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PRELIMINARY RECONNAISSANCE GEOLOGIC MAPS OF THE COLUMBIA RIVER BASALT GROUP IN PARTS OF EASTERN WASHINGTON AND NORTHERN IDAHO

By

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Introduction

The Columbia River Basalt Group comprises a tholeiitic flood-basalt province of moderate size, covering an area of about 2 x 10^5 km^2 with an estimated volume of about 2 x 10^5 km^3 (Waters, 1962). The group is the youngest assemblage of flood basalt known, with an age range from about 16.5 to 6 x 10^6 years b.p.; most eruptions took place between about 16.5 and 14 x 10^6 years b.p. (Watkins and Baksi, 1974; McKee and others, 1977).

Wide-ranging regional studies of the basalt, underway for the last 10 years, have been devoted primarily to defining stratigraphic and chemical relations for use in unraveling the history of the province and comparing the Columbia River basalt with flood basalt elsewhere. Recently, these studies have been accelerated because of the need to know more about the stratigraphy and structure of the basalt as related to potential storage of nuclear waste within the basalt pile. The accompanying maps are an initial result of this accelerated effort. These maps, together with a map of southeast Washington (Swanson and others, 1977; updated version by Swanson and others, 1979a), provide an overview of the basalt in much of eastern Washington and northern Idaho north of the Clearwater embayment. Large unmapped areas remain in Washington; these are scheduled to be completed in 1979, after which a map of the basalt throughout eastern Washington will be prepared. The accompanying maps are preliminary, as only limited field checking has been completed, and certain inconsistencies exist, particularly in a poorly exposed area along the border of the Yakima and Wenatchee quadrangles. The maps will be upgraded in the summer of 1979 but are being issued now in order to make them available to other workers and to fulfill agreements with the U.S. Department of Energy.

We conducted most of the geologic mapping in 1978, supported by 180 chemical analyses from Washington State University and previous analyses from the U.S. Geological Survey; the analyses helped greatly in checking flow correlations. Older geologic maps were consulted, but recent advances in stratigraphic knowledge of the basalt required remapping. Mapping was rapid, generally consisting of extrapolating between exposures rather than walking out contacts. The maps are thus termed reconnaissance, although we believe that they portray most significant features accurately at the scale of presentation. Mapping in 1978 was conducted by full-time and temporary personnel of the U.S. Geological Survey under Interagency Agreement No. EW-78-I-06-1978 with the U.S. Department of Energy in support of the Basalt Waste Isolation Program, administered by Rockwell Hanford Operations, Richland, Washington.

General aspects

The Columbia River Basalt Group is characterized by most features considered typical of flood-basalt provinces. Flows are voluminous, typically 10-30 km^3 with maximum volume of 700 km^3, and many cover large areas, as much as 40,000 km^2. They generally advanced as sheetfloods, rather than as channelized or tube-fed flows, and form thick cooling units composed of one or more thinner flows. Eruptions took place from fissure systems tens of kilometers long. Small spatter ramparts formed but are poorly preserved owing to bulldozing by flows and later erosion. Cinder cones are very rare. In these and other features, the Columbia River basalt contrasts with that produced by basaltic plains or oceanic volcanism (Greeley, 1977).

The flows cover a diverse assemblage of rocks (see Description of Map Units) on an erosional surface of considerable local relief, 1000 m or more in places, near the margin of the Columbia Plateau. Some of the prebasalt hills today stand high above the plateau surface, especially in the Spokane quadrangle. Little is known about the nature of the rocks or prebasalt surface beneath the central part of the plateau. Sparse evidence suggests that a thick weathered or altered zone caps a sequence of lower Tertiary volcanic rocks beneath the Pasco Basin (Raymond and Tillson, 1968; Newman, 1970; Jackson, 1975; Swanson and others, 1979b).

Stratigraphy

Formal stratigraphic subdivision of the Columbia River Basalt Group has recently been made (Swanson and others, 1979b) (fig. 1). Considerable effort was expended in doing this, in order to provide a strong framework for topical studies. Some additional flows have been found in Idaho and Oregon since the nomenclature was established, but they can easily be fit into one of the three formations in the Yakima Basalt Subgroup (fig. 1).

The criteria used to recognize specific stratigraphic units include petrography, magnetic polarity, and chemical composition. Petrography and magnetic polarity can be evaluated in the field and, taken together in overall stratigraphic context, are generally reliable. Chemistry is an invaluable guide to check and correct field identifications. In fact, use of chemical analyses for correlation purposes is so rewarding, and necessary in places, that no field study of the basalt should be undertaken without provision for chemistry.

The formal stratigraphic units have been described in detail by Swanson and others (1979b), Swanson and Wright (1978), and Camp and others (1979); only general statements are made here.

Imnaha and Picture Gorge Basalts

Neither of these two formations crops out within the area covered by the accompanying maps.

Outcrops of the Imnaha Basalt are confined to extreme southeast Washington, northeast Oregon, and adjacent Idaho, where feeder dikes are known. Whether the Imnaha occurs farther west beneath younger rocks is conjectural. It covers a surface of rugged local relief and has an aggregate thickness of more than 500 m.

The Picture Gorge Basalt is apparently coeval with part of the Grande Ronde Basalt, as judged by interbedded relations (Cockerham and Bentley, 1973; Nathan and Fruchter, 1974) and reconnaissance magnetostratigraphic work (R. D. Bentley and D. A. Swanson, unpub. data, 1977). It crops out only in and surrounding the John Day Basin in north-central Oregon, where feeder dikes comprise the Monument dike swarm (Waters, 1961; Fruchter and Baldwin, 1975). Possibly the ancestral Blue Mountains uplift kept most flows from spreading northward out of the basin. The formation is at least 800 m thick; Thayer and Brown (1966) report a thickness of more than 1,800 m at one locality, although faulting may have duplicated part of the section.

Grande Ronde Basalt

The Grande Ronde Basalt is the oldest formation of the Columbia River Basalt Group shown on the accompanying maps. It is the most voluminous and areally extensive formation in the group, underlying most of the Columbia Plateau with an estimated volume of more than 150,000 km^3. Its thickness varies widely depending on underlying topography; the thickest known section exceeds 1000 m in drill holes in the Pasco Basin, and sections 500-700 m thick occur in the Blue Mountains and other uplifted or deeply incised areas. The Grande Ronde is subdivided into four magnetostratigraphic units on the basis of magnetic polarity; these units provide the only regionally useful subdivisions of the formation. Feeder dikes occur throughout the eastern half of the plateau and are apparently not confined to distinct swarms as formerly thought (Waters, 1961). The Grande Ronde conformably overlies the Imnaha Basalt and underlies the Wanapum Basalt. Commonly a thick soil, and locally sediments, occur on top of the Grande Ronde; they indicate a significant time break, although probably no longer than a few tens of thousands of years based on local interbedded relations between the Grande Ronde and Wanapum Basalts in southeast Washington (Swanson and others, 1979b).

Wanapum Basalt

The Wanapum Basalt is the most extensive formation exposed on the surface of the Columbia Plateau in Washington but is much less voluminous than the Grande Ronde, probably having a volume of less than 10,000 km^3. On a local scale, the Wanapum overlies the Grande Ronde conformably, except for minor erosion or interbedding. On a regional scale, however, the Wanapum overlies progressively older basalt from the center toward the eastern margin of the plateau. Such onlap is not apparent along the northern and western margins, as the accompanying maps show. These relations suggest that the plateau had tilted westward before Wanapum time. We discuss the timing of this tilting later in this summary.

The oldest member of the Wanapum Basalt, the Eckler Mountain Member, occurs fairly extensively in southeast Washington (Swanson and others, 1979a) but was recognized only in the St. Maries, Idaho, area on the accompanying maps. A possible vent for the one or more flows in this area is just north of Clarkia, Idaho.

The Frenchman Springs Member crops out widely in the western, as well as southeastern (Swanson and others, 1979a), part of the plateau. Its volume is probably 3,000 to 5,000 km^3. Generally three to six flows, in places as many as ten, occur in any one section. Flows were erupted from north-northwest trending dikes extending through the Walla Walla area of southeast Washington (Swanson and Wright, 1978; Swanson and others, 1979a). Highly porphyritic flows, possibly of local derivation, are distinguished with difficulty from the Roza Member in the Soap Lake area; these flows may have erupted along the northward extension of the known feeder system.

The Roza Member is well known, and readers are referred to papers by Lefebvre (1970) and Swanson and others (1975; 1979b), as well as the accompanying Description of Map Units for background information. The general distribution of the Roza (see accompanying maps and that by Swanson and others, 1979a) suggests that the central part of the Columbia Plateau had begun to subside (relative to its margins; absolute subsidence is not implied) before Roza time, as the member pinches out toward the west and northwest margins of the plateau as well as toward the east margin. The occurrence of the Roza near the north margin of the plateau north of Wilbur appears to violate this scheme; however, this area is along the projected trend of the Roza's vent system (Swanson and others, 1975), and the flow near Wilbur may have been erupted locally from a fissure cutting the flank of the gentle subsidence basin.

General characterization of the Priest Rapids Member is given in the Description of Map Units and by Swanson and others (1979b). It is the youngest member throughout most of the northern part of the Columbia Plateau. Feeder dikes occur near Orofino, Idaho, south of the mapped area (W. H. Taubeneck, T. L. Wright, and D. A. Swanson, unpub. chemical data, 1977; V. E. Camp, unpub. map, 1978), and a probable vent is located near Emida, Idaho. However, more vents must exist, as intracanyon flows of the member extend far up the ancestral St. Joe River valley. These flows are not highly pillowed, suggesting that they were erupted from an upstream vent, dammed the river, and flowed down a nearly dry valley, rather than back-filling a valley down which a river was pouring. Moreover, Griggs (1976) measured flow directions showing downstream movement in the Priest Rapids Member along Coeur D'Alene Lake. We looked for, but did not find, vents along the St. Joe drainage system, but we feel that they must be present. Griggs' flow directions along the St. Maries River show dominant upvalley movement, consistent with the presence of abundant pillow and hyaloclastite complexes signifying interaction with a major river. In and near Spokane, flows of the Priest Rapids Member fill valleys as much as 100 m deep eroded into the Latah Formation, which was deposited directly on the Grande Ronde Basalt. These ancient valleys virtually coincide with the modern valleys of Hangman Creek, Spokane River, Rathdrum Prairie, and the low area between Spokane and Chattaroy.

Saddle Mountains Basalt

This formation is the youngest in the Columbia River Basalt Group, about 13.5 to 6 x 10^6 m.y. old, and contains flows erupted during a period of waning volcanism, deformation, canyon cutting, and development of thick but local sedimentary deposits between flows. The Saddle Mountains Basalt has a volume of only about 2,000 km^3, less than one percent of the total volume of basalt, yet contains by far the greatest chemical and isotopic diversity of any formation in the group.

The Umatilla is one of the most extensive members in the formation. In Washington, the Umatilla occurs in two separated areas--in extreme southeast Washington (in the Troy and Lewiston basins and Uniontown Plateau) (Swanson and others, 1979a) and in south-central Washington mostly west of the Columbia River and south of Yakima Ridge. These two areas are connected across northern Oregon by remnants of the Umatilla filling a broad shallow valley leading from its source in southeast Washington and neighboring Oregon to the south-central part of the plateau (D. A. Swanson and T. L. Wright, unpub. map, 1978). The valley crosses the presentday Blue Mountains near Tollgate, Oregon. The Umatilla spread out from the mouth of the broad valley, probably in the Milton-Freewater area, to form a sheet flood covering much of south-central Washington. Lava was channelled along some canyons eroded during post-Wanapum time, as along Yakima Ridge. The Umatilla provides the earliest evidence of extensive erosion and canyon-cutting of Columbia River basalt on the Columbia Plateau, although erosion of basalt was substantial in the Columbia River Gorge before Priest Rapids time (Beeson and Moran, 1979; Melvin H. Beeson, oral commun., 1978).

The Wilbur Creek and Asotin Members were erupted in southeast Washington or, more likely, the Clearwater embayment of Idaho. From there, the flows advanced down valleys and gorges leading from the Uniontown Plateau to the central part of the Columbia Plateau; remnants of valley-filling flows occur in the LaCrosse area, on Rattlesnake Flat, near Warden and Othello, and elsewhere (Swanson and others, 1979a). The flows crossed the northern part of the Pasco Basin and moved down canyons along Yakima Ridge as far west as Yakima. The flows overlie quartzitic gravel of extra-plateau derivation along Yakima Ridge and clearly trace a westward course of the ancestral Columbia River from the Pasco Basin to Yakima. These two members, and the younger Esquatzel Member(?), are not separated on the accompanying map of Yakima Ridge, as we recognized the presence of the Asotin and Esquatzel (?) on the basis of chemistry after mapping was recessed.

The Esquatzel Member(?) apparently followed a similar course along Yakima Ridge but occupied different valleys and canyons farther upstream. The Esquatzel occurs as isolated intracanyon remnants along and just north and west of the modern Snake River upstream from the Devils Canyon area (Swanson and others, 1979a). It apparently was erupted within the ancestral Snake drainage, flowed downcanyon, and then either crossed an interfluve into the ancestral Columbia drainage or flowed directly into the Columbia if the two rivers joined in the central part of the plateau at that time. The evidence from the Wilbur Creek, Asotin, and Esquatzel Members indicates that the dominant drainage direction was westward across the Columbia Plateau at that time and involved ancestors of the Snake, Columbia, and possibly Palouse Rivers.

The Pomona and Elephant Mountain Members are well known through the work of Schmincke (1967b). Mapping in southeast Washington (Swanson and others, 1979a) shows that flows of both members were erupted in extreme northeast Oregon or western Idaho and flowed down the ancestral Snake River canyon before spilling onto the plateau surface near Mesa. Flows of both members occur as broad sheet floods across much of the western part of the plateau, but their distribution even here was locally governed by developing, structurally-controlled topography. For example, the Pomona fills a deep, narrow canyon, possibly of the ancestral Columbia, along Yakima Ridge, and both members are confined to a broad, structurally low area across the Horse Heaven Hills and Plateau.

The three youngest members, the Buford, Ice Harbor and Lower Monumental, do not occur in the map area. The Buford is confined to a small area in northeast Oregon and adjacent Washington, where it must have been erupted. The Ice Harbor was erupted from north-northwest fissures in the Basin City-Ice Harbor-Reese area on the east limb of the Pasco Basin, and flows are found only in the eastern and southern part of the Pasco Basin and the lower Walla Walla River area. The Lower Monumental Member is confined to the present-day Snake River canyon throughout its known extent from Lewiston, Idaho, to Devils Canyon, Washington (Swanson and others, 1979a).

Vent systems

One of the major findings of recent mapping has been identification of sources for most stratigraphic units and even single flows. Criteria such as dikes (filled fissures), spatter, thick piles of degassed flows, and abundant collapsed pahoehoe (Swanson, 1973) have been used to define vent areas for flows in all formations and members except the Wilbur Creek, Asotin, Esquatzel, Pomona, Buford, and Lower Monumental Members of the Saddle Mountains Basalt. The vents lie along north to north-northwest dikes; thus vent systems for related flows are elongate parallel to the dikes.

Sources for the Grande Ronde Basalt are distributed across the eastern half to two-thirds of the Columbia Plateau, but those for other units are more restricted (Swanson and Wright, 1979a). For example, dikes for the Picture Gorge Basalt are confined within the John Day Basin and neighboring areas, those for the Frenchman Springs Member within a zone 60 km wide and probably more than 200 km long, and those for the Ice Harbor Member within a zone 15 km wide and about 90 km long. On a still finer scale, vent systems for specific flows are nearly linear, as they occur along single dikes or closely spaced related dikes. Examples are the vent system for the Roza Member (probably less than 5 km wide and now known to be more than 165 km long [Swanson and others, 1975; P. R. Hooper, unpub. map, 1978]), the basalt of Robinette Mountain in the Eckler Mountain Member (a single dike extending at least 25 km across the Blue Mountains), the basalt of Basin City in the Ice Harbor Member (possibly a single dike at least 50 km long), and several chemically distinct flows in the Grande Ronde Basalt (T. L. Wright and D. A. Swanson, unpub. data, 1978). Knowledge of the geometry of the vent systems allows prediction of where vents for specific flows should occur once one such vent is found. It further provides fundamental constraints relating to problems of magma generation, storage, and eruption mechanics.

Invasive flows

Weakly consolidated sedimentary rocks, generally medium-grained sandstone and finer-grained rocks, occur between many flows near the margin of the plateau and between some of the younger flows in local structural basins on the plateau. The sedimentary rocks rest depositionally on the underlying flow in many places, but in many others the contact relations show that the subjacent basalt intrudes or invades the sediment. Schmincke (1967c) was one of the first to recognize this, and recent work has demonstrated how common such invasive relations are. We estimate that more than half of the observed contacts between basalt and sedimentary rocks on the Columbia Plateau are invasive.

How are such contacts interpreted? Do they signify "normal" intrusive relations, in which basaltic magma never reached the surface before solidifying as in classic dikes and sills, or are they formed as lava flows burrow into unconsolidated sediments accumulating on the ground surface (invasive flows of Byerly and Swanson, 1978)? Both processes produce similar results.

The key to proper interpretation lies in the stratigraphy. If the basalt is at its proper stratigraphic position relative to overlying flows, it almost certainly was a flow that invaded sediments at the ground surface. This is because thin sedimentary deposits, generally less than 10 m thick on the plateau, are light and hence exert little confining pressure; vesiculating magma rising and encountering such sediments would certainly blast through rather than spreading laterally into them.

Mapping and chemical studies have shown that, in every example so far found on the plateau, the invasive basalt is at its expected stratigraphic position relative to overlying flows and hence is an invasive flow (Schmincke, 1967c; Camp, 1976; Byerly and Swanson, 1978; D. A. Swanson, G. R. Byerly, and T. L. Wright, unpub. data, 1978). We include in this interpretation two thick sills previously interpreted in the classic sense (Hammond sill of Hoyt, 1961, and the "Whiskey Creek sills" of Bond, 1963); work in both areas (Byerly and Swanson, 1978 and unpub. data; V. E. Camp, unpub. data, 1978) shows that even these thick sills are in proper stratigraphic position relative to overlying flows.

These conclusions are significant, because they show that invasive relations provide insufficient, and in fact probably totally misleading, evidence for the former presence of magma beneath the area.

For example, invasive relations are particularly well displayed along the northwest margin of the plateau, where all other evidence negates the former presence of magma bodies; no intrusive relations are found here in any situation other than one involving sediments, and the invading flows are in their proper stratigraphic position relative to other flows. Invasive relations also demonstrate the unreliability of using sedimentary interbeds as stratigraphic guides on the Columbia Plateau. The basalt flows are always in their proper stratigraphic position, but the interbeds, at least fine-grained ones, are commonly not, owing to rafting by invasive flows.

Deformation

Folds and faults

We restrict this brief discussion to the area covered by the accompanying maps.

The northeast part of the Columbia Plateau is little deformed. Prominent zones of regional joints near Cheney, first recognized by Griggs (1973), lie along projections of major structures in older rocks in northern Idaho and may reflect either slight post-Priest Rapids movement or adjustment of the basalt pile to structurally-controlled topography in underlying rocks.

The northwestern and western parts of the plateau are strongly folded and faulted in places. The structures have different trends in different areas (see accompanying maps), and no single stress system seems satisfactory to account for all the structures. Folding began at least as early as the end of Grande Ronde time, as shown by thinning of a post-Grande Ronde pre-Frenchman Springs sedimentary interbed, the Vantage Member of the Ellensburg Formation, toward the crest of the Naneum Ridge anticline in the Wenatchee Mountains (Tabor and others, in press). Folding during Saddle Mountains time is apparent from unconformities along Yakima Ridge (Holmgren, 1967; R. D. Bentley, unpub. map, 1978) and elsewhere. However, most deformation clearly post-dates Elephant Mountain time; an 8.5 m.y. flow of the Ice Harbor Member occurs near the crest of the Horse Heaven anticline at Wallula Gap, showing later uplift. In all probability, most folding is of late Miocene and Pliocene age.

Most faulting in Washington is associated with folding. Both normal and reverse or thrust faults occur. Presumably faults are the same age as the folds. Faults offset Thorp Gravel in Kittitas Valley (Waitt, 1979) and undated colluvium in northern Oregon 25 km south of Walla Walla.

Efforts are underway to understand the stress regime that produced the deformation of the western part of the plateau. A profitable approach is offered by H. P. Laubscher, as discussed by Kienle and others (1977). No conclusions have yet been reached.

Timing of plateau subsidence

Recent mapping has provided new information related to timing of regional deformation. Much of this information and resulting interpretation is now preliminary, but an eventual outcome of ongoing study is expected to be a reasonably good chronology related to deformation and associated erosion and deposition.

Sedimentary interbeds tell us much about when the Columbia Plateau began to subside, or, more precisely, when the subsidence recognizably affected topography. Interbeds within the Grande Ronde Basalt are common around the margin of the plateau but not in the center, as shown by core from deep holes in the Pasco Basin (Atlantic Richfield Hanford Company, 1976). This relation suggests that marginal areas of the plateau were lower than central areas during at least most of Grande Ronde time. This suggestion is tentatively supported by similar thicknesses of magnetostratigraphic unit N_2 in the Grande Ronde Basalt in and west of the present Pasco Basin (Beck and others, 1978; D. A. Swanson and G. R. Byerly, unpub. data, 1977). Thus, the Pasco Basin, and the plateau in general, apparently did not start to subside until at least late Grande Ronde time. Westward thickening of magnetostratigraphic units in the Grande Ronde Basalt in southeast Washington (Swanson and Wright, 1976), combined with the lack of evidence for plateau subsidence, suggests a regional westward paleoslope across the plateau to the foothills of the Cascade Range possibly maintained by slow westward tilting. A major river, an ancestral Columbia, apparently flowed southward along the crease between the

Cascades and the plateau, as shown by the subarkosic composition of detritus in interbeds in the Wenatchee Mountains (Tabor and others, in press) and the Tieton River area west of Yakima (Swanson, 1967).

The ancestral Columbia River was flowing onto the plateau southeast of Wenatchee at the end of Grande Ronde volcanism, as the subarkose of the Vantage Member of the Ellensburg Formation, presumably deposited by the ancestral Columbia, thins both east and west of the presentday Columbia between Cresent Bar and the Frenchman Hills (Tabor and others, in press). The Columbia was apparently diverted onto the plateau by the rising Naneum Ridge anticline, which created the Wenatchee Mountains and the Hog Ranch axis of Mackin (1961).

This diversion does not necessarily imply that subsidence of the plateau had also begun. In other words, the effects of relatively local uplift and regional subsidence have not yet been distinguished. However, two related statements can be made: 1) no river, ancestral Columbia or otherwise, flowed along the margin of the Columbia Plateau crease south of the Wenatchee Mountains at a later time, suggesting either Cascade uplift, plateau subsidence, or both; 2) the Pasco Basin did not become an important topographic feature until much later, probably after Elephant Mountain time. This second point is supported by 1) paleocurrent directions measured by Schmincke (1967a), which do not converge on the Pasco Basin: 2) the presence of canyon-filling Saddle Mountains flows overlying Columbia River-type gravel extending across the northern part of the Pasco Basin and along Yakima Ridge; and 3) the long distance that sheet flows of the Pomona and Elephant Mountain Members advanced west of the present basin. The distribution of the Roza and possibly the Priest Rapids Members suggests that the western margin of the plateau was higher than the central part during late Wanapum time; this may reflect early episodic subsidence, Cascade uplift, influence of local uplifts, or some combination of these factors.

Available evidence suggests that regional subsidence, if initiated before Elephant Mountain time, must have been centered west of the presentday Pasco Basin. Our feeling is that such subsidence as reflected by topography did not become prominent until post-Elephant Mountain time. The distribution of the conglomerate of Snipes Mountain southwest of the present day Pasco Basin is consistent with such late subsidence.

The reconstructed gradient of the ancestral Snake River upstream from Devils Canyon during Lower Monumental time (about 6 m.y.b.p.) is similar to that of the modern Snake. We interpret this to indicate little if any westward tilting of the east limb of the plateau in the last 6 m.y. (Swanson and Wright, 1979b). Accordingly, regional subsidence was essentially completed by this time, and subsequent deformation has been of more local character, possibly including that creating the modern Pasco Basin itself.

Most of the Columbia River Basalt Group was erupted before about 14 m.y.b.p. If subsidence of the plateau prior to Elephant Mountain time (about 10.5 m.y.b.p.) was insufficient to affect topography, then it seems unlikely that this subsidence reflected isotatic adjustment to the thick basalt pile; otherwise, it would have begun much earlier. Consequently, plateau subsidence probably has its ultimate cause in tectonism, not isostatic response.

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Series	Group	Subgroup	Formation	Member	K-Ar age (m.y.)	Magnetic polarity
Upper Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	Lower Monumental Member	6[3]	N
				Erosional unconformity		
				Ice Harbor Member		
				basalt of Goose Island	8.5[3]	N
				basalt of Martindale	8.5[3]	R
				basalt of Basin City	8.5[3]	N
				Erosional unconformity		
				Buford Member		R
				Elephant Mountain Member	10.5[3]	N,T
				Erosional unconformity		
Middle Miocene				Pomona Member	12[3]	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		
				Wilbur Creek Member		N
				Umatilla Member		N
				Local erosional unconformity		
			Wanapum Basalt	Priest Rapids Member		R_3
				Roza Member		T, R_3
				Frenchman Springs Member		N_2
				Eckler Mountain Member		
				basalt of Shumaker Creek		N_2
				basalt of Dodge		N_2
				basalt of Robinette Mtn.		N_2
Lower Miocene			Grande Ronde Basalt		14-16.5[2]	N_2
						R_2
			Picture Gorge Basalt[4]	(basalt of Dayville; basalt of Monument Mtn.; basalt of Twickenham)[1]	(14.6-15.8)[1,2]	N_1
			?			R_1
			Imnaha Basalt[4]			R_1
						T
						N_0
						R_0?

[1] Information in parentheses refers to Picture Gorge Basalt

[2] Data mostly from Watkins and Baksi (1974)

[3] Data from McKee and others (1977)

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

Figure 1.--Stratigraphic nomenclature, age, and magnetic polarity for units within the Columbia River Basalt Group. N, normal polarity. R, reverse polarity. T, transitional polarity. Subscripts refer to magnetostratigraphic units of Swanson and others (1977; 1979a). Geologic time scale from Berggren and Van Couvering (1974).

EXPLANATION

Contact, approximately located; dotted where concealed

High-angle fault; bar and ball on downthrown side where known; dotted where concealed

Thrust fault; sawteeth on upper plate; dotted where concealed

Strike-slip fault, showing relative horizontal movement; dotted where concealed

Crest of anticline, showing direction of plunge; dashed where approximately located; dotted where concealed

Trough of syncline, showing direction of plunge; dashed where approximately located; dotted where concealed

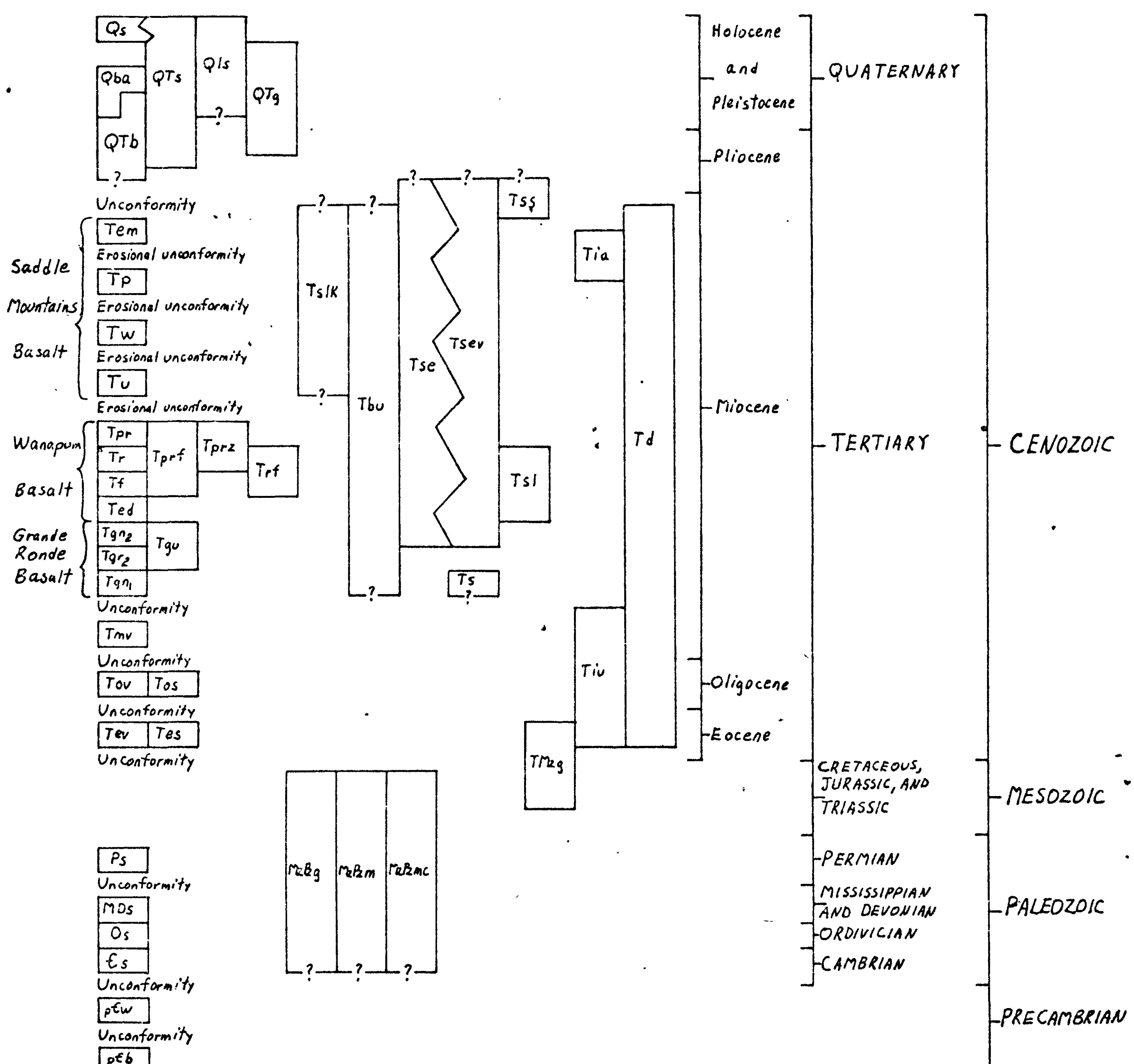
Axis of monocline, showing abrupt decrease of dip in direction of arrows; dashed where approximately located; dotted where concealed

Axis of monocline, showing abrupt increase of dip in direction or arrows: dashed where approximately located; dotted where concealed

Prominent regional joints

Vent area

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qs SEDIMENTARY DEPOSITS--Alluvium, morainal and glacial outwash material, and gravel, sand and silt deposited by Missoula floods. Locally includes loess of Palouse Formation. More extensive than shown; generally mapped only where important bedrock relations are obscured

Qls LANDSLIDE DEPOSITS--Poorly sorted chaotic deposits, generally with hummocky topography. Mostly along contact of poorly lithified or clay-rich sediments and overlying flows of Grande Ronde or Wanapum Basalt. Includes deposits of block slides

Qba ANDESITE AND BASALT--Includes Tieton Andesite and overlying flows of olivine basalt in the Tieton and lower Naches River drainages (Becraft, 1950; Swanson, 1978). Tieton Andesite has K-Ar age of about 1 m.y. (Kienle and others, 1979)

QTs LOESS AND RINGOLD FORMATION--Mostly loess of Palouse Formation, but locally includes fine sand and silt possibly correlative to Ringold Formation. More extensive than shown; mapped only where important bedrock relations are obscured

QTg GRAVEL--Includes Thorp Gravel (Waitt, 1979) in Kittitas Valley, Cowiche gravel of Smith (1903) in Cowiche and Ahtanum Creek drainages, and fan, pediment, and high-level terrace gravel elsewhere. Probably mostly Pliocene. Fission-track dates from Thorp Gravel are about 3.7 m.y. (Waitt, 1979)

QTb OLIVINE BASALT--Principally basalt flows and cinder in the Goldendale area (Sheppard, 1967; Sylvester, 1978). Includes olivine basalt flow and cinder in two small areas on Bethel Ridge north of Rimrock Lake (Swanson, 1978). Probably mostly Pliocene. K-Ar dates for flows in the Goldendale area range from 0.9 to 4.5 m.y. (Kienle and others, 1979)

YAKIMA BASALT SUBGROUP OF COLUMBIA RIVER BASALT GROUP

SADDLE MOUNTAINS BASALT--Includes:

Tem — Elephant Mountain Member--Nearly aphyric basalt flows of Elephant Mountain chemical type (Wright and others, 1973). Normal to transitional magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979). K-Ar age about 10.5 m.y. (McKee and others, 1977). Occurs in Frenchman Hills and in Horse Heaven Hills and Plateau

Tp — Pomona Member--Slightly phyric basalt flow of Pomona chemical type (Wright and others, 1973). Contains small phenocrysts of plagioclase, clinopyroxene, and olivine. Reversed magnetic polarity (Rietman, 1966; Choiniere and Swanson, 1979). K-Ar age about 12 m.y. (McKee and others, 1977). Fills shallow valleys in Yakima Ridge-Wenas Creek area and occurs extensively in Horse Heaven Hills and Plateau

Tw — Wilbur Creek Member--Intracanyon basalt flow along south side of Yakima Ridge. Very sparsely plagioclase-phyric. Fine-grained. Normal magnetic polarity. Chemical composition given in Swanson and Wright (1978, table 3.1). May locally include Asotin and Esquatzel Members of Saddle Mountains Basalt.

Tu — Umatilla Member--Fine-grained basalt flow of Umatilla chemical type (Wright and others, 1973). Typified by very even grain size and near lack of phenocrysts. Normal magnetic polarity (Rietman, 1966). Fills ancient canyon along south side of Yakima Ridge and occurs in Horse Heaven Hills and Plateau

Tslk

Basalt of Sprague Lake--Sparsely phyric basalt flow or flows filling shallow ancient valley eroded into Priest Rapids Member in the Lamont-Sprague area southwest of Spokane. Chemically distinct from most other flows of Columbia River Basalt Group (T. L. Wright and D. A. Swanson, unpub. data, 1978). Normal magnetic polarity. Possibly equivalent to Weissenfels Ridge Member of Saddle Mountains Basalt (Swanson and others, 1979)

WANAPUM BASALT--Includes:

Tpr

Priest Rapids Member--Fine to coarse-grained basalt flows with reversed magnetic polarity (Rietman, 1966). Throughout most of mapped area, flows are of Rosalia chemical type (Swanson and Wright, 1978); such flows are nearly aphyric and contain groundmass olivine visible in fine-grained samples. South of a line between Sprague Lake and Rosalia, flows of Lolo chemical type (Wright and others, 1973; Swanson and Wright, 1978) comprise the member; these flows, which overlie those of Rosalia chemical type at Sprague Lake and in the Horse Heaven Hills and Plateau, contain phenocrysts of olivine and commonly plagioclase. A vent area for flows of Rosalia type occurs near Emida, Idaho; pyroclastic material erupted from this vent was recognized by Bishop (1969) but interpreted as laharic debris. Commonly overlies and invades weakly lithified subarkosic sandstone, siltstone, and claystone near border of Columbia Plateau; these sedimentary rocks, generally unmapped because of scale, are assigned to the Latah Formation in the Spokane area and the Ellensburg Formation in the Waterville-Bridgeport area. Feeder dikes reported in Spokane area (Pardee and Bryan, 1926) are invasive flows (Byerly and Swanson, 1978) of Priest Rapids Member in the Latah Formation. Interbedded with volcaniclastic rocks of Ellenburg Formation near Yakima.

Tr

Roza Member--Basalt flows of Roza chemical type (Wright and others, 1973) that consistently contain several percent single, in places clotted, plagioclase phenocrysts averaging nearly 10 mm across and evenly distributed throughout most flows. In places, particularly northeast of Moses Lake, upper vesicular zone of a flow is aphyric or very sparsely phyric. Transitional magnetic polarity (Rietman, 1966) within map area, but this is unreliable criterion for field identification because of overprint of present normal magnetic field. Consists of one or two flows throughout most of map area; three flows may occur in Wilson Creek-lower Grand Coulee area (Lefebvre, 1970). Difficult to distinguish from some porphyritic flows in Frenchman Springs Member in places, especially near Soap Lake. Invasive into diatomite south of Quincy and in Frenchman Hills. Vent areas near Macall and Revere form northernmost known part of linear vent system (Swanson and others, 1975). Member observed to pinch out between Rock and Bonnie Lakes southwest of Spokane and at several places near Columbia River north of Wilbur

Tprz

Priest Rapids and Roza Members, undivided--Shown only where map scale and steep topography prohibit separation

Tf

Frenchman Springs Member--Basalt flows of Frenchman Springs chemical type (Wright and others, 1973). Many flows contain irregularly distributed plagioclase glomerocrysts as much as 50 mm across, but some are virtually aphyric. Generally fine- to medium-grained. Normal magnetic polarity (Rietman, 1966). Overlies subarkosic sandstone and siltstone of Vantage Member of Ellensburg Formation (unmapped in places) along Columbia River; the Vantage thins away from the Columbia and is absent or generally less than 0.5 m thick near the crest of the Wenatchee Mountains, in Moses Coulee and lower Grand Coulee, and along Crab and Wilson Creeks. South of Quincy, underlies unmapped diatomite (Squaw Creek Member of Ellensburg Formation)

Tprf Priest Rapids, Roza, and Frenchman Springs Members, undivided--Shown only where map scale and steep topography prohibit separation

Trf Roza and Frenchman Springs Members, undivided--Shown only where map scale and steep topography prohibit separation

Ted Eckler Mountain Member--Includes one or more coarse-grained, sparsely plagioclase-phyric basalt flows of Dodge chemical type (Swanson and others, 1979b) first recognized by Griggs (1976; his low-Fe Picture Gorge type flows) in St. Maries River drainage of northern Idaho. Probable vent area occurs in T. 43 N., R. 2 W. north of Clarkia. Less porphyritic than most flows in the basalt of Dodge (Swanson and others, 1979a) in southeast Washington. Overlies arkosic sandstone in places

GRANDE RONDE BASALT--Basalt flows, aphyric to very sparsely plagioclase-phyric, comprising thickest and most voluminous formation in Columbia River Basalt Group. Generally fine-grained and petrographically nondistinct. Chemical composition varies within a broad field now termed Grande Ronde chemical type (Yakima chemical type of Wright and others, 1973). In western part of area, flows of high-Mg Grande Ronde chemical type generally overlie flows of low-Mg type in upper part of section. Flows range in thickness from less than 1 m to more than 50 m but are generally between 10 and 20 m. Many flows near margin of Columbia Plateau are invasive into interbedded subarkosic sediments, forming sill-like bodies such as the Hammond sill of Hoyt (1961; Byerly and Swanson, 1978; Swanson and Wright, 1978); such invasive flows are as much as 120 m thick. Covers and laps out on rugged topography developed on older rocks around margins of Columbia Plateau, where flows are commonly pillowed. Divided into magnetostratigraphic units on basis of dominant magnetic polarity

Tgn_2 Upper flows of normal magnetic polarity in Grande Ronde Basalt

Tgr_2 Flows of reversed magnetic polarity in Grande Ronde Basalt

Tgu Flows of unknown magnetic polarity, undivided--Shown only in small area along Naches River where magnetic measurements have not been made

Tgn_1 Lower flows of normal magnetic polarity in Grande Ronde Basalt

Tbu BASALT, UNDIVIDED--Large, columnar-jointed blocks of fresh, plagioclase-phyric basalt at high elevation in Idaho east of Garfield, Washington. Mapped as Columbia River Basalt Group by Griggs (1973). No basalt found in place. Chemical composition unlike any known for Columbia River Basalt Group (T. L. Wright and D. A. Swanson, unpub. data, 1978). Possibly derived from eroded shallow intrusive body. Age unknown, but may correlate with Columbia River Basalt Group.

ELLENSBURG FORMATION--Weakly lithified sedimentary rocks interbedded with and overlying Columbia River Basalt Group in western part of Columbia Plateau. Mapped only where thickness or exposed area permits. Subdivided into three units

Tse Subarkosic deposits--Fluvial and lacustrine sandstone, siltstone, and lesser claystone and conglomerate, consisting chiefly of detritus eroded from rocks older than Columbia River Basalt Group. Mainly found along present or inferred ancestral course of

Columbia River northeast of Kittitas Valley and east of the Hog Ranch axis of Mackin (1961). Commonly host to invasive flows of Grande Ronde Basalt or Priest Rapids Member. In Goldendale area, unit contains significant component of volcanic detritus, as in unit Tsev

Tsev Volcaniclastic deposits--Well to poorly sorted, weakly lithified andesitic to rhyolitic detritus erupted from contemporaneous volcanoes in Cascade Range and transported into area by water, mudflows, air, and locally pyroclastic flows. In mapped area, generally confined to area west of Hog Ranch axis of Mackin (1961). Thickest between Naches River and Wenas Creek, where most of unit is younger than Pomona Member, but also occurs between older flows of Columbia River Basalt Group

Tss Conglomerate of Snipes Mountain--Weakly consolidated river gravel and sand containing abundant quartzite and metavolcanic clasts. Interpreted as channel deposit of ancestral Columbia River on Snipes Mountain (not mapped) and across Horse Heaven Hills and Plateau in post-Elephant Mountain time (Schmincke, 1967a)

Tsl LATAH FORMATION--Weakly lithified, fluvial and lacustrine arkosic sand-, silt-, and claystone in Spokane area. Interbedded through section of Columbia River Basalt Group (Griggs, 1976, fig. 6); thickest deposit between Grande Ronde Basalt and Priest Rapids Member. Host to numerous invasive flows

Ts SANDSTONE AND SILTSTONE--Moderately well-lithified arkosic to subarkosic deposits underlying locally oldest flow of Grande Ronde Basalt along Columbia River north of Wilbur. Sandstone is commonly crossbedded; siltstone is leaf-bearing. At least 20 m thick where mapped, but thinner unmapped deposits occur in many places along northern margin of Columbia Plateau. Apparently conformable with overlying basalt. May be coeval with lower part of Ellensburg and Latah Formations

Tia ANDESITE--Hornblende andesite plugs on and north of Burch Mountain north of Wenatchee. Petrographically similar to volcanic rocks in Ellensburg Formation. K-Ar age of about 11.0 m.y. (R. W. Tabor, oral commun., 1978). May be a source of volcanic debris in Beverly Member of Ellensburg Formation between Elephant Mountain and Pomona Members at Sentinel Gap along the Columbia River just east of map area (Grolier and Bingham, 1978).

Tmv FIFES PEAK FORMATION--Basaltic andesite, andesite, and lesser dacite and rhyolite flows and breccias in Cascade Range. Underlies Grande Ronde Basalt with erosional unconformity. K-Ar and fission-track ages indicate middle and early Miocene age (Hartman, 1973; Vance and Naeser, 1977)

Tov OLIGOCENE VOLCANIC ROCKS--Includes flows, tuffs, and breccias, mostly andesitic and dacitic, in Ohanapecosh Formation and unnamed andesitic to rhyolitic breccia and tuff. Generally zeolitized. Fission-track ages are mid-Oligocene (Vance and Naeser, 1977)

Tos OLIGOCENE SEDIMENTARY ROCKS--Chiefly epiclastic sandstone, shale, and conglomerate of Wenatchee formation of Gresens (1976) in Wenatchee area (Gresens and others, 1977)

Tev EOCENE VOLCANIC ROCKS--In western part of map area, includes Teanaway Basalt, Taneum Andesite, basalt of Frost Mountain of Tabor and others (in press), rhyolite flows and tuff, and Naches formation of Stout (1964). Includes the Sanpoil Volcanics (Pearson and Obradovich, 1977) in a north-northwest-trending zone along and north of the lower part of the Spokane River.

Tes EOCENE SEDIMENTARY ROCKS--Includes the Roslyn and partly correlative Chumstick Formations (Tabor and others, in press; Gresens and others, 1977), the Swauk Formation, and, southwest of Kittitas Valley, the Manastash Formation. Chiefly subarkosic sandstone

Td DIABASE DIKES--Mapped only in two dikes north of Clarkia, Idaho (Hietanen, 1963). Amphibole-bearing. Probably early Tertiary but possibly equivalent to Columbia River Basalt Group

Tiu INTRUSIVE ROCKS--Fine- to medium-grained, commonly porphyritic, generally mafic plugs, dikes, and irregular intrusive bodies. May in part be equivalent to the large batholithic complexes in unit TMzg. In Cascade Range, probably form subvolcanic bodies associated with lower and middle Tertiary volcanism

TMzg PLUTONIC ROCKS--Coarse-grained granitoids, chiefly granodiorite and quartz monzonite, associated with large batholithic complexes in the crystalline terrain along the northern margin of the Columbia Plateau. Includes outliers of the Idaho Batholith. Probably mostly of Cretaceous and Eocene age

MzPzg PLAGIOGRANITE--Highly sheared tonalite and trondhjemite near Rimrock Lake west of Yakima (Swanson, 1978). In fault contact with surrounding rocks

MzPzm METAMORPHIC ROCKS--Chiefly high-grade gneiss, schist, amphibolite, and foliated quartzite. Includes the Swakane Biotite Gneiss between Wenatchee and Entiat and the Methow Gneiss near Pateros north of Lake Chelan. Also includes relatively low-grade metamorphic rocks, particularly greenstone, of the Paleozoic Corvada Group north of the mouth of the Spokane River (Campbell and Raup, 1964) and meta-sedimentary rocks of probable Paleozoic age northwest and south of Rearden (Griggs, 1973; Becraft, 1963)