5 m.y. old (McKee and others, 1977) and is the product of the youngest known eruptive activity in the central Columbia Plateau.

Helz (1978) has completed an exhaustive study of the Ice Harbor Member, stressing petrogenetic implications, and her work should be consulted by those interested in further information concerning the member.

LOWER MONUMENTAL MEMBER

A nearly aphyric flow overlies poorly consolidated river gravel 80 m above the present Snake River just south of Lower Monumental Dam, Walla Walla County, southeast Washington. Field relations show that this flow partly filled an ancestral Snake River canyon eroded into rocks as young as the Elephant Mountain Member. The flow is here named the Lower Monumental Member; its type locality is in a prominent roadcut 1 km south of the dam in the NW¼SE¼ sec. 3, T. 12 N., R. 34 E., Lower Monumental Dam quadrangle (pl. 1, fig. *Q*), where the member is about 30 m thick.

The age relation of the Ice Harbor and Lower Monumental Members cannot be firmly established on stratigraphic grounds. Our preferred interpretation is that the Lower Monumental is younger, as it occurs within a canyon whose lower end appears to be eroded into the Ice Harbor Member. Whole-rock potassium-argon age determinations support this interpretation, indicating an age of about 6 m.y. for the Lower Monumental Member, about 2.5 m.y. younger than the Ice Harbor (McKee and others, 1977).

Many remnants of one or more intracanyon flows correlated with the Lower Monumental occur along the present course of the Snake River from the type locality upstream to the mouth of Asotin Creek, a distance of about 150 km along the course of the river (pl. 1, fig. *Q*; Swanson and others, 1977, 1979). The member averages about 25 m thick; locally it thickens to about 60 m. It has normal magnetic polarity (Choiniere and Swanson, 1979).

The member is compositionally similar to the Lolo chemical type but is distinguished from it chiefly by slightly higher Na_2O and K_2O (table 2, No. 31) contents. It can be confused with the Elephant Mountain Member in the field, but inspection with a hand lens shows moderately abundant (about 2.5–3 percent) microphenocrysts of olivine in the Lower Monumental not generally seen in the Elephant Mountain Member.

The Lower Monumental Member is interpreted to have been erupted in the eastern part of the Columbia Plateau and to have flowed down the ancestral Snake River as far as the type locality. It was produced by the youngest known volcanic activity in the Columbia River Basalt Group.

Camp (1976), with the concurrence of Swanson and Wright, interpreted a dike in the Lewiston Basin as a feeder for the Lower Monumental Member. However, this dike has been found to extend up the northwest wall of Tenmile Creek Canyon (about 6 km southeast of Asotin) to, but not through, the capping Pomona Member. We now believe that the dike is older than the Pomona and may be a feeder for flows in the Weissenfels Ridge Member.

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