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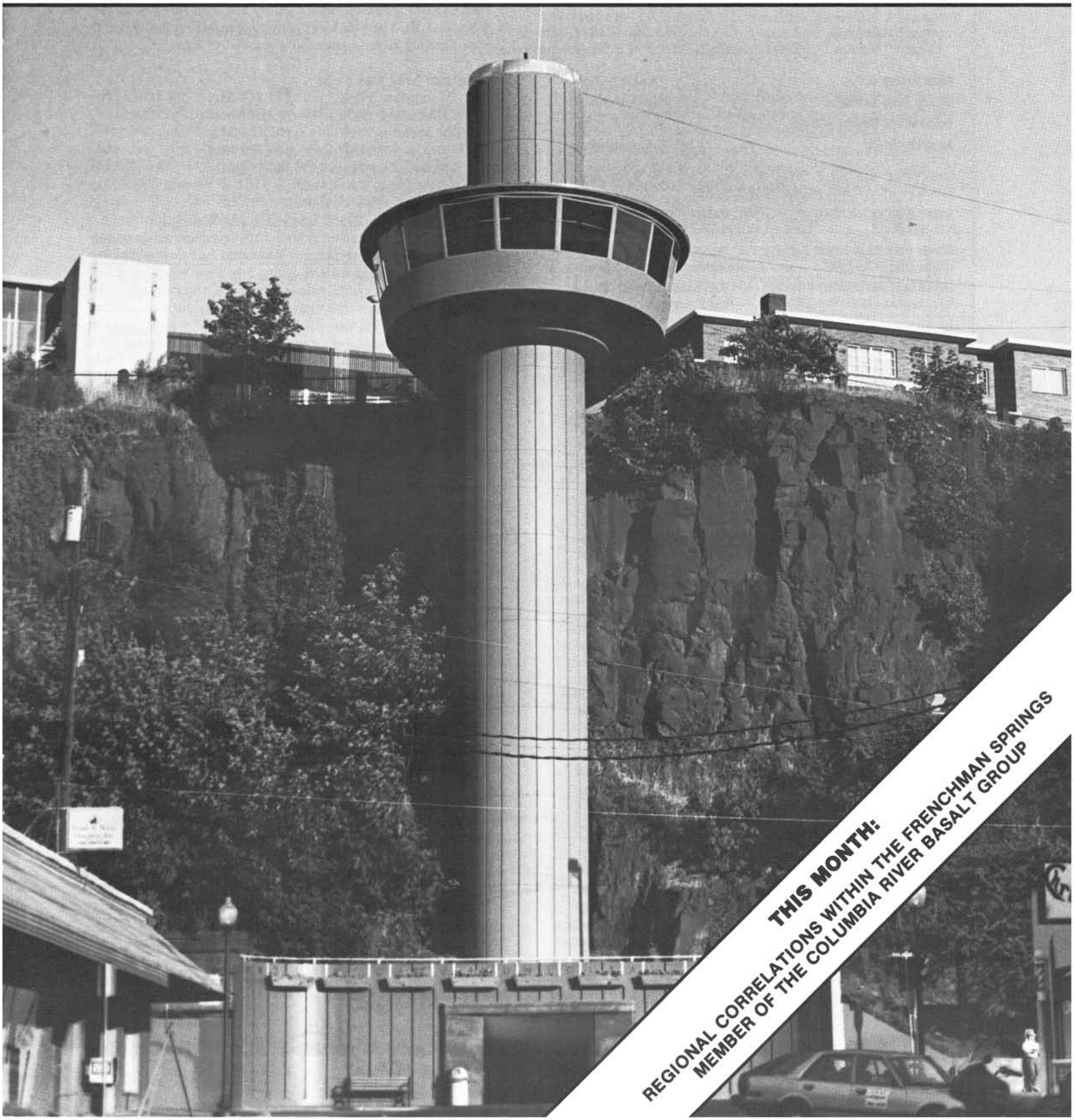

THIS MONTH:

REGIONAL CORRELATIONS WITHIN THE FRENCHMAN SPRINGS MEMBER OF THE COLUMBIA RIVER BASALT GROUP

OREGON GEOLOGY

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The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of their bibliographic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Frenchman Springs Member basalt flow at Oregon City Municipal Elevator, a local landmark south of Portland. Base of the elevator is at the Vantage horizon, and upper landing is at the top of the lower of two flows of the basalt of Ginkgo. See discussion in article beginning on next page.

OIL AND GAS NEWS

Columbia County — Mist Gas Field

Reichhold Energy drilled and completed Crown Zellerbach 12-1 in sec. 1, T. 5 N., R. 5 W. The well was drilled to a total depth of 1,721 ft and completed on June 30 at 1.1 MMcfd. Next, the company will drill Crown Zellerbach 31-16 in sec. 16, T. 5 N., R. 4 W.

ARCO spudded Columbia County 23-19 on July 1 in sec. 19, T. 6 N., R. 5 W. The well has a proposed total depth of 3,200 ft. Taylor Drilling is the contractor.

Production: Mist Gas Field

January 1985:	271,717 Mcf
February 1985:	242,077 Mcf
March 1985:	301,885 Mcf
April 1985:	300,775 Mcf
May 1985:	340,793 Mcf

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
318	Reichhold Energy Columbia County 24-23 009-00161	SW¼ sec. 23 T. 6 N., R. 5 W. Columbia County	Location; 2,600.
319	ARCO Columbia County 14-18 009-00162	SW¼ sec. 18 T. 4 N., R. 3 W. Columbia County	Application; 12,000.

□

BLM report identifies resource-exploration targets in Malheur County

Eight northern Malheur County areas of possible exploration interest for base and precious metals, such as gold, silver, mercury, arsenic, copper, or lead, were identified in a study recently published by the U.S. Bureau of Land Managment (BLM). The study, entitled *Geology—Energy—Mineral Resource Survey, Mahogany Planning Unit, Northern Malheur Resource Area, Vale District, Oregon,* is now available from BLM in microfiche form for $7.

Barringer Resources, Inc., of Golden, Colorado, conducted the study for BLM as a so-called "G-E-M" study (geology-energy-minerals), assessing the area's resource potential with emphasis on metallic-mineral and geothermal resources. For this purpose, published geological, geophysical, and geochemical data were compiled, stream-sediment and heavy-mineral samples and soil and rock-chip samples were collected and analyzed, and the analytical data were then evaluated statistically. Regional structural trends were evaluated through use of Landsat multispectral scanner data.

The resulting report contains 114 pages of interpretive text, a data appendix of almost the same length, and 16 separate plates including geologic and sample-location maps, distribution maps for 13 resource minerals, and a Landsat interpretation map that combines Landsat lineaments, volcanic features, and geochemically anomalous areas.

In its conclusions, the report recommends further exploration primarily for the Three Fingers Rock area and the Alkali Creek-Bishop Ranch area. Of secondary significance are the anomalous areas at Whiskey Creek, Mahogany Gap, Bannock Ridge, Spring Creek, Succor Creek, and Diamond Butte. □

Regional correlations within the Frenchman Springs Member of the Columbia River Basalt Group: New insights into the middle Miocene tectonics of northwestern Oregon

by Marvin H. Beeson, Geology Department, Portland State University, Portland, Oregon 97207; and Karl R. Fecht, Stephen P. Reidel, and Terry L. Tolan, Geosciences Group, Rockwell International, P.O. Box 800, Richland, Washington 99352

ABSTRACT

The Frenchman Springs Member of the Miocene Columbia River Basalt Group consists of generally plagioclase-phyric and chemically distinctive basalt flows that cover approximately 179,000 km^2 in Oregon and Washington. A regional stratigraphic framework that divides the Frenchman Springs Member into six distinctive units is developed on the basis of composition (Cr, P_2O_5, TiO_2, and MgO), paleomagnetic data, stratigraphic position, and, to a lesser extent, lithology.

We have found that the Frenchman Springs Member does not interfinger with any other Wanapum Basalt members or with the Grande Ronde Basalt. This finding is based on reevaluation and reinterpretation of the Benjamin Gulch section in southeastern Washington, which was previously cited as the only known site where Wanapum and Grande Ronde Basalt interfinger. Our reinterpretation provides significantly different constraints on and implications for the petrogenesis of the Columbia River basalts.

The distribution of individual, successive Frenchman Springs units is useful in interpreting the middle Miocene tectonics of western Oregon. The Frenchman Springs units originated from fissure eruptions in eastern Oregon and Washington, flowed westward, and were funneled through the Miocene Cascade Range by southwest-trending synclinal troughs that appear to be a westward extension of the Yakima fold belt. The two principal paths were along the Dalles-Mount Hood and Mosier-Bull Run synclinal troughs. The Frenchman Springs flows encountered two major northwest-trending structural zones in the present-day Willamette Valley area, the Portland Hills-Clackamas River zone and the Mount Angel-Gales Creek zone, that deflected or defeated the advance of certain flows. The absence of Frenchman Springs flows in the center of the Willamette Valley suggests that it was not an active tectonic depression in middle Miocene time. The Miocene Oregon Coast Range was penetrated by Frenchman Springs flows in two areas: (1) along the present-day path of the Columbia River, and (2) from west of Salem, Oregon, to the ocean near Newport, Oregon.

INTRODUCTION

The Frenchman Springs Member of the Wanapum Basalt consists of up to 21 flows that were erupted from fissures and vents in northeastern Oregon and eastern Washington during middle Miocene time about 15 million years (m.y.) ago (Swanson and others, 1979b) (Figure 1). Together, these Frenchman Springs flows cover approximately 179,000 km^2 in Oregon and Washington and have an estimated volume of 15,600 km^3. The Frenchman Springs Member is principally distinguished by its stratigraphic position, composition (Wright and others, 1973; Swanson and others, 1979b), and the presence of plagioclase phenocrysts or glomerocrysts. However, plagioclase phenocryst/glomerocryst abundance, thickness, and outcrop appearance of these flows over their areal extent are variable. Furthermore, the number of flows per section is highly variable, and no one section contains all known flows. These variabilities have made it difficult to develop a reliable regional stratigraphy based solely on physical characteristics, thus limiting the usefulness of units as they have been defined by

SERIES		GROUP	SUB-GROUP	FORMATION	MEMBER	K-Ar AGE (m.y.)	MAGNETIC POLARITY
MIOCENE	UPPER	COLUMBIA RIVER BASALT GROUP	YAKIMA BASALT SUBGROUP	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6	N
					Erosional Unconformity		
					ICE HABOR MEMBER	8.5	
					Basalt of Goose Island		N
					Basalt of Martindale		R
					Basalt of Basin City		N
					Erosional Unconformity		
					BUFORD MEMBER		R
	MIDDLE				ELEPHANT MOUNTAIN MEMBER	10.5	R,T
					Erosional Unconformity		
					POMONA MEMBER	12	R
					Erosional Unconformity		
					ESQUATZEL MEMBER		N
					Erosional Unconformity		
					WEISSENFELS RIDGE MEMBER		
					Basalt of Slippery Creek		N
					Basalt of Lewiston Orchards		N
					ASOTIN MEMBER		N
					Local Erosional Unconformity		
					WILBER CREEK MEMBER		
					Basalt of Lapwai		N
					Basalt of Wahluke		N
					UMATILLA MEMBER		
					Basalt of Sillusi		N
					Basalt of Umatilla		N
					Local Erosional Unconformity		
				WANAPUM BASALT	PRIEST RAPIDS MEMBER	14.5	
					Basalt of Lolo		R
					Basalt of Rosalia		R
					ROZA MEMBER		T,R
					FRENCHMAN SPRINGS MEMBER		
					Basalt of Lyons Ferry		N
					Basalt of Sentinel Gap		N
					Basalt of Sand Hollow		N
					Basalt of Silver Falls		N,E
					Basalt of Ginkgo		E
					Basalt of Palouse Falls		N
					ECKLER MOUNTAIN MEMBER		
					Basalt of Shumaker Creek		N
					Basalt of Dodge		N
					Basalt of Robinette Mountain		N
	LOWER			GRANDE RONDE BASALT			N_2
						15.5 - 16.5	R_2
				PICTURE GORGE BASALT	(Basalt of Dayville, Basalt of Monument Mountain, Basalt of Twickenham)	(14.6-15.8)	N_1
							R_1
				IMNAHA BASALT		16.5 - 17.0	R_1
							T
							N_0
							R_0

Figure 1. Stratigraphic nomenclature, age, and magnetic polarity for the Columbia River Basalt Group, as revised by Swanson and others (1979b) and modified by the authors. N = normal magnetic polarity; R = reversed magnetic polarity; T = transitional magnetic polarity; E = excursional magnetic polarity.

previous workers in both local and regional geologic investigations (e.g., resolution of structural problems, timing and rate of deformation studies, and regional tectonic rotation studies).

The purpose of this paper is threefold: (1) to provide basic information from our extensive studies on the composition, paleomagnetics, lithology, and stratigraphy of the Frenchman Springs Member; (2) to introduce an informal stratigraphic nomenclature* for these Frenchmån Springs units that is applicable to the entire areal extent of the member; and (3) based on this work, to present new evidence on the distribution of Frenchman Springs units that provides some constraints on the middle Miocene tectonics of the northern Oregon Cascade Range, Willamette Valley, and Oregon Coast Range.

FRENCHMAN SPRINGS MEMBER STRATIGRAPHY

Review of previous work

Mackin (1961, p. 12-13) originally proposed the name "Frenchman Springs Basalt Member" for the plagioclase-phyric flows exposed in Frenchman Springs Coulee (secs. 19-20 and 29-30, T. 18 N., R. 23 E., Grant County, south-central Washington, and defined the member on the basis of (1) stratigraphic position, (2) the presence of large plagioclase phenocrysts/glomerocrysts, and (3) intraflow structures. Subsequent work (Bingham and and Grolier, 1966; Lefebvre, 1966; Diery and McKee, 1969; Kienle, 1971) utiltized these field criteria to identify the "Frenchman Springs Basalt Member" throughout much of the central/western Columbia Plateau and western Oregon.

Wright and others (1973) distinguished a Frenchman Springs chemical type which, when combined with field criteria, provides the basis for reliable identification of this member. Numerous other workers (Meyers, 1973; Ledgerwood and others, 1973; Swanson and Wright, 1976; Swanson and others, 1977; Bentley, 1977a,b; Hammond and others, 1977; Grolier and Bingham, 1978; Beeson and Moran, 1979; Swanson and others, 1979a,b; Bentley and others, 1980; Gardner and others, 1981; Reidel and Fecht, 1981; and Swanson and others, 1981) have provided data that have helped delineate the approximate areal extent as well as provide descriptions of the physical characteristics of Frenchman Springs flows.

Previous workers have successfully locally subdivided the Frenchman Springs Member (Figure 2) on the basis of texture and primary structures (Mackin, 1961) and on the basis of plagioclase phenocryst abundance and relative stratigraphic position (Bentley, 1977a,b; Bentley and others, 1980; Bentley and Campbell, 1983); but classification by such criteria has proved unreliable over the whole Columbia Plateau because of the variability of these features.

*Units described here are presented informally. They will be introduced formally with additional data at a later date.

MACKIN (1961, p.8)	BENTLEY (1977a, p.361)	BENTLEY AND CAMPBELL (1983)	THIS PAPER
			BASALT OF LYONS FERRY
SENTINEL GAP FLOW	UNION GAP FLOWS	FLOWS OF UNION GAP	BASALT OF SENTINEL GAP
SAND HOLLOW FLOW	KELLEY HOLLOW FLOWS SAND HOLLOW FLOWS	FLOW OF KELLEY HOLLOW† FLOW OF BADGER GAP**	BASALT OF SAND HOLLOW*
	MARY HILL FLOW		BASALT OF SILVER FALLS
GINKGO FLOW	GINKGO FLOW	GINKGO FLOWS	BASALT OF GINKGO
	PALOUSE FALLS FLOW		BASALT OF PALOUSE FALLS

† Equivalent to the Sand Hollow and Sentinel Gap Flows of Mackin (1961)
** Sand Hollow Flow of Bentley (1977a)
* Includes Basalt of Sheffler (Swanson and others, 1980)

Figure 2. Chart showing correlation of previously defined units of the Frenchman Springs Member to those of this paper.

Frenchman Springs Member stratigraphy and proposed nomenclature

Detailed mapping of Frenchman Springs flows in western Oregon (Beeson and Tolan, unpublished data, 1980) and extensive subsurface/surface correlation investigations of the Frenchman Springs flows in south-central Washington (Reidel and Fecht, unpublished data, 1980) demonstrate that flows identifiable through lithology, stratigraphic position, and lateral tracing show chemical compositions that are consistent within narrow limits but that vary significantly between flows. Chromium (Cr), P_2O_5, TiO_2, and MgO prove to be the most useful for subdividing the Frenchman Springs. Compositional data are summarized in Table 1. These variations along with stratigraphic position allow us to subdivide the Frenchman Springs Member into six units that define a unique regional stratigraphy (Figure 3). Our stratigraphic synthesis is the result of analysis of measured sections from over 200 localities, including surface exposures and numerous boreholes from the Columbia Plateau and western Oregon and Washington.

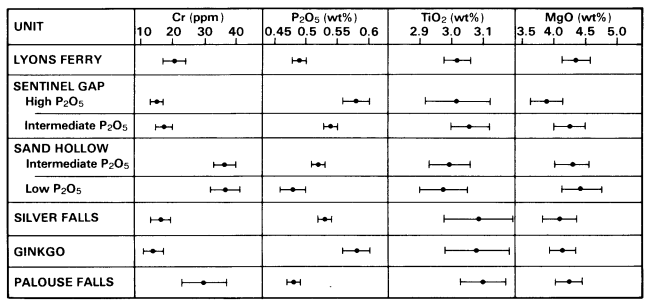


Figure 3. Diagram showing selected compositional variations among units of the Frenchman Springs Member with regard to stratigraphic position. Points represent mean concentrations, and the bar is one standard deviation on either side of the mean value (Table 1).

In addition, paleomagnetic data and lithologic descriptions were compiled for each of the six units to further characterize these subdivisions. Paleomagnetic data from Rietman (1966), Choiniere and Swanson (1979), Rockwell Hanford Operations (unpublished data, 1980-1985), Robert Simpson and James Magill (unpublished data, 1980 and 1982), and Sheriff (1984) are summarized in Table 1. Because these data record two distinctive excursions of the geomagnetic field and also more subtle secular variations in normal field directions, they can aid in stratigraphic determinations. Although the lithologic characteristics of some Frenchman Springs flows are highly variable and thus are not well suited for stratigraphic correlation, a summary of the most consistent and distinctive lithologic characteristics of each unit is presented in Table 1.

Basalt of Palouse Falls

The oldest known Frenchman Springs flow was originally identified by Bentley (1977a,b) and named the Palouse Falls flow after exposures found at Palouse Falls, Washington (Figure 4a). We adopt Bentley's usage and type locality (Table 1) and assign the name basalt of Palouse Falls to this unit. We redefine this unit, however, on the basis of criteria and characteristics presented in Table 1.

The areal distribution of the basalt of Palouse Falls (Figure 4a) is one of the most restricted and is centered on the Pasco

Table 1. *Summary of properties of Frenchman Springs units introduced in this paper.*

	BASALT OF PALOUSE FALLS	BASALT OF GINKGO	BASALT OF SILVER FALLS	BASALT OF SAND HOLLOW Low P_2O_5	BASALT OF SAND HOLLOW Intermediate P_2O_5	BASALT OF SENTINEL GAP Intermediate P_2O_5	BASALT OF SENTINEL GAP High P_2O_5	BASALT OF LYONS FERRY
NUMBER OF FLOWS	1	4(?)	4(?)	4	3(?)	2(?)	2	1
AREAL EXTENT	~26,400 km^2	~139,700 km^2	~60,600 km^2	~150,200 km^2		~52,900 km^2		~29,800 km^2
VOLUME	~590 km^3	~4190 km^3	~900 km^3	~7880 km^3		~1600 km^3		~450 km^3
PALEOMAGNETIC DATA: NUMBER OF SITES†	5	18	12	22	10	5	11	2
PALEOMAGNETIC DATA: INCLINATION	17.5°-25.1°	34.3°-44.9°	52.6°-69.6°	55.6°-64.2°	53.3°-74.5°	52.7°-60.7°	57.8°-63.6°	59.6°-66.2°
PALEOMAGNETIC DATA: DECLINATION	72.2°	155°-162.9°	21.3°-161.9°	352.3°-8.5°	330.5°-4.1°	13.6°-17.4°	4.9°-26.6°	348.0°-358.2°
LITHOLOGY	Sparsely phyric to phyric with tabular and equant plagioclase phenocrysts that are commonly less than 0.3 cm in size. Groundmass is fine grained and microphyric with acicular plagioclase microphenocrysts.	Flows are typically phyric to abundantly phyric with plagioclase glomerocrysts/ phenocrysts. Glomerocrysts commonly range from 0.3 to 2 cm in size. Groundmass is fine to medium grained and is sparsely microphyric with tabular plagioclase microphenocrysts.	Flows range from sparsely to abundantly phyric with plagioclase phenocrysts/ glomerocrysts that are commonly 0.3 to 1.5 cm in size. Groundmass is medium to coarse grained and is abundantly microphyric with equant and acicular plagioclase microphenocrysts.	Flows range sparsely to abundantly phyric with plagioclase phenocrysts/ glomerocrysts that commonly range from 0.3 to 3 cm in size. Uneven lateral and vertical distribution of phenocrysts/ glomerocrysts common. Groundmass is fine to coarse grained and is microphyric with acicular plagioclase microphenocrysts.	Flows are rarely to sparsely phyric with plagioclase phenocrysts/ glomerocrysts that commonly range from 0.3 to 2 cm in size. Groundmass is fine to medium grained and is sparsely microphyric with acicular plagioclase microphenocrysts.	Rarely to sparsely phyric with plagioclase phenocrysts/ glomerocrysts that range from 0.3 to 2 cm in size. Groundmass is fine to medium grained and is microphyric with equant and acicular plagioclase microphenocrysts.	Rarely phyric with plagioclase phenocrysts that are commonly less than 1 cm in size. Groundmass is fine grained and is sparsely to abundantly microphyric with acicular plagioclase microphenocrysts.	Rarely to sparsely phyric with plagioclase phenocrysts that range from 0.5 to 1 cm in size. Groundmass is medium grained and is microphyric with equant and acicular plagioclase microphenocrysts.
TYPE AND REFERENCE LOCALITIES	**Type Locality:** NW1/4, NW1/4, sec. 31, T. 14 N., R. 37 E. West side canyon, south of Palouse Falls. **Reference Localities:** NE1/4, sec. 24, T. 13 N., R. 36 E. One mile north of Lyons Ferry Bridge. SE1/4, sec. 33, T. 13 N., R. 34 E. Devils Canyon, west of Lower Monumental Dam.	**Type Locality:** SW1/4, NW1/4, sec. 19, T. 17 N., R. 23 E. Road cuts on State Route 10. **Reference Localities:** SE1/4, sec. 33, T. 13 N., R. 34 E. Devils Canyon, west of Lower Monumental Dam. SW1/4, sec. 13, T. 1 N., R. 19 E. North of Scott Canyon on east side of John Day River. Sec. 71, T. 2 S., R. 1 E. Road cuts along Interstate 205 between the bridge and rest area.	**Type Locality:** SW1/4, sec. 7, T. 8 S., R. 2 E. Exposure at upper North Fork Falls, North Fork of Silver Creek. **Reference Localities:** SW1/4, sec. 13, T. 1 N., R. 19 E. North of Scott Canyon on east side of John Day River. NW1/4, NW1/4, sec. 31, T. 14 N., R. 37 E. West side canyon, south of Palouse Falls. SE1/4, sec. 33, T. 13 N., R. 34 E. Devils Canyon, west of Lower Monumental Dam.	**Type Locality:** NW1/4, SE1/4, sec. 28, T. 17 N., R. 23 E. Cliff exposures above State Route 26. **Reference Localities:** SW1/4, sec. 13, T. 1 N., R. 19 E. North of Scott Canyon on east side of John Day River. Sec. 33, T. 7 N. R. 31 E. East side of Wallula Gap. NE1/4, sec. 60, T. 2 S., R. 2 E. On Center Street near Oregon City Shops.		**Type Locality:** Sec. 9 and 4, T. 16 N., R. 23 E. Outcrops along State Route 243. **Reference Localities:** Sec. 33, T. 7 N., R. 31 E. East side of Wallula Gap. SW1/4, sec. 13, T. 1 N., R. 19 E. North of Scott Canyon on east side of the John Day River. NW1/4, sec. 50, T. 2 S., R. 2 E. Outcrop on Glen Echo Road.		**Type Locality:** NE1/4, sec. 24, T. 13 N., R. 36 E. One mile north of Lyons Ferry bridge. **Reference Localities:** NW1/4, sec. 16, T. 11 N., R. 24 E. Road cuts above 2,640 ft. elev. on State Route 128. SW1/4 sec. 13, T. 1 N., R. 19 E. North of Scott Canyon on east side of the John Day River. NE1/4, sec. 7, T. 1 N., R. 11 E. Outcrops at 2,200 ft. elev. on Snakehead Point.

COMPOSITION

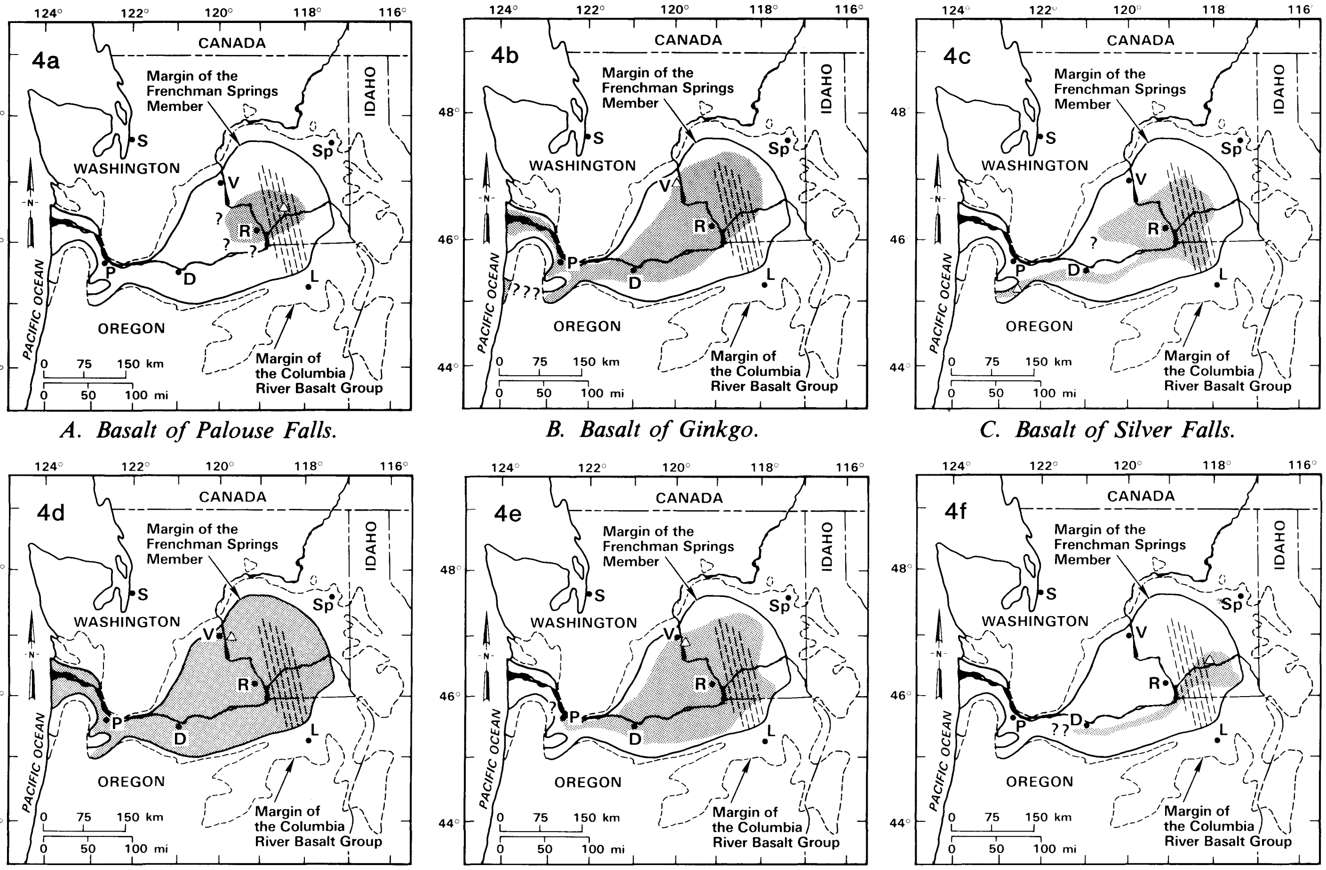
	Palouse Falls X̄	1σ	N	Ginkgo X̄	1σ	N	Silver Falls X̄	1σ	N	Sand Hollow Low P_2O_5 X̄	1σ	N
*SiO^2	51.26	0.60	16	51.55	0.55	38	51.46	0.63	24	51.82	0.49	55
Al_2O_3	14.15	0.38	16	14.38	0.31	38	14.65	0.43	24	14.58	0.33	55
TiO^2	3.10	0.07	16	3.08	0.10	38	3.09	0.11	24	2.91	0.07	55
FeO	14.66	0.29	16	14.19	0.37	38	14.21	0.52	24	13.79	0.51	55
MnO	0.24	0.02	16	0.23	0.02	38	0.23	0.03	24	0.22	0.02	55
CaO	8.29	0.24	16	8.03	0.28	38	8.01	0.30	24	8.18	0.26	55
MgO	4.26	0.20	16	4.16	0.21	38	4.12	0.24	24	4.42	0.26	55
K_2O	1.01	0.17	16	1.23	0.16	38	1.19	0.17	24	1.19	0.14	55
Na_2O	2.36	0.50	16	2.34	0.31	38	2.31	0.47	24	2.20	0.37	55
P_2O_5	0.48	0.01	16	0.58	0.02	38	0.53	0.01	24	0.48	0.02	55
**Cr	30.0	6.4	4	13.9	2.4	23	16.4	2.3	17	36.5	4.5	38

	Sand Hollow Intermediate P_2O_5 X̄	1σ	N	Sentinel Gap Intermediate P_2O_5 X̄	1σ	N	Sentinel Gap High P_2O_5 X̄	1σ	N	Lyons Ferry X̄	1σ	N
*SiO^2	51.60	0.63	35	51.86	0.34	20	51.92	0.63	19	52.04	0.52	7
Al_2O_3	14.43	0.31	35	14.20	0.32	20	14.45	0.36	19	14.32	0.34	7
TiO^2	2.98	0.06	35	3.06	0.06	20	3.02	0.10	19	3.02	0.04	7
FeO	13.81	0.63	35	14.12	0.38	20	14.02	0.46	19	13.80	0.46	7
MnO	0.22	0.03	35	0.22	0.01	20	0.23	0.03	19	0.20	0.01	7
CaO	8.20	0.23	35	7.89	0.23	20	7.82	0.29	19	7.91	0.24	7
MgO	4.31	0.27	35	4.28	0.20	20	3.91	0.24	19	4.38	0.20	7
K_2O	1.29	0.14	35	1.35	0.11	20	1.41	0.16	19	1.24	0.08	7
Na_2O	2.44	0.21	35	2.28	0.25	20	2.43	0.42	19	2.40	0.18	7
P_2O_5	0.52	0.01	35	0.54	0.01	20	0.58	0.02	19	0.49	0.01	7
**Cr	36.8	3.1	34	17.5	2.4	16	14.8	1.9	21	20.7	3.2	4

X̄ = Mean
1σ = One standard deviation
N = Number of analyses used in computing mean

* = All oxide values in wt%
** = Values in ppm

† = 3 to 10 cores per site. Kappa values range from 100 to greater than 600. Alpha 95 values range from 1.7 to 7.9.



A. *Basalt of Palouse Falls.* B. *Basalt of Ginkgo.* C. *Basalt of Silver Falls.*

D. *Basalt of Sand Hollow.* E. *Basalt of Sentinel Gap.* F. *Basalt of Lyons Ferry.*

Figure 4. Maps showing inferred original extent (stippled areas) of units of the Frenchman Springs Member defined in this paper. Known and inferred dike and vent areas are shown schematically by parallel dashed lines. Locations of type localities are designated by open triangles. Cities: Sp = Spokane; L = La Grande; R = Richland; V = Vantage; D = The Dalles; S = Seattle; P = Portland.

Basin. Compositionally it is characterized by low P_2O_5 and high Cr. The paleomagnetic orientation of this unit appears to be excursional and unique among Frenchman Springs units (Table 1).

Basalt of Ginkgo

Mackin (1961) named the basal Frenchman Springs flow at Ginkgo State Park near Vantage, Washington, the Ginkgo flow (Figure 4b). We adopt Mackin's usage and type locality (Table 1) and assign the name basalt of Ginkgo to this unit. We redefine this unit, however, on the basis of criteria and characteristics presented in Table 1. The basalt of Ginkgo has a wide distribution (Figure 4b) and is generally the basal unit except where the basalt of Palouse Falls is present. The basalt of Ginkgo can usually be distinguished from the overlying basalt of Silver Falls by being much less microphyric (Table 1). Paleomagnetically, the basalt of Ginkgo is distinctive because it records an excursion of the geomagnetic field (Table 1), but as a few cores from two flows in the basalt of Silver Falls show similar directions (Robert Simpson and James Magill, personal communication, 1982), other characteristics must be included to insure an accurate identification.

The Ginkgo flows were the first Frenchman Springs flows to enter western Oregon. The basalt of Ginkgo extends along the present Columbia River embayment to the coast. It also occurs as an intracanyon flow from the Mount Hood area through the Willamette Valley to the coast south of Lincoln City (Figure 4b). Somewhere east of the present-day Mount Hood, the basalt of Ginkgo apparently encountered the canyon of the ancestral Columbia River, which channeled these lavas southwestward to the Newport, Oregon, area. The intracanyon occurrence of the basalt of Ginkgo was first discovered by Elizabeth Storm Norman (1980), and the extent and direction of this intracanyon flow were mapped out by M.H. Beeson, C.W. Hoffman, and T.L. Tolan (unpublished data, 1980). Good exposures of the Ginkgo intracanyon flow occur in the Molalla and Abiqua Rivers and Butte and Silver Creeks (Figure 5). The most westerly known exposure of the basalt of Ginkgo as an intracanyon flow is near Parrish Gap, Oregon, where the unit is more than 500 ft thick. Ginkgo pillow basalt and hyaloclastite near Marion, Oregon, and Hungry Hill record the backfilling of a major tributary or river, possibly an ancestral Willamette River at this locality. Although no outcrops of the basalt of Ginkgo have yet been found in the Oregon Coast Range, a projection of the course of the Ginkgo intracanyon flow (Figure 6) points toward the vicinity of Newport, Oregon, where thick accumulations of Ginkgo occur and were mapped as Cape Foulweather Basalt (Snavely and others, 1973).

Basalt of Silver Falls

The basalt of Silver Falls is here named after excellent exposures of this unit at Silver Falls State Park in western Oregon (Table 1). At this locality, three Silver Falls flows occur between an interbed at the top of the Grande Ronde Basalt and the basalt of Sand Hollow. We define this unit on the basis of criteria and characteristics presented in Table 1. The basalt of Silver Falls lies along a distinctly southwesterly trend from the Pasco Basin to Salem, Oregon (Figure 4c).

Figure 5. Fluvial conglomerate beneath the Ginkgo intracanyon flow at Butte Creek, southeast of Scotts Mills, Oregon. The conglomerate represents gravels deposited by an ancestral Columbia River. Note the absence of pillow basalts and hyaloclastites at the base of the flow; pillows and hyaloclastic debris are observed only where the intracanyon flow encountered tributary streams.

Compositionally, the basalt of Silver Falls is easily distinguished from the overlying basalt of Sand Hollow but less so from the underlying basalt of Ginkgo. A combination of P_2O_5 content and paleomagnetic and lithologic characteristics (Table 1) is usually sufficient to separate it from the basalt of Ginkgo and make a confident identification.

Two flows from the basalt of Silver Falls yielded a scattering of paleomagnetic directions generally falling between the Ginkgo excursion direction and a more normal direction. These flows may have recorded the transition between these directions as they cooled. Another possibility is that the excursion direction has been overprinted in parts of these flows by the present-day field direction. Other flows in the basalt of Silver Falls record good normal directions.

The basalt of Silver Falls is abundantly microphyric, which is its most characteristic lithologic property. Also it is commonly macrophyric, but the abundance of phenocrysts is highly variable.

Basalt of Sand Hollow

Mackin (1961) named the flow overlying the Ginkgo flow the Sand Hollow flow for its occurrence at Sand Hollow just southeast of Vantage, Washington. We adopt Mackin's usage and type locality (Table 1) and assign the name basalt of Sand Hollow to this unit. We redefine this unit, however, on the basis of criteria and characteristics presented in Table 1. The basalt of Sand Hollow is the most extensive of the Frenchman Springs units (Figure 4d) and may consist of up to seven flows. The basalt of Sand Hollow, like the basalt of Ginkgo, reached the Pacific Coast.

The basalt of Sand Hollow is composed of low P_2O_5 and intermediate P_2O_5 compositional types, with 0.51 weight percent P_2O_5 as the dividing line. We do not subdivide it on this basis, however, because the two types interfinger, and the P_2O_5 content may vary within some flows, making subdivision uncertain over the extent of the unit.

The basalt of Sand Hollow has a very diverse lithology; it has some of the coarsest grained flows, is generally phyric, and also contains some of the largest plagioclase phenocrysts and glomerocrysts (up to 5 cm) of any Frenchman Springs flows. Paleomagnetically, the basalt of Sand Hollow displays a normal, nonexcursional direction (Table 1).

Basalt of Sentinel Gap

Mackin (1961) named the uppermost Frenchman Springs flow in the Vantage area the Sentinel Gap flow after exposures along the Columbia River between Vantage and Sentinel Gap. We adopt Mackin's usage and type locality (Table 1) and assign it the name basalt of Sentinel Gap. We redefine this unit, however, on the basis of criteria and characteristics presented in Table 1.

The basalt of Sentinel Gap occupies the core of the Frenchman Springs distribution pattern on the Columbia Plateau and traverses the Cascade Range into the Portland, Oregon, area (Figure 4e).

The basalt of Sentinel Gap can be informally separated into intermediate- and high-P_2O_5 compositional types (Table 1). In addition to the variation in P_2O_5, the intermediate-P_2O_5 type commonly has slightly higher MgO concentrations (Figure 3).

The basalt of Sentinel Gap usually contains only a few scattered plagioclase phenocrysts that are typically small (<1 cm in size). Paleomagnetic directions in the basalt of Sentinel Gap tend to be more to the northeast than those from the basalt of Sand Hollow. However, care must be used in distinguishing the basalt of Sentinel Gap solely on the basis of the paleomagnetic directions because of the slight overlap in declinations and the possibilities of horizontal tectonic rotations.

Basalt of Lyons Ferry

The youngest known Frenchman Springs flow is hereby named basalt of Lyons Ferry after exposures of this unit at its type locality (Table 1). We define this unit on the basis of criteria and characteristics presented in Table 1. The basalt of Lyons Ferry has a restricted areal extent that is centered near Walla Walla, Washington, and elongated westward toward The Dalles, Oregon (Figure 4f). This unit does not appear to be an intracanyon flow despite its linear pattern.

Compositionally, the basalt of Lyons Ferry has low P_2O_5 and low Cr (Figure 3), making it distinct from the underlying basalt of Sentinel Gap. The basalt of Lyons Ferry is sparsely plagioclase phyric and often coarse grained. The paleomagnetic direction of this flow, based on results from two sample sites, is slightly to the west of the directions derived from the basalt of Sentinel Gap.

Radiometric ages and boundary conditions

Recent K-Ar and ^{40}Ar-^{39}Ar dates on samples of the Columbia River Basalt Group from western Oregon yield an average age of 15.3 m.y. for both the Frenchman Springs and the Grande Ronde Basalt (Lux, 1981). Lux concludes that these

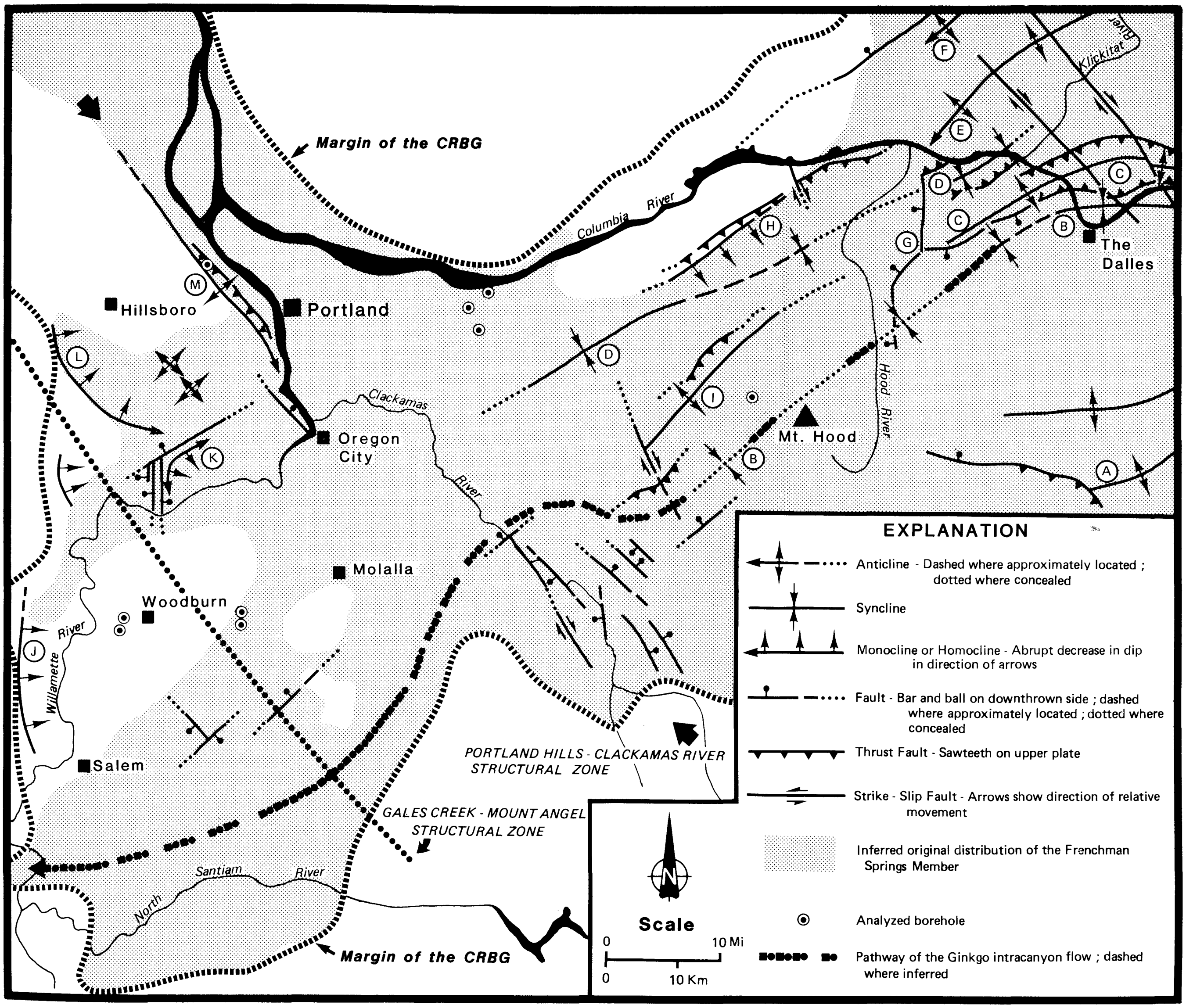


Figure 6. Generalized sketch map showing selected major structures in western Oregon and Washington and the pathway of the Ginkgo intracanyon flow. Structural features shown include the following: A = Tygh Ridge; B = Dalles-Mount Hood syncline; C = Columbia Hills; D = Mosier-Bull Run syncline; E = Bingen anticline; F = Horse Heaven Hills-Simcoe Mountains uplift; G = Hood River fault zone; H = Eagle Creek homocline; I = Bull Run anticline; J = Eola Hills homocline; K = Parrett Mountain structure; L = Chehalem Mountain homocline; M = Portland Hills anticline.

data suggest that much of the total volume of the Columbia River basalt was erupted from independent magma reservoirs that were, in part, contemporaneous and that these data support field observations that the Frenchman Springs Member and Grande Ronde Basalt may be interfingered (Wright and others, 1973; Swanson and others, 1979b). These conclusions drawn by Lux are misleading and deserve further discussion. Geologic mapping of the Columbia River basalt in western Oregon by Beeson and Tolan (unpublished data, 1980-1981) has revealed no occurrences of interfingering of Grande Ronde and Frenchman Springs flows. Instead, the Frenchman Springs flows always lie above the Grande Ronde Basalt. Lux (1981) did not cite any location where the Frenchman Springs Member and Grande Ronde Basalt are known to be interfingered in western Oregon.

We conclude on the basis of our field mapping that the Grande Ronde Basalt and the Frenchman Springs Member of the Wanapum Basalt do not interfinger in western Oregon, as suggested by Lux (1981). In fact, the Grande Ronde-Frenchman Springs boundary (the Vantage horizon) in western Oregon is characterized in places by an erosional unconformity or an interbed that varies from fluvial/lacustrine sediments to a thick paleosol in which large trees were rooted (Figure 7). The overlapping radiometric dates obtained by Lux for the Frenchman Springs Member and the Grande Ronde Basalt reveal more about the suitability of K-Ar and ^{40}Ar-^{39}Ar dates for certain types of detailed volcanic stratigraphy studies than they do about the actual stratigraphic relationships and age equivalence of the Frenchman Springs Member and Grande Ronde Basalt.

Interfingering of flows of the Frenchman Springs Member (and other Wanapum Basalt Members) with flows of Grande Ronde Basalt was reported to occur south of Pomeroy, southeastern Washington, by Swanson and Wright (1976), Swanson and others (1977), Swanson and others (1979b), Swanson and others (1980), and Swanson and Wright (1981).

Figure 7. Vantage horizon at West Linn, Oregon. Note large upright tree, thin interbed, and deep soil zone.

During the course of our work in developing a stratigraphy for the Frenchman Springs Member, this section at Benjamin Gulch was carefully examined to determine which Frenchman Springs units interfingered with the Grande Ronde Basalt. The only Frenchman Springs flows we found at Benjamin Gulch were the basalts of Sentinel Gap and Lyons Ferry, which occur stratigraphically far above the base of the Frenchman Springs Member (Figure 1). Furthermore, neither these Frenchman Springs units nor the other Wanapum flows interfinger with Grande Ronde flows as previously reported. Instead we found that the section at Benjamin Gulch is repeated by two normal faults (Figures 8a and b) that are on trend with, and are logically part of, the Hite fault system. Failure to recognize these faults in the earlier reconnaissance mapping of this area appears to have led to the conclusion that flows of Wanapum and Grande Ronde Basalt interfinger here.

Our conclusion that the Frenchman Springs Member and the Grande Ronde Basalt are not interfingered has obvious implications pertaining to the petrogenesis of the Columbia River Basalt Group. Swanson and Wright (1981, p. 19) interpret interfingering of the Grande Ronde Basalt, basalt of Dodge (Wanapum Basalt) (Figure 1), and Frenchman Springs Member as indicating that eruptions of greatly different magma chemistries overlapped in time. This inferred overlapping of diverse magma chemistries implies that large volumes of compositionally different magmas could be produced in very close proximity, reflecting different petrogenetic processes. If these units were interfingered, it would also suggest that different units of the Columbia River Basalt Group may not necessarily reflect a chemical evolution in the mantle through time but instead, a highly complex, heterogeneous mantle on a local scale with magmas that were generated and accumulated in place before being erupted. However, the absence of interfingering removes the most important petrogenetic constraint supporting that model and instead suggests that the hiatus between the Grande Ronde Basalt and Wanapum Basalt may be closely related to the petrogenetic process responsible for the compositional changes seen in the Wanapum Basalt and the significant decrease in the rate and volume of basalt erupted in post-Grande Ronde time. A more thorough discussion of the petrogenesis of the Frenchman Springs Member and its implications on the petrogenetic history of the Columbia River basalt will be presented elsewhere (Beeson and others, in preparation).

FRENCHMAN SPRINGS STRATIGRAPHY AND MIOCENE TECTONICS OF WESTERN OREGON

The ability to identify and map individual Frenchman Springs units allows us to determine their distributional patterns. Because of the large volume and relatively fluid behavior of these basalt flows, they tended to follow existing lows in the topography created by structural deformation and/or erosion and conversely were diverted by or thinned over topographic highs created by structural uplift or constructional relief created by earlier lava flows or contemporaneous Cascadian volcanism. Thus the distributional patterns and

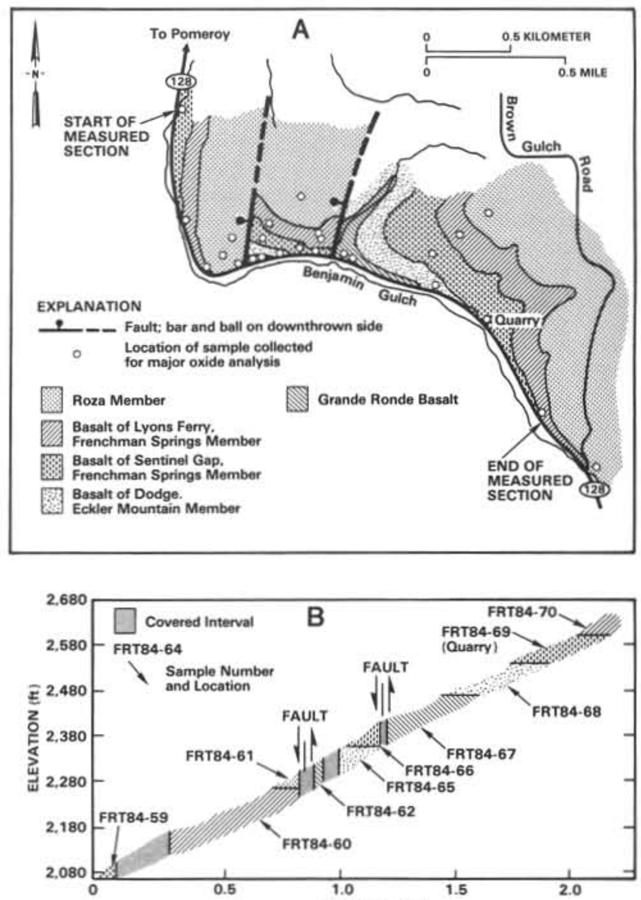


Figure 8. A. Geologic map of a portion of the Benjamin Gulch, Washington, area. B. Schematic representation of the measured section along Highway 128 at Benjamin Gulch. See Figure 8A for location of measured section.

thicknesses of Frenchman Springs units provide partial information on the position, age, and history of structural features, which, in turn, helps better define the middle Miocene tectonic setting of western Oregon.

Miocene Cascade Range

Columbia River basalt flows crossed the Miocene Cascade Range through an 80-km-wide lowland that extended from the site of the present-day Columbia River Gorge south to the Clackamas River region (Anderson, 1978; Beeson and Moran, 1979). It seems likely that this feature is of tectonic origin, but its age and the reason for its presence are not clearly understood.

Within this lowland, the paths of the Frenchman Springs units were in large part controlled by northeast-trending folds that are the westward extension of the Yakima fold belt (Figure 6). The geometry of these folds within the Cascade Range differs little from their geometries described on the Columbia Plateau (Bentley and others, 1980; Reidel, 1984; Hagood, 1985). In the Cascades, the anticlinal ridges typically have an asymmetric, box-fold geometry and thrust faults along their steeper limbs. These ridges are separated by broad, flat synclinal basins that served as the main pathways for the Frenchman Springs flows.

Detailed studies of the anticlinal portion of Yakima folds on the Columbia Plateau (Reidel, 1984; Hagood, 1985) have demonstrated that these folds were growing during Columbia River basalt time. This is also the case for the extension of the Yakima folds within the Cascade Range. Vogt (1981) found that part of the N_2 Grande Ronde Basalt section pinched out against the Bull Run anticline (extension of the Columbia Hills) (Figure 6) and that the Frenchman Springs Member section thinned across the crestal portion of the anticline. Subsequent work by Vogt and Tolan (unpublished data, 1981) found that the thinning of the Frenchman Springs section across the crestal portion of the Bull Run anticline resulted from (1) the exclusion of the oldest and youngest Frenchman Springs flows (basalts of Ginkgo and Sentinel Gap) from the crestal areas and their confinement to the syncline, and (2) the thinning of, and possible exclusion of, certain Sand Hollow flows across the crestal area. This evidence suggests that the Bull Run anticline was growing from at least late Grande Ronde time (approximately 16 million years before the present [m.y. B.P.]) through Frenchman Springs time (approximately 15 m.y. B.P.).

To the north of the Bull Run anticline is the N. 60° E.-trending Eagle Creek homocline (Figure 6). This structure, in part, defines the northern limb of the Bull Run syncline. Dips off the Eagle Creek homocline decrease from 23° to less than 10° near the axis of the syncline. A thrust fault with more than 300 m of vertical stratigraphic offset is found along the northwestern side of the structure (Tolan, unpublished data, 1980) (Figure 6). Though the present observed geometry of this structure is homoclinal, it may have once been an asymmetric boxfold similar in many respects to the Bull Run anticline. It is possible that the northwestern limb of this structure was removed by the ancestral Columbia River that flowed along the northwestern side of this structure from approximately 14 m.y. to 2 m.y. ago (Tolan and Beeson, 1984; Tolan and others, 1984a).

As in the case of the Bull Run anticline, the Frenchman Springs Member section thins and pinches out onto the southeastern side of the Eagle Creek homocline (Tolan, unpublished mapping, 1980). The Eagle Creek homocline appears to have acted as a barrier to the northward spread of the Frenchman Springs Member. This, combined with the overall thinning of the N_2 Grande Ronde section across this structure indicates that the Eagle Creek homocline was also growing during the same period of time as the Bull Run anticline.

The Mosier-Bull Run and Dalles-Mount Hood synclines (Figure 6) were used by the advancing Frenchman Springs flows as the two primary routes through the Miocene Cascades. By the onset of Frenchman Springs volcanism, the ancestral Columbia River had established a canyon within the Dalles-Mount Hood syncline that extended as far east as The Dalles, Oregon (Figure 6). The earliest Frenchman Springs units (basalts of Ginkgo and Silver Falls) to enter the Miocene Cascades primarily used the Dalles-Mount Hood syncline route. However, the later basalt of Sentinel Gap used the more northerly Mosier-Bull Run syncline route (Figure 6). The reason for this shift in routes appears to have been tied to contemporaneous Cascadian volcanism that produced the Rhododendron Formation. Rhododendron volcanism apparently closed off the Dalles-Mount Hood syncline, thus leaving the Mosier-Bull Run syncline as the only route through the Cascades during mid- to late-Frenchman Springs time.

Willamette Valley

The transition from the Cascade Range to the Willamette Valley occurs across a northwest-trending wrench fault zone that we call the Portland Hills-Clackamas River structural zone (Figure 6). Most of the Yakima folds that can be traced through the Cascades appear to die out just east of this fault zone (Figure 6). The structural style of the Portland Hills-Clackamas River structural zone changes along strike to the northwest. In the Clackamas River area, this zone is broad and characterized primarily by northwest-trending, right-lateral strike-slip and dip-slip faults that have vertical to nearly vertical fault planes (Anderson, 1978). Farther northwest in the Portland, Oregon, area, this zone becomes a faulted, northwest-trending asymmetrical anticline (Beeson, unpublished mapping, 1981) (Figure 6).

Movement along this structural zone in middle Miocene time created a topographic high that caused the total thickness of the Columbia River basalt to drop from approximately 600 m in the Clackamas River area (Anderson, 1978) to approximately 150 m in the Molalla River area as well as throughout most of the Willamette Valley. Columbia River Basalt Group units that thinned or terminated across this zone are scattered throughout the Columbia River basalt section, indicating continuing tectonic activity throughout this time interval.

Stream erosion during the hiatus that followed Grande Ronde volcanism produced a channel extending from the Dalles-Mount Hood syncline across the Portland Hills-Clackamas River structural zone southwest through the Willamette Valley area toward Salem, Oregon. In addition to following this river channel, the basalt of Ginkgo also flowed across the Portland Hills-Clackamas River structural zone at a low point in the Milwaukie-Oregon City area and proceeded as far west as Amity, Oregon (Figures 4b, 6).

The next Frenchman Springs unit (basalt of Silver Falls) entered the Willamette Valley area via only the Dalles-Mount Hood syncline; it then crossed the Portland Hills-Clackamas River structural zone and proceeded southwestward toward Salem. Three Silver Falls flows occur in the Molalla River, Butte Creek, and Silver Creek areas; but only one is found to the southwest of the northwest-trending Mount Angel-Gales Creek structural zone (Figure 6). This northwest-trending structural zone was apparently also active during Frenchman Springs time and was effective in stopping the westward progress of these Silver Falls flows.

Sand Hollow flows are ubiquitous among Frenchman Springs units in the Cascade Range, but only one distinctive Sand Hollow flow extends southwest through the Willamette Valley area (Figures 4d and 6). It is confined to the south side of the Frenchman Springs distribution pattern and has not been found in drill holes within the Willamette Valley (Figure 6). This Sand Hollow flow does not reach the Salem Hills area but terminates in the Waldo Hills. Sand Hollow flows are more numerous in the Oregon City-Milwaukie area but do not extend much west of this area.

The Willamette Valley is often depicted as part of a large north-south-trending trough that extends northward to the Puget Lowlands and that probably has existed since Miocene time. Our data show no evidence that a continuous Willamette Valley basin was in existence when the Frenchman Springs flows inundated the area but rather that northeast-southwest-trending structural zones controlled the distribution of Frenchman Springs units throughout the Willamette Valley as far as the present-day Coast Range. No Frenchman Springs units have been encountered in wells that penetrate the Columbia River basalt (Figure 6) in the center of the Willamette Valley (Beeson, unpublished data, 1984). It is highly unlikely that the Frenchman Springs units are missing as a result of erosion. Instead these units probably never reached this area, which indicates that the Willamette Valley was not a broad north-south trough at that time.

The distribution patterns of the basalts of Ginkgo and Sand Hollow in northwestern Oregon suggest the existence of the Portland basin in middle Miocene time. Outcrops of both of these Frenchman Springs units occur along the present-day Columbia River embayment extending toward the Pacific Coast. Although both of these units are found in the Portland area, their distribution does not suggest continuous pathways toward the coast. The basalt of Ginkgo occurs in the Oregon City area and southwestward but is absent on the Portland Hills. The basalt of Sand Hollow also occurs in the Oregon City area, but only isolated patches lying directly on the Grande Ronde Basalt occur in the Portland Hills. The only possible pathway toward the coast seems to be through the Portland basin, which lies between the Portland Hills and the pre-Columbia River basalt rocks across the Columbia River in Washington. These Frenchman Springs units are apparently now buried beneath thick valley fill of the Troutdale Formation. The existence of the Portland basin in middle Miocene is logical, if it is understood to be genetically related to the then-active Portland Hills-Clackamas River structural zone rather than the not yet active Willamette Valley trough. The shape of the Portland basin is highly suggestive of a pull-apart basin tectonically related to wrench faulting (Aydin and Nur, 1982). We conclude that the Portland basin is a pull-apart basin that was already active in Frenchman Springs time.

It is our conclusion that the northwest-trending Clackamas River-Portland Hills and the Mount Angel-Gales Creek structural zones (Figure 6) were topographic barriers to some Frenchman Springs flows. The Frenchman Springs flows in the Willamette Valley followed southwestward paths along the south and north side of the Columbia River basalt distribution pattern. The distributional pattern of the Frenchman Springs units shows no evidence for the existence of a broad north-south-trending structural basin (Willamette Valley) during Frenchman Springs time. The Portland basin is a pull-apart basin genetically related to the Portland Hills-Clackamas River structural zone that was active in Frenchman Springs time.

Coast Range

The occurrence of middle Miocene basalt that can be correlated chemically and paleomagnetically with the Columbia River Basalt Group along an extensive stretch of coast from Seal Rocks, Oregon, to Grays Harbor, Washington, indicates that the Coast Range Mountains were not a continuous barrier to flows of the Columbia River basalt (Beeson and others, 1979). The principal outlet was along the present-day path of the Columbia River where both Ginkgo and Sand Hollow flows occur. The path of the Ginkgo intracanyon flow from the Salem area to the Newport area was probably a stream valley through an incipient Coast Range. If any remnants of the flow survived uplift and erosion of the Coast Range, they have not yet been found. Thus the exact location of this intracanyon flow has not yet been determined.

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A portion of the field work was supported by the U.S. Geological Survey under U.S. Geological Survey-U.S. Department of Energy Interagency Agreement EY78-2-06-1078. Field work conducted by Beeson and Tolan during 1980 and 1981 in western Oregon was part of the regional geologic studies effort of the Basalt Waste Isolation Project administered by the Rockwell Hanford Operations for the U.S. Department of Energy. Marvin Beeson had a Northwest College and University Association for Science (NORCUS) appointment with Rockwell Hanford Operations during his 1983-1984 sabbatical leave from Portland State University. This time of cooperative research was essential for integration of data from the Columbia Plateau and western Oregon. All major-oxide analyses used in this study were performed by Peter Hooper, Washington State University, and funding was provided by Rockwell Hanford Operations.

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*(Continued on page 96, **Basalt**)*

Solicitor finds Interior Department has authority to issue mineral leases within EEZ off U.S. coast

Department of the Interior Solicitor Frank K. Richardson has issued a legal opinion concluding that the Department is authorized to issue mineral leases within the Exclusive Economic Zone (EEZ) off the coasts of the 50 states. The EEZ is that area which generally lies between 3 and 200 miles off the coasts of the United States and its territories.

The opinion clears the way for Minerals Management Service (MMS) to continue planning activities for possible leasing in Pacific Ocean areas thought to have metalliferous sulfide minerals, including a number of strategically important minerals such as chromium, zinc, copper, molybdenum, silver and platinum. However, no decisions have been made to actually proceed with such sales. Any decision to conduct a lease sale would only come after extensive study and consultation with affected states.

Representatives from California, Oregon and Hawaii have been working with MMS on joint state-federal task forces to consider the economic, the engineering and the environmental aspects of possible ocean mining in Pacific offshore areas.

— *Department of the Interior news release*

***(Basalt,** continued from page 95)*

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So you thought mountain ranges were complicated*

by Myrl F. Beck, Department of Geology, Western Washington University, Bellingham, Washington 98225

Remember the time when it was thought that the major features of the Earth's crust were riveted in place as securely as armor plates on a battleship? It took courage to be a tectonic theorist, but life may have been easier for the quadrangle-mapper. In those days, crustal blocks mostly moved up and down, or perhaps a few tens of kilometers laterally at most, so one naturally looked for solutions to local geographical problems in one's own backyard. If granitic debris suddenly appeared in a sedimentary section, it meant uplift of the granitic batholith immediately across the valley. There was no need to complicate life by looking any further.

Even with the advent of early plate-tectonic theory the quadrangle-mapper's task was still much the same; unless his map area spanned a major suture, the several parts of his study area could still be assumed always to have been close together, barring a few highly unusual, and geologically easily recognizable, circumstances. But time has complicated this simple picture. In the past decade, a combination of geology and paleomagnetism has shown that at least one orogenic belt (the North American Cordillera) is a moraine of crustal fragments, many with oceanic affinities, transported intact from points of origin hundreds or thousands of kilometers away. Geological studies showed that many adjacent Cordilleran crustal blocks are too unlike one another in stratigraphy and structural history to have evolved in juxtaposition, and that some of these crustal blocks, or terranes, are wholly exotic to North America. To settle this issue paleomagnetism has provided dramatic evidence of ultra-long-distance transport of crustal blocks.

This microplate model is familiar to many geologists. Orogenesis and the growth of the continent are held to have been more the result of collision and off-scraping of these prefabricated crustal elements than of subduction of the oceanic plates upon which they rode. The model also holds that, once attached to North America, many of these terranes were disrupted by strike-slip faulting; the resulting fragments are now distributed along the continent's edge, placed there by a process that might be termed tectonic longshore drift. Large rotations about vertical axes also may occur during this stage. Because subduction along the western edge of North America has been north-oblique since at least the late Mesozoic, transport and rotation in the Cordillera seem to have been mostly northward and clockwise, respectively. The scale of the process is hotly debated; some pieces of the Cordilleran mosaic are as small as a house, but others clearly are at least as large as, say, Vancouver Island.

Nevertheless, it still seems to be true that mountain belts are a product of plate interaction, and that they are built at plate margins, usually at the edge of a continent. It should follow that major events in the tectonic history of mountain belts reflect major changes in the behavior of plates. It should, therefore, be possible to investigate the nature of orogenic cause-and-effect by observing correlations between important tectonic transitions in a mountain belt (as from overthrust to extensional faulting) and events along the plate margin (as, for instance, a change from rapid to slow convergence).

But a mountain belt is an exceedingly complex recorder. Tectonic events overwrite earlier deformations on the same piece of crust without completely erasing the earlier record — thereby making both records hard to interpret. Also, continental crust in an orogenic belt varies enormously in thickness, age, and physical properties from place to place; it seems hopelessly optimistic to assume that the same orogenic response will always follow a particular plate-tectonic event. The timing of tectonic events is a further problem. Such 'events' last several millions or tens of millions of years, and most are complex and progressive — that is, they involve several geological processes acting simultaneously or in sequence. It is hard to know when an 'event' actually starts or stops. Thus, correlations with plate-tectonic phenomena are bound to be difficult to make, and often will not be particularly convincing.

Still more trouble arises because of the nature of the record of relative plate motions. In the Cordilleran example, three oceanic plates (Farallon, Kula, Pacific) and one continental plate (North America) are involved. According to most plate models, direct Pacific-North America interaction has been a factor in Cordilleran tectonics only for the last 30 million years or so. The chief culprits have been the Farallon and Kula plates, of which, respectively, very little and nothing remain. We deduce the relative motion histories of these two plates from what we hope are mirror-image anomaly patterns recorded on the Pacific plate — thereby putting ourselves explicitly at the mercy of the symmetrical spreading hypothesis of plate tectonics. Likewise, many models make use of the trends of Hawaiian Islands and the Emperor Seamount chain to deduce absolute motion of the Pacific plate. Any inaccuracy in the notion that hotspots are fixed relative to each other thus transfers directly to our plate reconstructions. Finally, it has recently been shown that inaccuracies in specifying stage poles for finite rotations increase with the age of the pole, and may become quite large. This means that some of our Mesozoic reconstructions may be seriously in error.

But where was the Kula-Farallon-North America triple junction during the late Mesozoic and early Tertiary? Since the relative motions of Kula-North America and Farallon-North America were quite different at times, the triple junction ought often to have separated regions of distinctly different tectonic style. It may have moved up and down the coastline rather erratically, however. Perhaps the geology will help us locate the triple junction and thereby improve the plate models. The tectonic consequences of transferring large exotic terranes from the oceanic to the continental crust are poorly known; in particular the effect on plate motions is uncertain.

Whether or not the Cordilleran microplate model can be applied to other mountain belts remains to be seen. For the present, pity the poor quadrangle-mapper. No longer can he assume that the batholith across the valley was there when his sedimentary section began recording its influx of granitic debris; without definite paleomagnetic or geological evidence to the contrary, it might instead have been part of, say, Sumatra. □

*Reprinted by permission from *Nature*, December 13, 1984, v. 312, p. 600.

Open-file reports available

This is just a reminder to you that the Oregon Department of Geology and Mineral Industries (DOGAMI) has approximately 70 of its open-file reports available for purchase and another 20 that are out of print but available for in-library use.

Please feel free to request a copy of the list of open-file reports from the DOGAMI Portland office. □

BOOK REVIEW

by Dennis L. Olmstead, Petroleum Engineer and sometime river runner, Oregon Department of Geology and Mineral Industries

Rivers of the West: A Guide to the Geology and History, by Elizabeth and William Orr, 1985, 8½ by 11 in., 334 pages, $14.95. Available at local bookstores or from the authors at P.O. Box 5286, Eugene, OR 97405

This book, which in the author's own words, "was written to help make the experience of rafting — or backpacking — along western rivers more enjoyable," is a valuable addition to river-running guidebooks already in print. The title is somewhat misleading, however, because it really discusses selected rivers of Idaho, Oregon, California, and a small portion of Nevada. All of the popular rivers of these states are not included, but the eighteen runs covered by the work are well done. Oregon rivers treated in the guide are the Deschutes, Grande Ronde, John Day, Klamath, Owyhee, and Santiam Rivers.

The Indian history, in particular, is interesting, especially in areas where rock art and signs of dwellings still remain. Early military and settlers' sites are also itemized, along with the placer mines that are particularly evident along these rivers.

The geology section of each chapter gives the river runner a good understanding of the rocks seen along the rivers as well as the geologic processes and events that shaped them. The authors avoid technical jargon whenever possible and illustrate much of their information with line drawings and sketch and geologic maps. They go beyond the geology of the areas around the rivers and even conduct brief excursions into submarine processes and features such as mid-ocean ridges and black smokers, thereby adding some spice to these geology sections of the text.

Topographic maps of each of the rivers and surrounding area are included and although occasionally difficult to read are a help to boaters planning visits to these rivers.

Several of the runs are too long for the number of days listed, for example, 29 mi in one day and 43 mi in one to two days. Persons planning visits to these rivers should consult other river-running guidebooks. References to these guides are not included in the suggested readings, however, but would be a useful addition to later editions of this book.

In all, the volume presents a view of the river environment seldom discussed in guidebooks and would be of interest to any river runner on the West Coast. □

Collections shown at State Capitol mineral display

In the State Capitol display case of the Oregon Council of Rock and Mineral Clubs the Roxy Ann Mineral Club of Medford is currently showing a collection arranged by club members Harold and Billie Kenyon, Dwight and Gertrude McCorkle, and Wes and Dorothy Riley. The more than 80 items displayed include geodes, nodules, crystals, whopper pendants, petrified wood, limb casts, porcelain jasper, and many specimens of dendritic agate. The display will remain until the end of August.

On September 1, a new display will be installed by the Klamath Falls Rock and Arrowhead Social Club and arranged by its members Charles and Janice Rasdal and Howard Tomlin. The mostly mixed lapidary display will include approximately 100 specimens of rocks from southern and southwestern Oregon and will feature a regional specialty, Lincoln Copco agate. This show will remain on display through the month of November. □

Oregon ground-water resources detailed in USGS report

Did you know that about 60 percent of the population of Oregon depends on ground water for fresh-water supply, although public supply withdrawals account for only about 6 percent of the total ground-water withdrawals in the state?

Did you know that ground-water withdrawals total 1.1 billion gallons per day in Oregon, and that of this amount 75 percent was used for irrigation, 12 percent for rural-domestic and livestock use, 7 percent for industrial use, and — see above —6 percent for public-supply use?

Did you know that principal aquifers in Oregon consist of unconsolidated sediments and several types of volcanic rock, and that one of the most productive aquifers underlies the Willamette Valley, with wells commonly yielding 100-500 and, in some instances, more than 2,000 gallons per minute?

These are some highlights from the Oregon section of the second annual National Water Summary recently released by the U.S. Department of the Interior. The 467-page report, prepared by the U.S. Geological Survey (USGS) includes a state-by-state summary that is the most comprehensive report assembled yet on the distribution, availability, and use of the nation's ground-water resources.

The Oregon state section of the National Water Summary, which was prepared in cooperation with state and local agencies, contains maps that show the location of aquifers (water-bearing rock formations) and major areas of ground-water withdrawals, tables that describe the characteristics of the aquifers and extent of ground-water withdrawals, and a section on ground-water management activities and responsibilities within the state.

On the occasion of the release, Secretary of the Interior Don Hodel said: "The statistics showing our growing dependence on ground water will be surprising to many. Ground-water use has more than doubled since 1950, from 34 billion gallons a day to over 88 billion gallons a day... Ground water is now the source of drinking water for more than 50 percent of the population. More and more I am convinced that adequate water supply and adequate water quality will be the resource issues of the coming decade."

The 1984 National Water Summary of the U.S. Geological Survey presents an overview of the occurrence, distribution, and use of ground water in each state, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Trust Territory of the Pacific Islands, Saipan, Guam, and American Samoa. The report also reviews 100 of the most significant hydrologic and water-related events that occurred during the 1984 water year and presents articles that expand on a number of specific water issues such as the occurrence of nitrate in ground water, an explanation of ground-water declines in selected areas, and discussions of the distribution and trends of several water-quality constituents in major rivers.

For Oregon, the Oregon Water Resources Department, in cooperation with the USGS, maintains a statewide water-data network and conducts investigations of the state's water resources.

The report, published by the USGS as Water-Supply Paper 2275, *National Water Summary 1984: Hydrologic Events, Selected Water-Quality Trends, and Ground-Water Resources,* is available for $29.00 per copy from the Eastern Distribution Branch, U.S. Geological Survey, 604 S. Pickett St., Alexandria, VA 22304. Orders must include check or money order payable to Department of the Interior — USGS and specify the report number (WSP 2275).

— *USGS news release*

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