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THIS MONTH:
NEOGENE HISTORY OF THE COLUMBIA RIVER:
COLUMBIA RIVER GORGE FIELD TRIP GUIDE, PART I

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

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

Looking to the northeast at the southwestern end of the Columbia River Gorge. Crown Point (right side of photo) is located on one of the ancient channels of the Columbia River discussed in two-part article and field trip guide beginning on next page. (Photo courtesy Oregon State Highway Division)

NEW DOGAMI PUBLICATIONS

Two new reports were released by the Oregon Department of Geology and Mineral Industries (DOGAMI). They are available now for purchase or inspection at the DOGAMI offices in Portland, Baker, and Grants Pass, whose addresses are listed in the box on page 86. Prepayment is required for all orders under $50.

Released June 29, 1984:

GEOLOGIC MAP OF THE WILHOIT QUADRANGLE, OREGON, by P.R. Miller and W.N. Orr. DOGAMI Geological Map Series GMS-32, $4.00.

The new geologic map describes geologic formations south of Molalla, Clackamas County, and east of Silverton, Marion County, that reveal sea-shore environments of approximately 20-40 million years ago.

At a scale of 1:24,000, the two-colored map covers the 7½-minute quadrangle that centers around the former resort community of Wilhoit in the foothills of the Western Cascades. It identifies nine bedrock geologic units of Tertiary age, emphasizing aspects of sedimentation and paleontology and reconstructing paleoenvironments of the Oligocene and early Miocene epochs. The explanatory material on the map sheet includes two geologic cross sections and an innovative graphic presentation of the geometry of the middle-Tertiary geologic units—a three-dimensional "exploded view" of these units and their relationships.

The Wilhoit quadrangle map is the first in a series of three maps of the area. The other two, the Scotts Mills and Stayton NE 7½-minute quadrangles, will be completed later this year.

Released July 20, 1984:

BIOSTRATIGRAPHY OF EXPLORATORY WELLS IN WESTERN COOS, DOUGLAS, AND LANE COUNTIES, OREGON, by D.R. McKeel. DOGAMI Oil and Gas Investigation 11, $6.00.

This biostratigraphic study of nine southwest Oregon wells contains valuable new data for correlating Eocene and older geologic units in the subsurface. Detailed biostratigraphic data for six of the wells had not been available up to now.

Using analyses of nearly 800 samples, the 19-page report provides, for each well, an introductory summary, sample-by-sample listings of fossil and key lithologic highest occurrences, and concluding interpretations of the age and paleoenvironment for each distinctive well interval. Included in the report is a subsurface illustration which contains a surface location map and key fossil correlations for all the wells in the form of two separate generally north-south cross sections.

A striking result of the study is that the fossil record points to a shoaling event, a sudden and very short-lived change (geologically speaking) of the generally continuous deep-water deposition to a shallow-water environment during early Eocene time. This event may have been regional over the west coast of the United States. Another noteworthy conclusion is the previously unpublished presence of Paleocene marine sediments overlying volcanic rocks within the Roseburg Formation. Evidence for this was found in four of the wells. □

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. □

Exploring the Neogene history of the Columbia River: Discussion and geologic field trip guide to the Columbia River Gorge

Part I. Discussion

by Terry L. Tolan and Marvin H. Beeson, Portland State University, Portland, Oregon 97207, and Beverly F. Vogt, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97201*

The following field trip guide is designed to let you see firsthand the rocks that reveal evidence of the dynamic history of the ancestral Columbia River. It is based largely on information presented in a recently published paper by Tolan and Beeson (1984). It will be printed in two parts: Part I in this issue discusses the geology, stratigraphy, and geologic history of the Columbia River Gorge and the ancestral and present-day Columbia River; Part II, which will appear in next month's issue, contains the actual trip log and map of the route. References used in both parts of the paper appear at the end of Part I.

Due to space limitations, it is not possible for this guide to provide a review of all aspects of the geology of the Columbia River Gorge. However, there are two other published field trip guides that can fill this role. The first guide, by Aaron C. Waters (1973), describes the general geology of the Gorge and focuses on ancient lava and landslide dams that have blocked the Columbia River in the recent geologic past. The second guide, by John E. Allen (1979), is a comprehensive layman's guide to the geology, natural setting, and history of man in the Gorge. The guide by Waters may be purchased from the Portland office of the Oregon Department of Geology and Mineral Industries (DOGAMI); the book by Allen may be purchased from local bookstores.

More detailed maps of the Gorge are also available. The U.S. Forest Service sells a topographic trail map, *Forest Trails of the Columbia Gorge*. Local map dealers and DOGAMI sell topographic maps of the area. Finally, a geologic map of The Dalles 1° by 2° quadrangle (Bela, 1982) covers the eastern area of this trip guide and may be purchased from DOGAMI.

Road distances are given in miles, and all the other measurements are in metric units. Approximate conversion factors are as follows: 1 centimeter =0.4 inch, 1 meter=3.3 feet; 1 kilometer=0.6 mile; 1 cubic kilometer=0.24 cubic mile. *—Ed.*

INTRODUCTION

The evolution of the spectacular gorge of the lower Columbia River has fascinated many geologists over the years (Williams, 1916; Bretz, 1917; Buwalda and Moore, 1927, 1929; Barnes and Butler, 1930; Allen, 1932, 1979; Hodge, 1933, 1938; Warren, 1941; Treasher, 1942; Lowry and Baldwin, 1952; Waters, 1955, 1973; Trimble, 1963). Geologists have not agreed on all aspects of its development, however, such as relative locations of paths of the ancestral Columbia River and the modern-day river and the significance of fluvial sediments exposed within the Gorge area.

These differences of opinion on the locations of the courses of the ancestral Columbia have been extreme. For example, Hodge (1938, p. 847) suggested that the path of the ancestral Columbia lay south of the present-day Mount Hood and that the fluvial sediments exposed in the present-day Gorge were deposited by southerly or westerly flowing tributary streams. He hypothesized that lava flows from Cascade volcanoes eventually forced the ancestral Columbia River northward to its present-day path. In contrast, Lowry and Baldwin (1952) contended that the ancestral Columbia River has always been more or less in its present-day position.

These opposing views arose because various workers interpreted and correlated the Miocene-age and younger rocks differently (Figure 1). Most of the above-mentioned authors noted that it was difficult to trace with confidence individual stratigraphic units, particularly flows of the Miocene Columbia River Basalt Group which comprise most of the exposed section in the Gorge. Most were forced to treat the apparently uniform Columbia River basalt flows as an undifferentiated unit. Since the early 1960's, however, major advances in the understanding of the Columbia River Basalt Group have enabled geologists to identify and confidently map individual and/or groups of flows, and as a result, new insights have been gained into the overall history of the ancestral Columbia River. It is now believed that the position of the river has changed

SYSTEM/SERIES		UNIT	DESCRIPTION
QUATERNARY		SEDIMENTARY DEPOSITS	Alluvium, talus, active landslides, and flood deposits.
TERTIARY	PLIOCENE	BORING AND HIGH CASCADE LAVAS	Chiefly olivine/plagioclase phyric, high alumina basalt flows erupted from small shield volcanoes, cinder cones, and fissures. In the western end of the gorge and the Portland-Vancouver area these rocks are called the Boring Lavas.
	MIOCENE	TROUTDALE FORMATION	Fluvial conglomerates, sandstones, and siltstones deposited by the ancestral Columbia River. East of the axis of the Cascades in Washington, these sediments are considered part of the Ellensburg Formation. Thickness: 0 to + 365 m.
		RHODODENDRON FORMATION	Chiefly andesitic to dacitic lahars, mudflows, and agglomerates produced by Cascadian volcanism. Thickness: 0 to 200 m.
		COLUMBIA RIVER BASALT GROUP	Tholeiitic flood - basalt flows which were erupted from fissures in the eastern portion of the Columbia Plateau from 16.5 to 12 m.y. B.P. Thickness: 0 to + 1300 m.
		UNCONFORMITY	
		? EAGLE CREEK FORMATION ?	Interstratified fluvial conglomerates and andesitic lahars/mudflows. Thickness: 150 to 365 m.
		FIFES PEAK FORMATION	Chiefly porphyric andesite flows with interstratified laharic breccias. Exposed only north of the Columbia River. In gorge called 'Lava flows of Three - Corner Rock' by Hammond(1980). Thickness: 1000 m.
	OLIGOCENE	STEVENS RIDGE FORMATION	Chiefly light - colored massive beds of rhyolitic to dacitic ash - flow tuffs with lesser amounts of air - fall tuffs, volcaniclastics, and lithic - pumice beds. Exposed only north of the Columbia River Gorge. Thickness: 50 to 1500 m.
		UNCONFORMITY	
	EOCENE	OHANAPECOSH FORMATION	Basaltic to rhyolitic lava flows, lahars, tuffs, and volcaniclastic rocks which display a variable degree of alteration. Exposed north of the Columbia River. Believed to represent earliest deposits of Cascadian volcanism and are intercalated with marine sediments north of Wind River, Washington (Wise, 1970). Thickness: 900 to 5000 m.

Figure 1. Generalized stratigraphy of the Columbia River Gorge. Modified from Trimble (1963), Wise (1970), Waters (1973), and Hammond (1979, 1980).

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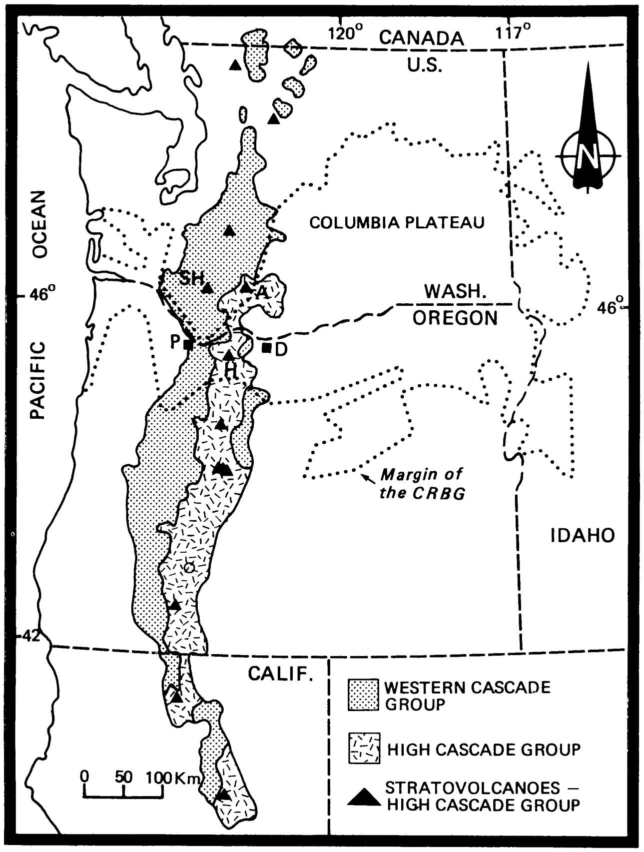

Figure 2. Generalized map of Washington, Oregon, and northern California showing distribution of the Western Cascade, High Cascade, and Columbia River Basalt Groups. P=Portland, D=The Dalles, H=Mount Hood, SH=Mount St. Helens, A=Mount Adams, CRBG=Columbia River Basalt Group. Modified from Hammond (1979, p. 220).

several times during the last 15 million years (m.y.) because (1) Columbia River basalt flows completely filled and thereby obliterated two of the canyons through which it flowed, (2) Cascadian volcanism created debris that eventually filled another canyon, and (3) uplift and folding influenced the location and depth of the river's present-day channel.

This field trip guide is designed to let you conduct a self-guided geologic field trip to see firsthand the rocks that reveal the dynamic history of the ancestral Columbia. This introductory text provides (1) a brief description of the different stratigraphic units that will be seen during the course of the trip and (2) an overview of the history of the ancestral Columbia River as we currently understand it. The road log will allow you to see important features that have helped us to decipher and interpret the history of the ancestral Columbia River.

STRATIGRAPHIC UNITS

PRE-COLUMBIA RIVER BASALT GROUP UNITS

The pre-Columbia River basalt units in the Gorge area (Figure 1) consist of middle Eocene to lower Miocene lava flows and volcaniclastic rocks (the Ohanapecosh, Stevens Ridge, Fifes Peak, and Eagle Creek Formations) (Wise, 1970; Hammond, 1980) that represent deposits from volcanoes which belonged to an ancestral Western Cascade Range that was active long before the High Cascades we see today (Figure 2). These older Western Cascade Group rocks (Hammond, 1979), which are exposed far more extensively on the Washington side of the Gorge than they are along the Oregon side, have been estimated to have a thickness of more than 6,000 m (Wise, 1970).

Although these oldest exposed units are important to our understanding of the geologic history of this area, they do not directly play an important part in the Neogene paleodrainage history of the ancestral Columbia River. Readers who are interested in more information about these rocks are referred to papers by Wise (1970), Waters (1973), and Hammond (1979, 1980).

COLUMBIA RIVER BASALT GROUP

The Columbia River basalt flows found in the Columbia River Gorge are some of the tholeiitic basalt flows of the Miocene Columbia River Basalt Group (Figure 3) that cover an area of roughly 200,000 km² in Oregon, Washington, and Idaho (Waters, 1962) with an estimated volume of over 382,000 km³ (Reidel and others, 1982). Radiometric age determinations suggest that flows of the Columbia River Basalt Group were erupted during a period from 17 to 6 m.y. ago, with more than 99 percent by volume being erupted in a 3.5-m.y. span from 17 to 13.5 m.y. ago (McKee and others, 1977, 1981).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vents in northeastern Oregon, eastern Washington, and western Idaho. The vent system which fed individual flows probably consisted of a network of closely spaced dikes whose active eruptive lengths were on the order of many tens of kilometers (Swanson and others, 1975; Swanson and Wright, 1981). Individual flows typically had volumes of 10 to 30 km³, but some individual flows are known to have exceeded 600 km³ in volume (Swanson and Wright, 1981). It is thought that the duration

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 HARBOR MEMBER		
					Basalt of Goose Island	8.5	N
					Basalt of Martindale	8.5	R
					Basalt of Basin City	8.5	N
					Erosional Unconformity		
					BUFORD MEMBER		R
					ELEPHANT MOUNTAIN MEMBER	10.5	N, T
					Erosional Unconformity		
	MIDDLE				POMONA MEMBER		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		N
					UMATILLA MEMBER	13.5	N
					Local Erosional Unconformity		
				WANAPUM BASALT	PRIEST RAPIDS MEMBER		R_3
					ROZA MEMBER		T, R_3
					FRENCHMAN SPRINGS MEMBER		N
					ECKLER MOUNTAIN MEMBER		
					Basalt of Shumaker Creek		N_2
					Basalt of Dodge		N_2
					Basalt of Robinette Mountain		N_2
	LOWER			GRANDE RONDE BASALT		15.5 - 16.5	N_2
							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		R_1 / T	N_0
							R_0

Figure 3. 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, m.y.=million years. Black bar in right-hand column indicates units known to be present in the Columbia River Gorge region.

of an eruption of a Columbia River basalt flow perhaps lasted from several days to as long as several weeks (Swanson and others, 1975; Swanson and Wright, 1981).

The combination of large volume and low viscosity of the erupting lavas enabled them to cover large areas and distances. The lava flows, which are called flood basalts because they covered such large areas, flowed into lowland areas, following existing stream or river channels when the chance arose. As they cooled and solidified within these channels, they also preserved the channels, making it possible for present-day geologists to determine Miocene drainage patterns.

Columbia River basalt flows entered western Oregon and Washington through a broad low which existed where the northern Oregon Cascades are found today (Beeson and Moran, 1979). The northern boundary of this lowland was just north of the present-day Columbia River Gorge; the southern boundary was in the vicinity of the Clackamas River (Anderson, 1978). Some of the westward-flowing Columbia River basalt flows that crossed the ancestral Cascade Range into western Oregon and Washington succeeded in also crossing the Miocene Coast Range, eventually reaching the ocean (Beeson and others, 1979) and probably flowing out onto the continental shelf (Snavely and others, 1980).

Not all of the flows from the various Columbia River Basalt Group units flowed as far as western Oregon and Washington (Figure 3). Those that are present in the Columbia River Gorge are denoted by the black bar on Figure 3 and are discussed below.

Grande Ronde Basalt

The Grande Ronde Basalt (Figure 4A) was erupted in a series of flows from fissures in the eastern portion of the Columbia Plateau (Figure 2) from about 16.5 to 15.5 m.y. ago (McKee and others, 1977; Long and Duncan, 1982). This formation has an approximate volume of 275,000 km^3 (Reidel and others, 1982), making it the most voluminous of all the Columbia River basalt formations. The greatest known thickness of Grande Ronde Basalt occurs in the Pasco Basin in south-central Washington, where more than 3 km was encountered in a deep borehole (Reidel and others, 1982). The thickest known section of Grande Ronde Basalt in western Oregon/Washington, over 1.3 km, is found at Dog Mountain in Washington on the eastern edge of the Gorge (J.L. Anderson, personal communication, 1980). More commonly, the Grande Ronde section in western Oregon and Washington ranges from 55 to 120 m in thickness (Beeson and Tolan, in preparation).

The Grande Ronde Basalt has been formally divided into four magnetostratigraphic units (Figure 3). These units consist of a series of flows that have the same remanent paleomagnetic polarity. In the geologic past, the Earth's magnetic poles have "flipped," or changed polarity, many times. As a basalt flow cools below the Curie point ($\sim 500°$ C), magnetic domains within the iron minerals (e.g., magnetite) present in the flow adopt the orientation of the Earth's magnetic field as it exists at that place and time. If the polarity of the Earth's magnetic field recorded at the time the flow cooled below the Curie point was the same as that of our present-day field, we term the flow "normal" ("N" below); if it had the opposite polarity of our present-day field, it is termed "reversed" ("R" below). The Grande Ronde Basalt magnetostratigraphic units have been numbered R_1, N_1, R_2, and N_2, with R_1 being the oldest unit. The paleomagnetic polarity of a flow is commonly determined in the field by checking the remanent magnetic polarity of oriented hand samples using a small, portable instrument called a fluxgate magnetometer.

In addition to the formal magnetostratigraphic units, the Grande Ronde Basalt in the Gorge area has been informally subdivided into two compositional types, called high MgO and low MgO, based on the relative concentrations of magnesium oxide (Beeson and Moran, 1979; Anderson, 1980; Tolan, 1982). Two or more high MgO flows (Table 1, column 2) are commonly found at the top of the N_2 magnetostratigraphic unit in the western portion of the Columbia Plateau (Bentley and others, 1980a; Anderson, 1980) as well as throughout western Oregon and Washington (Beeson and Moran, 1979; Beeson and Tolan, in preparation). These high MgO flows have higher amounts of MgO and CaO and lower amounts of SiO_2, K_2O, and TiO_2 than the low MgO Grande Ronde flows (Table 1, column 1) that comprise the bulk of the Grande Ronde section throughout the Gorge area. The jointing of N_2 high MgO Grande Ronde flows is commonly blocky to columnar, and in hand sample, the rocks are medium to coarse grained. In contrast, the jointing of the low MgO flows is characterized by the presence of both entablatures and colonnades (see Figure 5 for diagrammatic representation of various jointing features), and the low MgO rocks are glassy to fine grained. These differences in jointing and texture between N_2 high MgO and low MgO Grande Ronde flows are usually reliable enough to be used as criteria for mapping these flows in the western portion of the Columbia Plateau (Powell, 1978; Bentley and others, 1980a) and in western Oregon (Beeson and Tolan, in preparation).

High MgO Grande Ronde flows are not exclusive to the N_2 magnetostratigraphic unit in the Gorge area. Several high MgO flows have been found in the R_2 and N_1 magnetostratigraphic horizons and are compositionally indistinguishable from N_2 high MgO Grande Ronde flows.

Wanapum Basalt

The Wanapum Basalt, which constitutes only approximately 3 percent by volume of the Columbia River Basalt Group (Reidel and others, 1983), is divided into four members (Figure 3), of

Table 1. *Average major-oxide compositions of Columbia River Basalt Group units in the Columbia River Gorge. All concentrations are in weight percent. All analyses are XRF determinations by P.R. Hooper, Washington State University, Pullman, WA 99164. Numbers in parentheses indicate numbers of analyses used in computing averages.* FeO = FeO + 0.9(Fe_2O_3).

Oxide	Grande Ronde Basalt		Wanapum Basalt				Saddle Mts. Basalt
	Low MgO (23)	High MgO (23)	Frenchman Springs Member (49)	Roza Member (9)	Priest Rapids Member: Rosalia flow (20)	Priest Rapids Member: Lolo flow (5)	Pomona Member (5)
SiO_2	55.23	53.73	51.66	51.22	50.17	49.62	52.37
Al_2O_3	14.91	15.31	14.65	14.11	14.01	14.26	15.70
TiO_2	2.14	1.89	2.97	3.16	3.54	3.09	1.63
FeO	12.18	11.59	13.87	13.93	14.91	14.34	10.45
MnO	0.20	0.20	0.22	0.22	0.24	0.25	0.18
CaO	7.01	8.50	8.12	8.27	8.38	9.01	10.36
MgO	3.56	4.80	4.24	4.73	4.29	5.05	6.79
K_2O	1.70	1.17	1.23	1.25	1.23	1.04	0.57
Na_2O	2.53	2.32	2.32	2.31	2.36	2.41	1.51
P_2O_5	0.33	0.29	0.52	0.59	0.68	0.64	0.23

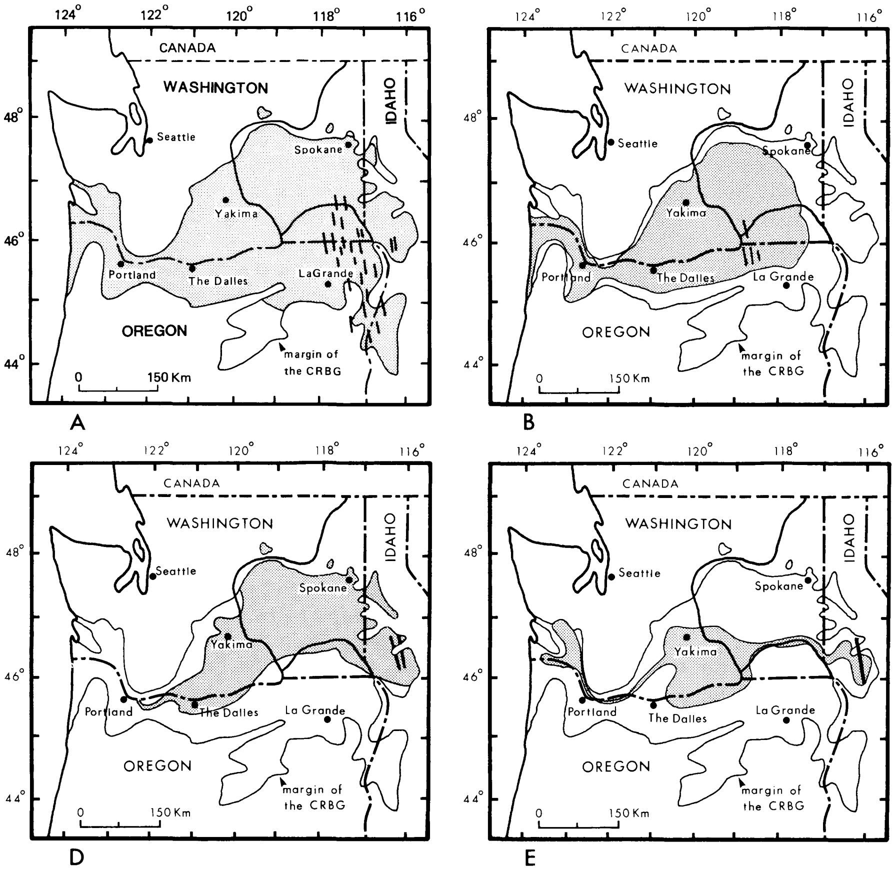

Figure 4. Maps showing distribution of selected Columbia River Basalt Group units and known source dikes. A. Grande Ronde Basalt. Modified from Snavely and others (1973) and Swanson and others (1979b). B. Frenchman Springs Member. Modified from Snavely and others (1973) and Swanson and others (1979b). C. Roza Member. Modified from Swanson and others (1979b). D. Priest Rapids Member. Data from Swanson and others (1979b, 1981), Vogt (1981), and Tolan (1982). E. Pomona Member. Modified from Snavely and others (1973), Anderson (1980), Swanson and others (1981), and Tolan (1982).

which only three, the Frenchman Springs, Roza, and Priest Rapids Members, have been found in the Gorge area (Anderson, 1979, 1981; Beeson and Moran, 1979).

Flows of Wanapum Basalt commonly overlie Grande Ronde Basalt, with the two formations generally separated by a local erosional unconformity or by an interbed called the Vantage Member on the Plateau and informally the "Vantage horizon" in this area (Beeson and Moran, 1979; Swanson and others, 1979b; Bentley and others, 1980a). The erosional unconformity or interbed between these formations has been interpreted to represent a significant hiatus (perhaps several hundred thousand years or much longer) between the end of the Grande Ronde volcanism and the general onset of Wanapum volcanism (Swanson and Wright, 1981).

Frenchman Springs Member: The Frenchman Springs Member consists of more than a dozen flows which were erupted from a northerly trending dike system in southeastern Washington and northeastern Oregon (Figure 4B). The total volume of this member has been estimated by Swanson and Wright (1981) to be 3,000 to 5,000 km^3.

Flows of the Frenchman Springs Member (Figure 3) overlie Grande Ronde Basalt and are generally overlain by flows of the Roza or Priest Rapids Members throughout much of the western portion of the Columbia Plateau (Anderson, 1979, 1981). In western Oregon and Washington, however, flows of the Frenchman Springs Member are commonly the last Columbia River Basalt Group unit to have been deposited over large areas, and they are usually unconformably overlain by younger non-Columbia River basalt units (Beeson and Moran, 1979; Beeson and Tolan, in preparation).

Frenchman Springs flows are commonly blocky to columnar jointed (Beeson and Moran, 1979; Bentley and others, 1980a), but in the Columbia Gorge area, an entablature/colonnade-style jointing similar to low MgO Grande Ronde flows is displayed by some flows (Tolan, 1982; Beeson and Tolan, in preparation). Frenchman Springs flows commonly contain clear to amber-colored plagioclase phenocrysts and/or glomerocrysts that range from 0.5 to 3 cm in size. The abundance of these plagioclase phenocrysts/glomerocrysts varies among flows, ranging from nearly none to more than several hundred per square meter. Frenchman Springs flows have a distinctive major oxide composition (Table 1, column 3) that distinguishes them from other Columbia River Basalt Group flows in the Gorge area. Frenchman Springs flows also have normal paleomagnetic polarity.

Roza Member: The Roza Member (Figure 3) was erupted from a narrow, 165-km-long linear vent system in southeastern Washington and northeastern Oregon (Swanson and others, 1975; Figure 4C). This unit is found throughout much of the central and western portions of the Columbia Plateau (Figure 4C) but apparently failed to cross the Miocene Cascade Range into western Oregon and Washington. In most areas where the Roza is present, it consists of one or two blocky- to columnar-jointed flows, but near the vent system up to four flows or "cooling units" have been reported (Swanson and others, 1979b).

The Roza Member is easily recognized in the field by its abundant small plagioclase phenocrysts (commonly less than 1 cm in size), which commonly exceed several hundred per square meter (Swanson and others, 1979b; Bentley and others, 1980a). These single, tabular plagioclase crystals and less common plagioclase glomerocrysts are usually evenly distributed throughout the entire flow. Phyric Frenchman Springs flows could be confused with Roza flows locally, but careful examination of the underlying and overlying flows usually establishes the true identity of a particular unit. The Roza Member is considered a good stratigraphic marker in the western half of the Columbia Plateau.

Chemically, the Roza Member is nearly identical to the Frenchman Springs Member (Table 1, column 4). The Roza Member has transitional paleomagnetic polarity (Swanson and others, 1979b).

Priest Rapids Member: The Priest Rapids Member (Figure 3) was erupted from dikes in western Idaho (Taubeneck and others, *in* Swanson and others, 1979b; Camp, 1981) and flowed westward into western Oregon (Figure 4D) via the channel of the ancestral Columbia River (Waters, 1973; Vogt, 1981; Tolan and Beeson, 1984) approximately 14 m.y. ago.

The Priest Rapids Member is subdivided into two compositional types: (1) an older one, the Rosalia type, which has high FeO and TiO_2 concentrations (Table 1, column 5) and, (2) a younger one, the Lolo type, which has lower FeO and TiO_2 and higher MgO concentrations (Table 1, column 6). Flows of both compositional types commonly display columnar to blocky jointing and are coarse grained in the central and western portions of the Columbia Plateau (Mackin, 1961; Bentley and others, 1980a). The older Rosalia flows are commonly aphyric, while the younger Lolo compositional type contains scattered plagioclase phenocrysts.

The Priest Rapids Member consists of up to four paleomagnetically reversed flows or flow lobes in some portions of the Columbia Plateau (Swanson and others, 1979a); more commonly, however, two flows are found in the western portion of the Plateau (Bentley and others, 1980a), and only a single intracanyon flow (Rosalia chemical type) has been found in western Oregon (Vogt, 1981; Tolan and Beeson, 1984).

Saddle Mountains Basalt

The Saddle Mountains Basalt consists of 10 chemically diverse members (Swanson and others, 1979b) and is the youngest formation within the Columbia River Basalt Group (Figure 3). Members of this formation were erupted intermittently during the final phase of Columbia River Basalt Group volcanism, which lasted from approximately 13.5 to 6 m.y. ago (McKee and others, 1977). The total volume of the Saddle Mountains Basalt has been estimated to be 3,000 km^3 (Swanson and Wright, 1981), much less than 1 percent of the total volume of the entire Columbia River Basalt Group.

Distribution of this formation is limited, with many of its members confined to structural lows or river canyons as intracanyon flows (Swanson and others, 1979a; Fecht and others, in press). Only the Pomona Member of the Saddle Mountains Basalt appears to have entered western Oregon and Washington.

Pomona Member: The Pomona Member, which in most areas consists of a single flow, was erupted from dikes in the Clearwater Embayment of western Idaho (Camp, 1979, 1981) about 12 m.y. ago (McKee and others, 1977). As the Pomona Member flowed from its source area, it was generally confined to the ancestral Clearwater/Snake River canyons (Camp, 1981), spreading laterally only in the central portion of the Columbia Plateau (Figure 4E). It continued to flow westward along the path of the ancestral Columbia River, crossing into western Washington and Oregon and eventually reaching the Pacific Ocean (Anderson, 1980; Tolan and Beeson, 1984). The distance from the source area of the Pomona Member to its distal end exceeds 500 km.

The distinctive physical characteristics of the Pomona Member make it an excellent stratigraphic marker (Swanson and others, 1979b). The Pomona flow commonly displays an easily recognized entablature-like jointing pattern that consists of apparently intertwining small-diameter columns. Pomona rocks are distinctive, in that they contain small tabular and equant plagioclase phenocrysts as well as clots of olivine that are generally less than 1 cm in size (Bentley and others, 1980a; Anderson, 1980; Tolan, 1982). The Pomona major-oxide composition separates it from other Columbia River Basalt Group flows in the Gorge area (Table 1, column 7). The Pomona Member also has reversed paleomagnetic polarity.

RHODODENDRON FORMATION

The Rhododendron Formation (Figure 1) consists of middle Miocene andesitic to dacitic volcaniclastic rocks (i.e., lahars, pyroclastic flows and fluvial deposits) and lava flows that were produced during a phase of explosive volcanism in the ancestral Cascade Mountains of northern Oregon (Peck and others, 1964; Priest and others, 1982). The Rhododendron Formation was originally described by Barnes and Butler (1930) in the Zigzag Mountain area west of Mount Hood and later formally named by Hodge (1933) after the town of Rhododendron, Oregon, which is located at the southwestern foot of Zigzag Mountain. The distribution of the Rhododendron Formation in the northern Oregon Cascades is localized; where present, the unit can reach thicknesses greater than 245 m (Beaulieu, 1977).

Rhododendron Formation rocks have been found interbedded with flows of the Columbia River Basalt Group in recently drilled deep geothermal exploratory wells on the western flank of Mount Hood (Priest and others, 1982). Reported K-Ar radiometric age determinations and stratigraphic relationships suggest the Rhododendron Formation in the northern Oregon Cascades was deposited from approximately 16 to 7 m.y. ago (Wise, 1969; Hammond, 1980; Priest and others, 1982).

The Rhododendron volcanoes in the western and central portions of the present-day Mount Hood area shed volcanic debris in all directions. To the north and east, Rhododendron lahars, mudflows, pyroclastic flows, and fluvial deposits collected in the northeast-trending Dalles and Mosier synclines (Figure 6). These volcaniclastic rocks were called the Dalles Formation by Newcomb (1966, 1969) and were more recently redefined by Farooqui and others (1981) as the Chenoweth Formation of the Dalles Group. Recent work by Gannett (1982) has demonstrated compositional similarities between the Rhododendron and Chenoweth Formations, providing compelling evidence that the rocks of the Chenoweth Formation are simply the distal equivalent of the Rhododendron Formation.

TROUTDALE FORMATION

The middle Miocene to Pliocene fluvial siltstones, sandstones, and conglomerates that are found through much of northern Oregon were formally named the Troutdale Formation by Hodge (1938, p. 873) after the town of Troutdale, Oregon, which is located at the

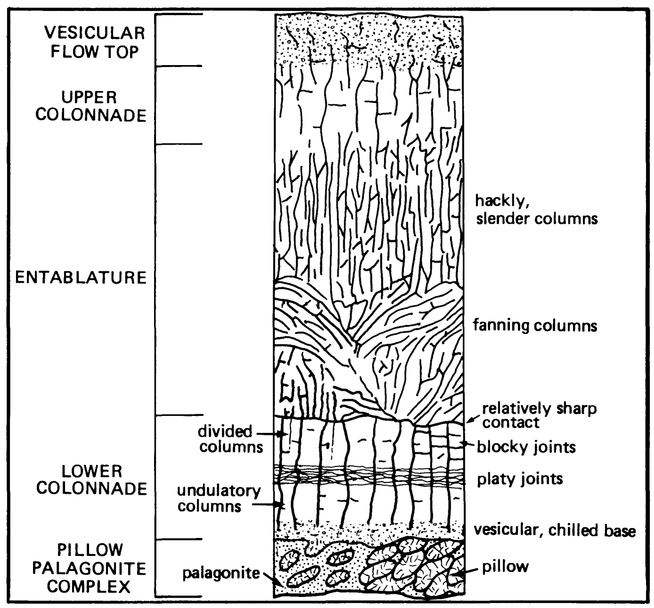

Figure 5. Diagrammatic representation of jointing patterns and flow features commonly found in Columbia River basalt. Not all features are present in all flows. The basal pillow-palagonite complex is found only in units that have flowed into water. Palagonite is an alteration product of basaltic glass (hyaloclastite). Modified from Swanson (1967) and Long and Davidson (1981).

western end of the Columbia River Gorge adjacent to cliff exposures of this formation along the lower Sandy River.

The Troutdale Formation, as originally defined by Hodge (1938) and subsequently mapped by other geologists, consists of two separate and distinct lithologic facies. The first facies is characterized by conglomerates that contain foreign clasts such as quartzite, schist, granite, and rhyolite for which no local sources can be found. This facies, which represents deposits of an ancestral Columbia River (Williams, 1916; Lowry and Baldwin, 1952; Trimble, 1963; Waters, 1973), is generally found in proximity to the modern-day Columbia River and is confined to the northern portion of the Willamette Valley (Figure 7). The Troutdale deposits found in the type area along the lower Sandy River southwest of the Gorge belong to this ancestral Columbia River facies of the Troutdale Formation (Tolan and Beeson, 1984). The other facies of the Troutdale Formation, which is characterized by conglomerates that contain only locally derived clasts, represents deposits of local Cascadian streams that drained into the Willamette lowland (Lowry and Baldwin, 1952; Baldwin, 1981).

In the Gorge area, the ancestral Columbia River facies of the Troutdale Formation can be divided into two lithologically distinct members (Tolan and Beeson, 1984): (1) a lower member of chiefly quartzite-bearing conglomerates and micaceous arkosic sandstone beds and (2) an upper member which contains mostly pebbly to cobbly vitric sandstones with basaltic conglomerate interbeds containing high-alumina basalt clasts from Boring and High Cascade lavas and less common foreign clasts.

The age of the ancestral Columbia River facies of the Trout-

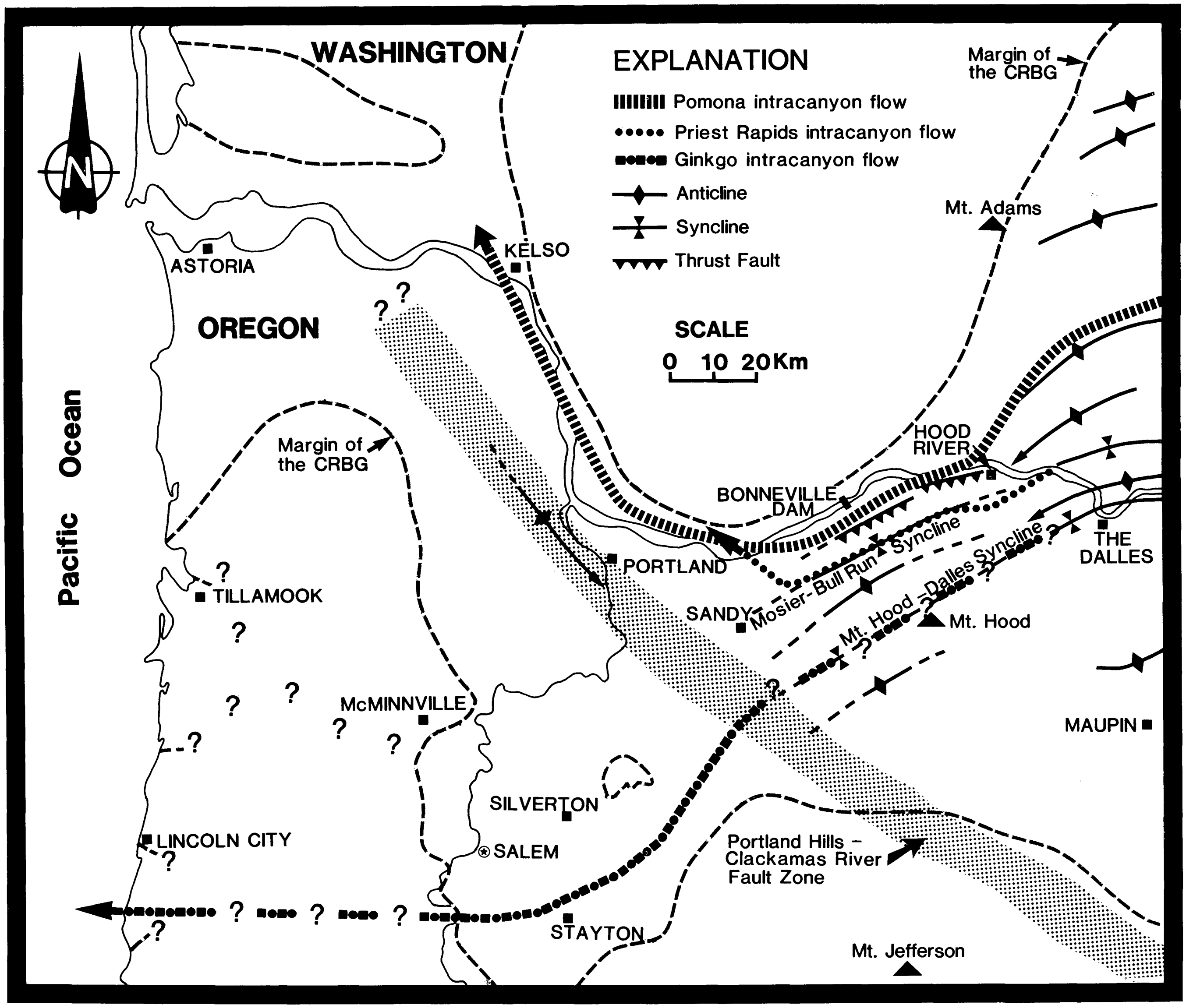

Figure 6. Sketch map showing selected major structures and the pathways of Columbia River basalt intracanyon flows in western Oregon and Washington. Northeast-trending faults and folds shown on the map are the extension of the Yakima Fold Belt through the Cascade Range (Vogt, 1981; Beeson and others, 1982; Beeson and Tolan, 1984). Most of these structures appear to die out just east of the Portland Hills-Clackamas River fault zone. Intracanyon flows of the Columbia River Basalt Group mark the former courses of the ancestral Columbia River through the Cascade Range. The Ginkgo intracanyon flow (Frenchman Springs Member) preserves the oldest ancestral Columbia River course identified to date (Beeson and Tolan, unpublished data, 1981). Note the northward jump in position of the subsequent Priest Rapids Member and Pomona Member intracanyon flows.

Columbia River basalt is known to crop out along the Oregon coast south of the margin indicated on the map. Dashed lines indicate limits of known outcrops of Columbia River basalt along the coast; question marks indicate possible flow pathways followed by the basalt as it flowed toward the coast.

dale Formation is constrained by the presence of lower member conglomerates which underlie the Pomona Member intracanyon flow (Anderson, 1980; Tolan and Beeson, 1984), which has a radiometric age of approximately 12 m.y. (McKee and others, 1977), and by high-alumina basalt flows which are interbedded with, and overlie the upper member of, the Troutdale Formation and which may be only 1 to 2 m.y. old (Tolan and Beeson, 1984). Thus it appears that deposition of the ancestral Columbia River facies of the Troutdale Formation probably spanned a period of greater than 10 m.y. in the Gorge area.

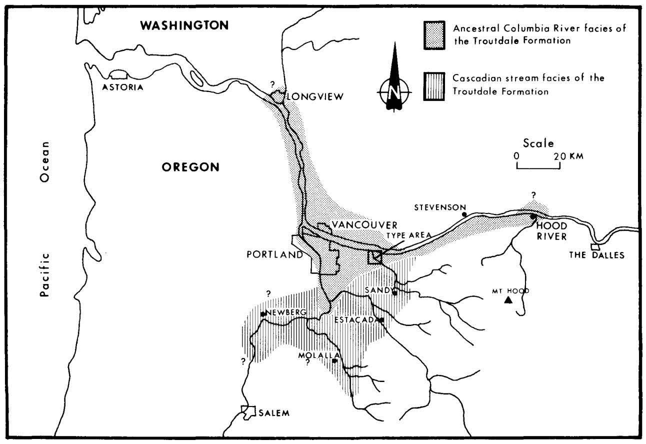

Figure 7. Map showing distribution of the ancestral Columbia River and Cascadian stream facies of the Troutdale Formation. From Tolan and Beeson (1984, p. 474).

BORING AND HIGH CASCADE LAVAS

Many of the conical and rounded hills which are found throughout the greater Portland-Vancouver area and the northern Oregon/southern Washington Cascade Range (Allen, 1975; Tolan and Beeson, 1984) represent volcanic vents that erupted primarily high-alumina basaltic lava flows. More than 90 such vents have been identified in this area (Allen, 1975), but they have not been extensively studied.

The high-alumina basalt flows in the Portland area (Table 2) have been named the Boring Lavas by Treasher (1942, p. 10) after a cluster of these volcanic vents and attendant flows that form the Boring Hills east of Portland. On the basis of lithology and stratigraphic position, Peck and others (1964) informally grouped the Boring Lavas with flows produced by High Cascade volcanism. Major-oxide analyses of Boring Lavas and High Cascade lavas from northern Oregon/southern Washington (Table 2) show that both are high-alumina basalts.

These high-alumina basalts are significant in that the presence or absence of Boring and High Cascade basalt clasts and vitric sands divides the ancestral Columbia River facies of the Troutdale Formation into two members. In the lower Gorge area, two high-alumina basalt flows (Table 2, columns 2 and 5) are found interbedded with the upper member of the Columbia River facies of the Troutdale Formation. Elsewhere in the lower Gorge area, high-alumina basalt flows are more often found overlying the Troutdale Formation (Trimble, 1963; Tolan, 1982).

The stratigraphic relationships of these rocks indicate that eruption of high-alumina basalts in the Gorge area probably began 6 to 4 m.y. ago (Tolan and Beeson, 1984) and continued episodically until the present (Hammond, 1980).

GEOLOGIC HISTORY – A SUMMARY

As noted above, the Neogene history of the ancestral Columbia River in northwestern Oregon has been the focus of much discussion and debate over the years. Regional geologic investigations, both in western Oregon and Washington and on the Columbia Plateau, have uncovered a wealth of new information on this region's paleodrainage history from middle Miocene time to the present. When these new data are combined with the observations and data from earlier investigators, a regional paleodrainage model that can be tested and built upon begins to emerge.

It is clear that the evolution of the Columbia River system has been shaped by the dynamic interplay of geologic events that occurred both in the Cascade Mountains and on the Columbia Plateau to the northeast. Since this field guide concentrates on the Gorge region, we will only briefly mention those geologic events and conditions occurring on the Columbia Plateau which we know to have had a significant impact on the evolution of the ancestral Columbia River system in western Oregon. For an excellent summary of information about the Neogene paleodrainage history of the Columbia Plateau, the reader is referred to a paper by Fecht and others (in press).

VANTAGE-FRENCHMAN SPRINGS TIME

To set the stage for the story of the ancestral Columbia River in the vicinity of the present-day Gorge, we must digress for a moment and describe the oldest identified course of the ancestral Columbia River in western Oregon. This course was established during "Vantage time," the hiatus between the last eruption of Grande Ronde flows and the first flows of the Frenchman Springs Member (Figure 3). During "Vantage time," the ancestral Columbia River appears to have followed the southwest-trending Mount Hood syncline (Figure 6) into western Oregon. This channel is known to have extended southwestward to near Salem, Oregon, where it probably turned westward and crossed the Miocene Coast Range to the Pacific Ocean (Beeson and Tolan, in preparation). The first Frenchman Springs flows to enter western Oregon followed this channel. Subsequent Frenchman Springs flows, probably combined with volcanic debris shed into the Mount Hood syncline by erupting Rhododendron volcanoes, succeeded in defeating the ancestral Columbia River along this course and in closing this route to the west (Beeson and Tolan, in preparation).

Because of their wide distribution, flows of the Frenchman Springs Member not only inundated and destroyed the ancestral Columbia River channel in western Oregon but also destroyed the existing and developing drainage systems throughout most of the Columbia Plateau (Figure 4B). However, the existing rivers and streams on the highlands surrounding the Columbia Plateau continued to drain onto the plateau surface, creating a system of shallow interconnected lakes whose waters eventually were drained from the Plateau via the Mosier-Bull Run syncline (Figure 6) which lay north of the closed-off Mount Hood syncline route.

ROZA TIME

From the end of Frenchman Springs volcanism to the eruption of the first Priest Rapids flow (Figure 3), the ancestral Columbia River re-established itself and, by headward erosion, whereby the river lengthened its course by erosion of its uplands at the head of its channel, created a new canyon in the Mosier-Bull Run syncline (Figure 6). During this period of time, the Roza Member was erupted onto the Columbia Plateau (Figure 4C). The Roza Member, like the Frenchman Springs flows before it, inundated a very large area, thereby halting any development of a drainage system in the central and western portions of the Columbia Plateau. Once again shallow interconnected lakes dotted the Plateau. Because the Roza Member apparently failed to reach the ancestral Columbia River channel, the ancestral Columbia River continued unabated the headward erosion of its canyon, eventually reaching the vicinity of Mosier, Oregon, before the first Priest Rapids flow was erupted.

PRIEST RAPIDS TIME

About 14 m.y. ago, the first flow of the Priest Rapids Member (Rosalia chemical type) was erupted (McKee and others, 1977) in the eastern portion of the Plateau (Figure 4D). Because of the geographic configuration of the land between the westernmost lake

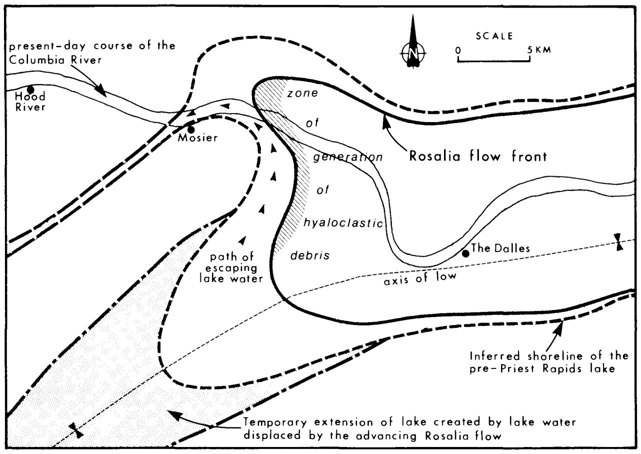

Figure 8. Sketch map showing approximate location of the lake and the head of the ancestral Columbia River channel that existed when the first Priest Rapids flow (Rosalia chemical type) entered the area. Arrows indicate path of escaping lake water where hyaloclastic debris was generated and transported when the Priest Rapids flow (flow front depicted on map) moved westward across the area. From Tolan and Beeson (1984, p. 470).

that occupied the Mount Hood-Dalles syncline and its outlet into the ancestral Columbia River canyon near Mosier, a unique situation developed when the Priest Rapids lava flow approached this area (Figure 8). As the Priest Rapids lava flow front advanced into the lake, it displaced a large amount of lake water. This water could not escape rapidly enough through the outlet of the lake and began to back up into the Mount Hood-Dalles syncline. The pent-up water eventually escaped across the active flow front of the Priest Rapids Member. The escaping water chilled the molten lava causing it to violently break up (phreatic brecciation), creating sand- to cobble-size fragments of glassy lava (hyaloclastite) that were carried in slurry-like surges into and down the ancestral Columbia River canyon. More than 8 km^3 of hyaloclastite was probably generated and flushed in advance of the lava flow into the ancestral Columbia River canyon, where it began to accumulate (Tolan and Beeson, 1984). This great amount of hyaloclastic debris drastically reduced the capacity of the canyon to contain the oncoming Priest Rapids lava, and the lava filled and overtopped the confines of the canyon along nearly its entire known length. The final result was the total obliteration of this course of the ancestral Columbia River.

TROUTDALE TIME

The destruction of the ancestral Columbia River pathway through the Mosier-Bull Run syncline by the Priest Rapids Member forced the river to move northward again (Figure 6) and establish yet another pathway through the Miocene Cascade Mountains. This new pathway, the Bridal Veil channel (Tolan and Beeson, 1984), was longer lived than its predecessors in that the river remained in it for probably more than 10 m.y. The ancestral Columbia River which occupied the Bridal Veil channel deposited the sands and gravels of the ancestral Columbia River facies of the Troutdale Formation.

The establishment of the Bridal Veil channel through the Miocene Cascade Mountains in post-Priest Rapids time was possible because apparently no known Saddle Mountains Basalt flow prior to the Pomona Member (Figure 3) had sufficient volume to reach this channel (Fecht and others, in press). This meant that the ancestral Columbia River had probably more than 1 m.y. from Priest Rapids time to Pomona time to incise the Bridal Veil channel. At Mitchell Point, approximately 5 mi west of Hood River, the Bridal Veil channel was at least 70 m deep (Anderson, 1980), while farther west at Bridal Veil, Oregon, this same channel was approximately 244 m deep and 2.4 km wide (Tolan and Beeson, 1984).

Approximately 12 m.y. ago, the Pomona Member was erupted from fissures in western Idaho (Camp, 1979, 1981) and entered the central portion of the Columbia Plateau as an intracanyon flow, spreading laterally when it encountered structural lows along its path (Figure 4E). The Pomona Member exited from the Plateau via the Bridal Veil channel through the Miocene Cascades and eventually reached the Pacific Ocean (Figure 4E). Because the Pomona Member did not fill or destroy the Bridal Veil channel, the ancestral Columbia River remained in the Bridal Veil channel in post-Pomona time.

For the next 6 m.y. following the eruption of the Pomona Member, the portion of the ancestral Columbia River and its major tributary streams located on the Columbia Plateau experienced major changes and reorganization in their courses and drainage patterns caused by waning Saddle Mountains Basalt volcanism, regional structural uplift and subsidence, and local volcanism (Fecht and others, in press). It appears the opposite is true for that

Table 2. *Major-oxide composition of selected Boring and High Cascade high-alumina basalt flows and dikes from northern Oregon and southern Washington. All concentrations are in weight percent. All analyses are XRF determinations by P.R. Hooper, Washington State University, Pullman, WA 99614.* FeO=FeO+0.9 (Fe_2O_3). *From Tolan and Beeson (1984).*

Column	1	2	3	4	5	6	7	8	9	10	11	12
Oxide												
SiO_2	53.17	50.58	50.05	55.95	49.72	51.19	56.91	49.06	52.63	51.94	50.53	55.12
Al_2O_3	18.19	17.41	17.09	18.65	18.07	16.78	18.17	17.57	18.33	17.04	17.23	17.71
TiO_2	1.42	1.33	1.50	1.15	1.32	1.57	0.95	1.23	1.23	1.72	1.33	1.65
$FeO^{\dagger}$	7.70	11.37	12.83	6.72	11.13	9.33	6.01	11.14	7.70	10.24	11.08	8.42
MnO	0.14	0.18	0.23	0.14	0.18	0.16	0.11	0.18	0.14	0.17	0.17	0.14
CaO	8.68	8.55	8.76	8.12	9.53	8.70	7.22	9.47	8.27	8.65	8.62	7.95
MgO	6.62	7.79	7.40	5.76	7.19	7.81	5.03	8.80	6.83	7.43	7.92	3.80
K_2O	1.13	0.20	0.09	0.79	0.04	1.14	1.32	0.00	1.11	0.62	0.59	1.26
Na_2O	2.39	2.27	1.73	2.28	2.46	2.76	3.80	2.20	3.27	1.70	2.11	3.32
P_2O_5	0.38	0.14	0.14	0.23	0.16	0.36	0.27	0.14	0.28	0.29	0.21	0.42

Column number	*Location*
1	Flow, NE¼NW¼ sec. 6, T. 1 N., R. 1 E., Portland quadrangle, Oregon. Collected along West Burnside Road east of Mount Calvary cemetery
2	Flow, NW¼SW¼ sec. 30, T. 1 N., R. 5 E., Bridal Veil quadrangle, Oregon. Collected above Old Scenic Highway west of Crown Point
3	Flow, center sec. 28, T. 1 N., R. 5 E., Bridal Veil quadrangle, Oregon. Collected at 120-m elevation on old logging road between Sheppard's Dell Park and Barr Road
4	Flow, SW¼SE¼ sec. 17, T. 1 N., R. 5 E., Bridal Veil quadrangle, Washington. Collected in road-cut on Highway 14 east of unnamed creek
5	Flow, NE¼NE¼ sec. 27, T. 1 N., R. 5 E., Bridal Veil quadrangle, Oregon. Collected at 365-m elevation on Palmer Mill Road
6	Flow, NW¼NW¼ sec. 26, T. 1 N., R. 5 E., Bridal Veil quadrangle, Oregon. Collected at 390-m elevation above Palmer Mill Road
7	Flow, NE¼SW¼ sec. 17, T. 1 N., R. 6 E., Bridal Veil quadrangle, Oregon. Collected at 480-m elevation in Multnomah Creek along the Larch Mountain trail (#441)
8	Flow, NE¼NW¼ sec. 7, T. 1 N., R. 7 E., Bonneville Dam quadrangle, Oregon. Collected at 640-m , elevation on Nesmith Point trail (#428)
9	Dike(?), SE¼NE¼ sec. 22, T. 2 N., R. 7 E., Bonneville Dam quadrangle, Oregon. Collected at 61-m elevation on the Eagle Creek campground road
10	Dike, T. 1 S., R. 8 E., Cherryville quadrangle, Oregon. Collected at the 550-m elevation in Blazed Alder Creek, Bull Run Watershed
11	Flow, SE¼SE¼ sec. 35, T. 4 S., R. 5 E., Fish Creek quadrangle, Oregon.
12	Dike, SE¼NW¼ sec. 22, T. 1 N., R. 9 E., Hood River quadrangle, Oregon. Collected at 370-m elevation along the Hood River below the Hood River Highway.

portion of the ancestral Columbia River that occupied the Bridal Veil channel through the Miocene Cascade Mountains. During this period of time, from approximately 12 to 6 m.y. ago, the ancestral Columbia River quietly deposited lower member Troutdale sands and gravels in the Bridal Veil channel to which it was confined. During the same period, Rhododendron volcanic activity in the Cascade Mountains episodically produced several lahars which found their way into the Bridal Veil channel and were subsequently covered and preserved by lower member Troutdale gravels (Figure 9). Overall, however, this phase of Cascadian volcanism had little discernible impact on the Bridal Veil channel.

This quiet period ended between 6 to 4 m.y. ago with the onset of High Cascade and Boring volcanism that produced high-alumina basalt flows that repeatedly reached the Bridal Veil channel. Phreatic brecciation of the basaltic lavas flowing into the ancestral Columbia River produced vast amounts of the hyaloclastic debris that now defines the upper member of the Troutdale Formation. This repeated influx of hyaloclastic debris resulted in the rapid aggradation of the Bridal Veil channel that eventually allowed the ancestral Columbia River to escape the confines of the Bridal Veil channel. Continued local basaltic volcanism eventually forced the ancestral Columbia River to the north of the Bridal Veil channel and finally capped this former course.

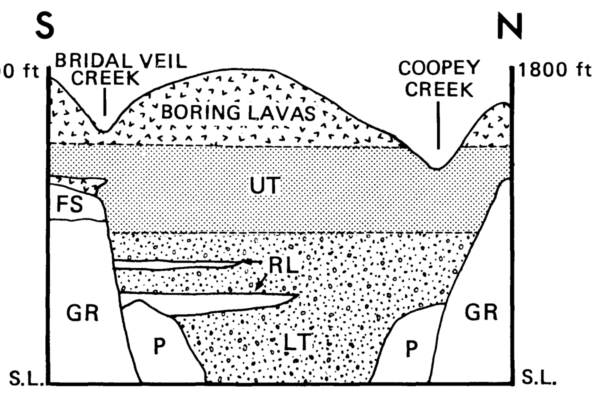

Figure 9. Generalized cross section through the Bridal Veil channel at Bridal Veil, Oregon. Stratigraphic units: GR = Grande Ronde Basalt, FS = Frenchman Springs Member of the Wanapum Basalt, P = Pomona Member of the Saddle Mountains Basalt, RL = Rhododendron lahars, LT = lower Troutdale member, UT = upper Troutdale member. From Tolan and Beeson (1984, p. 474).

PRESENT-DAY GORGE

The incision of the present-day Columbia River Gorge, which began with the onset of uplift related to the present-day High Cascades (Lowry and Baldwin, 1952; Trimble, 1963; Baldwin, 1981), marked the end of Troutdale deposition. Field relationships tentatively suggest that the onset of Cascadian uplift may have begun as late as 2 m.y. ago.

West of the rising High Cascades, the Columbia River began to cut its present-day canyon near where the more resistant Columbia River basalt laps out against older, less resistant volcanic and sedimentary rocks. The Columbia River was prevented from reoccupying and incising a new canyon in its former site by the high-alumina basalt flows that capped this pathway. East of the rising Cascades, the Columbia River appears to have begun to incise its canyon along the northern margin of the Bridal Veil channel. Thus the present-day course of the Columbia River was established.

The Columbia River Gorge was widened in Pleistocene time by catastrophic floods that resulted from the failure of glacial dams which had created ice marginal lakes northeast of the Columbia Plateau (Bretz and others, 1956; Baker and Nummedal, 1978). Other than widening and sculpting the Gorge, these floods had no lasting impact on the course of the Columbia River through the Cascades.

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NEXT MONTH: FIELD TRIP GUIDE

Publications available from AGI

One revised directory and one new publication are available from the American Geological Institute (AGI), 4220 King Street, Alexandria, VA 22302, phone (800) 336-4764.

The **Directory of Geoscience Departments, United States and Canada**, 22nd edition, fall 1983 ($16.50), includes 28 new departments (for a total of 804) and 503 more faculty names, plus major museum listings and expanded field course/camp information.

A Writer's Guide to Periodicals in Earth Science ($3.50) was published in cooperation with the Association of Earth Science Editors and edited by Wendell Cochran and Mimi Braverman. The aim of the Guide is "to help you find the right journal the first time, and to submit the manuscript in a form the journal's editor is most likely to accept." The Guide lists pertinent information from about 50 earth-science journals. A supplemental list gives the names and addresses for some 70 more international earth-science periodicals. □

NWMA announces annual convention

The 90th annual convention of the Northwest Mining Association (NWMA) will be held in Spokane, Washington, on December 6-8, 1984. The meeting theme will be the long-term future of mining in the United States. Over 2,500 participants are expected. The approximately 80 speakers will address technical, environmental, and management aspects of current concern in the minerals industry.

A pre-convention short course will be held in Spokane on December 3-5, 1984. The course will present the anatomy of a mine feasibility study in a workshop course using ten or more industry experts. The purpose is to provide the participants with a working understanding of the decisions and decision-making means for the development of an ore body from discovery to production.

Further information is available from NWMA, 633 Peyton Building, Spokane, WA 99201, phone (509) 624-1158. □

OIL AND GAS NEWS

Columbia County

Champlin Petroleum Company (Denver, Colo.) has begun drilling their well in northern Columbia County. The well, Puckett 13-36, was spudded June 24 and has a proposed depth of 3,500 ft. The location is 7 mi north of gas production in the Mist Gas Field, in sec. 36, T. 8 N., R. 5 W. The target is Cowlitz Formation, from which production occurs at Mist.

Lane County

The first oil and gas exploratory well in Lane County in nearly thirty years is being drilled near the town of Creswell. Leavitt Exploration and Drilling, a local company, is drilling Maurice Brooks 1 in sec. 34, T. 19 S., R. 3 W. Working one shift per day, progress will be slow to a proposed depth of 3,000 ft.

Douglas County

Hutchins and Marrs have begun work on Great Discovery 2 in early July in sec. 20, T. 30 S., R. 9 W. Proposed depth is 3,500 ft.

Mist gas production

Month	Total Mcf	Field avg. Btu	Total therms
April 1984	162,809	969	1,577,168
May 1984	221,886	968	2,113,191
Cumulative field production through May 1984	17,368,862		

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
264	Reichold Energy Corp. Columbia County 11-10 009-00129	NW¼ sec. 10 T.6 N., R.5 W. Columbia County	Application; 3,500
265	Reichold Energy Corp. Columbia County 43-27 009-00127	SE¼ sec. 27 T.6 N., R.5 W. Columbia County	Application; 2,600

□

GSOC meetings announced

The Geological Society of the Oregon Country (GSOC) holds noon luncheon meetings in the Standard Plaza Building, 1100 SW Sixth Ave., Portland, Oregon, in Room A adjacent to the third-floor cafeteria, and 8 p.m. evening lectures at Portland State University, Room 371, Cramer Hall. Upcoming meetings, topics, and speakers are:

September 7 (luncheon)—*Confucian Country Revisited after 52 Years*, by Hazel Newhouse, geography teacher, retired.

September 14 (lecture)—*Who Is Watching?* by Sally Russell, Friends of the Columbia River Gorge.

September 21 (luncheon)—*Morocco*, by Irma Greisel, science teacher, and Marianne Ott, photographer.

September 28 (lecture)—*Geology Work at Mount St. Helens and Spirit Lake*, by John Sager, chief geologist, U.S. Army Corps of Engineers.

For additional information about the lectures or luncheons, contact Viola L. Oberson, GSOC president, phone (503) 282-3685. □

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

GEOLOGY AND HYDROTHERMAL ALTERATION, GLASS BUTTES, SOUTHEAST OREGON, by Dulcy Annette Berri (M.S., Portland State University, 1982)

The Glass Buttes volcanic complex consists of many domes and individual vents that erupted both rhyolitic and basaltic lavas during the late Miocene to early Pliocene. The east half of the complex, in the vicinity of Little Glass Butte, contains interfingering, finely flow-banded rhyolite and black obsidian flows. The youngest unit, an obsidian, has been dated at 4.9 m.y. East of Little Glass Butte lie two northwest-trending ridges, Antelope and Cascade Ridges, composed of two or more overlapping exogenous domes that formed along northwest-trending faults.

The Brothers fault zone dominates local structure. Fault trends observed are northwesterly, and northeast trends may be conjugate fractures. The concentration of volcanism at Glass Buttes may be due to intersection of the Brothers fault zone with a west-northwest-trending silicic volcanic zone. Ensuing volcanism was bimodal, including glassy rhyolite, and the igneous body fostered a hydrothermal system.

Rhyolites are peraluminous, and silica content ranges from 73 to 79 percent. Growth of spherulites occurred during devitrification of the glassy rhyolites, with slight silica-enrichment during vapor-phase alteration. Hydration and groundwater leaching depleted soda, alumina, and silica in the glass. The plateau surrounding the buttes consists of olivine basalt, and a feldspathic basalt interfingers with rhyolite flows within the complex.

Hydrothermal alteration of rhyolite flows and glass was concentrated along faults in the eastern Glass Buttes. Massive cinnabar-bearing opalite was deposited from rising silica-rich geothermal waters accompanied by mercury-bearing vapors. Silicification occurred into footwall material, and irregular argillic alteration resulted from downward-percolating acidified groundwater.

The hydrothermal system has since cooled off or been plugged by opalite deposits. Eruption of lavas continued after alteration, further sealing the system. Late-stage fumarolic alteration indicates that limited escape of gases occurred through faults in the opalite.

The geothermal reservoir is 600 m or more below the surface. Repeated fracturing and resultant boiling of fluids suggest the potential for precious-metal deposits. Low-temperature fluids producing surface alteration could not transport most epithermal elements that subsequently were concentrated below the opalite cover. The steeply inclined zones of alteration imply a deep hydrothermal system and great depths to potentially economic mineral deposits.

A GEOPHYSICAL STUDY OF THE NORTH SCAPPOOSE CREEK-ALDER CREEK-CLATSKANIE RIVER LINEAMENT, ALONG THE TREND OF THE PORTLAND HILLS FAULT, COLUMBIA COUNTY, OREGON, by Nina Haas (M.S., Portland State University, 1983)

The Portland Hills fault forms a strong northwest-trending lineament along the east side of the Tualatin Mountains. An en-echelon lineament follows North Scappoose Creek, Alder Creek, and the Clatskanie River along the same trend, through Columbia County, Oregon. The possibility that this lineament follows a fault or fault zone was investigated in this study. Geophysical methods were used, with seismic-refraction, magnetic, and gravity lines run perpendicular to the lineament. The seismic-refraction models indicate the near-surface basalt is broken in many places, with 15-30 m (50-100 ft) vertical displacement down to the west at Bunker Hill along the Alder Creek fault. Gravity models required a faulted zone approximately two km wide across the lineament. The proposed fault zone is more clearly defined in the south, becoming more diffuse and branching in the northern part of the study area. The Bouguer gravity values from this study distort the −40 milligal contour farther to the northwest than is shown on the *Complete Bouguer Gravity Anomaly Map of Oregon* by J.W. Berg and J.V. Thiruvathukal, 1967 (Oregon Department of Geology and Mineral Industries Geological Map Series GMS-4b). The existence of sharp topographic features and the geophysical evidence indicate fault activity along the zone.

TRACE ELEMENTS IN VEINS OF THE BOHEMIA MINING DISTRICT, OREGON, by Laurence Stewart Istas (Ph.D., University of Washington, 1983)

Over 200 samples of quartz, rock, and sulfides were collected from the epithermal veins of the Bohemia mining district, Oregon for analysis by neutron activation and electron microprobe. Three major types of vein quartz exist at Bohemia. Type I is 5 percent of the total and has under 150 ppm Al and a few amorphous opaque inclusions. Type II is 85 percent of the total and has over 600 ppm Al, a few amorphous opaque inclusions, and Al micro-impurity zones. Type III is 10 percent of the total and has over 600 ppm Al, a few amorphous opaque inclusions, Al and K micro-impurity zones, and microscopic inclusions of rutile, kaolinite, and sericite. The rutile carries considerable Th, Sc, Hf, V, REE, and other oxide-forming elements. The rutile and silicate inclusions are relict from volcanic rock. All quartz contains fluid inclusions which contain Na and much less than stoichiometric Cl.

Types I and II intergrew on a micron scale. The intergrowth of Types I and II mixes with Type III on a grain-size scale. Type I quartz is interpreted as slow-growth, open-space quartz. Type II quartz is interpreted as fast-growth, open-space quartz. Type III quartz is interpreted as replacement quartz.

The Al in Type I quartz is a lattice substituent and its concentration is controlled by temperature. For Type I quartz, lattice Al is an accurate geothermometer, at least in the range of 250° to 325° C. Ti and Fe enter the quartz lattice at higher temperatures, as in plutonic quartz. Radiation-induced red-orange cathodoluminescence indicates low Al content in vein quartz. Inherent, weak blue, cathodoluminiscence indicates a non-aluminum lattice impurity, probably Ti. As and Sb are lattice substituents in vein quartz from Bohemia and other districts in the Cascades.

Three parameters have positive correlations with higher grades of gold ore: (1) gold content in quartz, (2) presence of low-Al quartz (Type I), and (3) kaolinite/sericite in microscopic inclusions in Type III quartz greater than 2/3. The location of ore at Bohemia is largely controlled by faults and their relationship to the stock. Impurities in quartz do not form zones either in individual veins or over the district, except as indirectly affected by structural control of intensity of alteration and mineralization. Fluids were probably dilute carbonate or bicarbonate solutions with very small amounts of gold. Large volumes of solution were circulated through the veins by convection, driven by plutonic heat. High-grade ore deposits require that the veins be open for long periods, although not necessarily continuously.

Even at this early stage of development, exploration methods based on Type I quartz and kaolinite/sericite in quartz appear to be competitive with and complementary to existing exploration methods using rock alteration or soil analysis for metals. Exploration based on trace gold in quartz and on vein K-feldspar needs to be tested on larger samples. □

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

		Price	No. copies	Amount
GMS-4:	Oregon gravity maps, onshore and offshore. 1967	$ 3.00	_____	_____
GMS-5:	Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00	_____	_____
GMS-6:	Preliminary report on geology of part of Snake River canyon. 1974	6.50	_____	_____
GMS-8:	Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00	_____	_____
GMS-9:	Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00	_____	_____
GMS-10:	Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00	_____	_____
GMS-12:	Geologic map of the Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	3.00	_____	_____
GMS-13:	Geologic map, Huntington and part of Olds Ferry 15-minute quadrangles, Baker and Malheur Counties. 1979	3.00	_____	_____
GMS-14:	Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00	_____	_____
GMS-15:	Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00	_____	_____
GMS-16:	Free-air gravity anomaly map and complete Bouguer gravity anomaly map, south Cascades, Oregon. 1981	3.00	_____	_____
GMS-17:	Total-field aeromagnetic anomaly map, south Cascades, Oregon. 1981	3.00	_____	_____
GMS-18:	Geology of Rickreall, Salem West, Monmouth, and Sidney 7½-minute quads., Marion/Polk Counties. 1981	5.00	_____	_____
GMS-19:	Geology and gold deposits map, Bourne 7½-minute quadrangle, Baker County. 1982	5.00	_____	_____
GMS-20:	Map showing geology and geothermal resources, southern half, Burns 15-minute quad., Harney County. 1982	5.00	_____	_____
GMS-21:	Geology and geothermal resources map, Vale East 7½-minute quadrangle, Malheur County. 1982	5.00	_____	_____
GMS-22:	Geology and mineral resources map, Mount Ireland 7½-minute quadrangle, Baker/Grant Counties. 1982	5.00	_____	_____
GMS-23:	Geologic map, Sheridan 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00	_____	_____
GMS-24:	Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00	_____	_____
GMS-25:	Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00	_____	_____
GMS-26:	Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00	_____	_____
GMS-27:	Geologic and neotectonic evaluation of north-central Oregon: The Dalles $1° \times 2°$ quadrangle. 1982	6.00	_____	_____
GMS-28:	Geology and gold deposits map, Greenhorn 7½-minute quadrangle, Baker/Grant Counties. 1983	5.00	_____	_____
GMS-29:	Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00	_____	_____
GMS-31:	Geology and gold deposits map, NW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00	_____	_____
GMS-32:	Geologic map, Wilhoit 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00	_____	_____

OTHER MAPS

Reconnaissance geologic map, Lebanon 15-minute quadrangle, Linn/Marion Counties. 1956	3.00	_____	_____
Geologic map, Bend 30-minute quad., and reconnaissance geologic map, central Oregon High Cascades. 1957	3.00	_____	_____
Geologic map of Oregon west of 121st meridian (U.S. Geological Survey Map I-325). 1961	5.50	_____	_____
Geologic map of Oregon east of 121st meridian (U.S. Geological Survey Map I-902). 1977	5.50	_____	_____
Landforms of Oregon (relief map, 17×12 in.)	1.00	_____	_____
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	$8.00 over the counter; $11.00 mailed	_____	_____
Geothermal resources of Oregon (map published by NOAA). 1982	3.00	_____	_____
Geological highway map, Pacific Northwest region, Oregon/Washington/part of Idaho (published by AAPG). 1973	5.00	_____	_____

BULLETINS

33.	Bibliography of geology and mineral resources of Oregon (1st supplement, 1937-45). 1947	3.00	_____	_____
35.	Geology of the Dallas and Valsetz 15-minute quadrangles, Polk County (map only). Revised 1964	3.00	_____	_____
36.	Papers on foraminifera from the Tertiary (v.2 [parts VI-VIII] only). 1949	3.00	_____	_____
44.	Bibliography of geology and mineral resources of Oregon (2nd supplement, 1946-50). 1953	3.00	_____	_____
46.	Ferruginous bauxite deposits, Salem Hills, Marion County. 1956	3.00	_____	_____
49.	Lode mines, Granite mining district, Grant County. 1959	3.00	_____	_____
53.	Bibliography of geology and mineral resources of Oregon (3rd supplement, 1951-55). 1962	3.00	_____	_____
61.	Gold and silver in Oregon. 1968	17.50	_____	_____
62.	Andesite Conference guidebook. 1968	3.50	_____	_____
65.	Proceedings of the Andesite Conference. 1969	10.00	_____	_____
67.	Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	3.00	_____	_____
71.	Geology of selected lava tubes, Bend area, Deschutes County. 1971	5.00	_____	_____
77.	Geologic field trips in northern Oregon and southern Washington. 1973	5.00	_____	_____
78.	Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	3.00	_____	_____
81.	Environmental geology of Lincoln County. 1973	9.00	_____	_____
82.	Geologic hazards of Bull Run Watershed, Multnomah and Clackamas Counties. 1974	6.50	_____	_____
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84.	Environmental geology of western Linn County. 1974	9.00	_____	_____
85.	Environmental geology of coastal Lane County. 1974	9.00	_____	_____
87.	Environmental geology of western Coos and Douglas Counties. 1975	9.00	_____	_____
88.	Geology and mineral resources, upper Chetco River drainage, Curry and Josephine Counties. 1975	4.00	_____	_____
89.	Geology and mineral resources of Deschutes County. 1976	6.50	_____	_____
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