STRATIGRAPHY AND STRUCTURAL GEOLOGY
OF PORTIONS OF SOUTH-CENTRAL WASHINGTON

by

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A B S T R A C T

In the southwestern part of the Columbia Basin Mio-Pliocene and Pleistocene formations are exposed. The Mio-Pliocene units have distinctive lithologies that can be correlated over hundreds of square miles, thus facilitating detailed structural mapping. The Mio-Pliocene formations are, from oldest to youngest, as follows: the Yakima basalt, the Selah, the Wenas basalt, and the Ellensburg. This sequence comprises a part of two mutually interfingered lithosomes - one of sedimentary rocks and the other of flood lavas. The Yakima basalt sheets and interbedded fluviatile, aeolian, and lacustrine sediments, including diatomite, record regional downwarping and mild localized warping during accumulation. The Selah formation consists essentially of fluviatile and aeolian clastics of volcanic origin derived from the present mountain areas to the west and probably to the north of the Columbia Basin. It also contains clastics apparently derived from erosion of the northern Columbia River drainage area. The Wenas basalt consists of one or two flood lava flows. Locally these flows are arbitrarily assigned to the Selah and Ellensburg formations. The basal part of the Ellensburg formation is similar to the Selah formation. Upper Ellensburg sediments consist largely of debris derived from rising anticlinal ridges. The Pleistocene Ringold formation overlies the Mio-Pliocene succession unconformably.

Petrographically the lavas are tholeiitic and are characterized by andesitic basalts and basaltic andesites. The volcanic-derived

clastics of the Selah and Ellensburg formations and of the sedimentary interbeds in the Yakima basalt consist overwhelmingly of hornblende andesite. The non-volcanic sediments are quartzose sands, and conglomerates containing pebbles of quartzite, basalt, and other rock types. Mixtures of volcanic and quartzose lithologies occur in the sedimentary lithosome and in the Ringold formation.

The anticlinal structures mapped are of three general types: (1) single, convex upward flexures; (2) broad arches with subsidiary flexures; (3) monocline-like structures bounded on one or both sides by subsidiary flexures and locally thrust to the north. In addition to thrust faulting transverse and normal faults are associated with the rise of the anticlines. More recent normal faults have slightly lowered the structural relief of some of the ridges. Two possible modes of genesis for the folding are suggested: (1) folding free of the basement, or (2) folding in direct response to deformation of the basement.

The indicated sequence of events is as follows: (1) accumulation of flood lavas and minor sedimentation accompanied by general downwarping; (2) localized mild differential warping and the accumulation of great volumes of andesitic detritus along with continued lava outpouring and non-volcanic sedimentation; (3) rise of anticlinal ridges and integration of the drainage system into essentially its present form; (4) continued or renewed differential warping and deposition of the Ringold formation; (5) upwarping of that formation to the north and perhaps nearly contemporaneous antithetic faulting.

CONTENTS

TEXT

ILLUSTRATIONS

FIGURES PAGE

TABLE

PLATES

PLATES

APPENDIX B - MAPS AND SECTIONS

STRATIGRAPHY AND STRUCTURAL GEOLOGY
OF PORTIONS OF SOUTH-CENTRAL WASHINGTON

INTRODUCTION

In south-central Washington late Cenozoic geological processes and structures may be conveniently studied where the complex Cascade Mountains grade into the Columbia Basin or Columbia "Plateau". The close relationship between geologic structure and topography facilitates such study, but except for the work of Smith (1903A, 1904) and Waters (1955 A), very little geological mapping has been done in the western part of the Basin. However, several contributions have been made toward the better understanding of the stratigraphy, so that it is now possible to correlate the Columbia River basalt flows and to arrive at structural details hardly possible before.

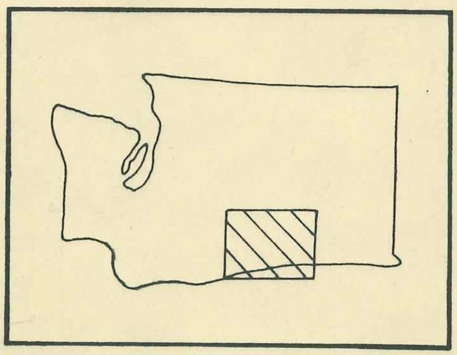


Figure 1.--Index map of Washington State showing general area of study.

The area studied includes some 2,000 square miles of the southwestern part of the Columbia Basin. In this area several anticlinal ridges and broad synclinal valleys extend eastward from spurs and valleys of the Cascade Mountains and, in general, gradually merge with the structure and topography of the Basin proper. The largest upland of the area is the southward sloping Horse Heaven Plateau, rimmed on the north by the Horse Heaven Hills. The Pasco Basin between the Horse Heaven Plateau and Saddle Mountains and the Umatilla Basin south of the Horse Heaven Plateau are local subdivisions of the Columbia Basin and form its topographic and structural lows.

In general the present topography of the anticlinal ridges has been produced by the stripping away of as much as several hundred feet of sediments and lava flows. Along the Columbia River glacial melt water floods of the type described by Bretz (1925) have greatly modified the topography. The Columbia and Yakima Rivers drain the area. Both rivers have antecedent courses through the major ridges in canyons or "gaps" several hundred feet deep, but follow synclinal courses in most of the studied areas. Local topographic relief varies from approximately 1,000 to 2,000 feet.

The climate is a moderate continental, semi-arid type with precipitation averaging about ten inches yearly. In the natural state the soil supports such vegetation as sagebrush and bunch grass, but much of the valley land is cultivated and some of the higher ground, notably the Horse Heaven Plateau, is planted in wheat and other grains.

FIGURE 2

TOPOGRAPHIC QUADRANGLE INDEX

SHOWING GEOLOGICAL MAP AREAS AND LOCATIONS OF MEASURED SECTIONS

CONTOUR INTERVAL 1000 FEET

Modified from U.S. Coast and Geodetic Survey Sectional Aeronautical Chart.

FIELD METHODS

The examined localities were selected on the basis of the rock exposures to provide examples of the structure and stratigraphy of areas which had not been studied previously in detail. Geologic mapping was done largely with the aid of air photographs and was plotted on topographic quadrangle sheets. Topographic maps of the area now include the seven and one-half minute divisions of the Beverly quadrangle and several fifteen minute quadrangles, but only the old thirty minute sheets are available in the greater part of the area. The latter do not allow the precise depicting of the relation of topography to geologic structure, but are satisfactory for conveying a general impression. Stratigraphic sections were measured with a hand level or with a tape.

ACKNOWLEDGMENTS

Interest in the geology of the Columbia Basin was originally aroused during a study of the Ellensburg formation suggested by Dr. Howard A. Coombs. The present study was suggested by the faculty of the University of Washington Department of Geology. Professors Coombs, Julian D. Barksdale, J. Hoover Mackin and Harry E. Wheeler critically read the manuscript and made valuable suggestions. Professors Mackin and Wheeler also gave advice in the field.

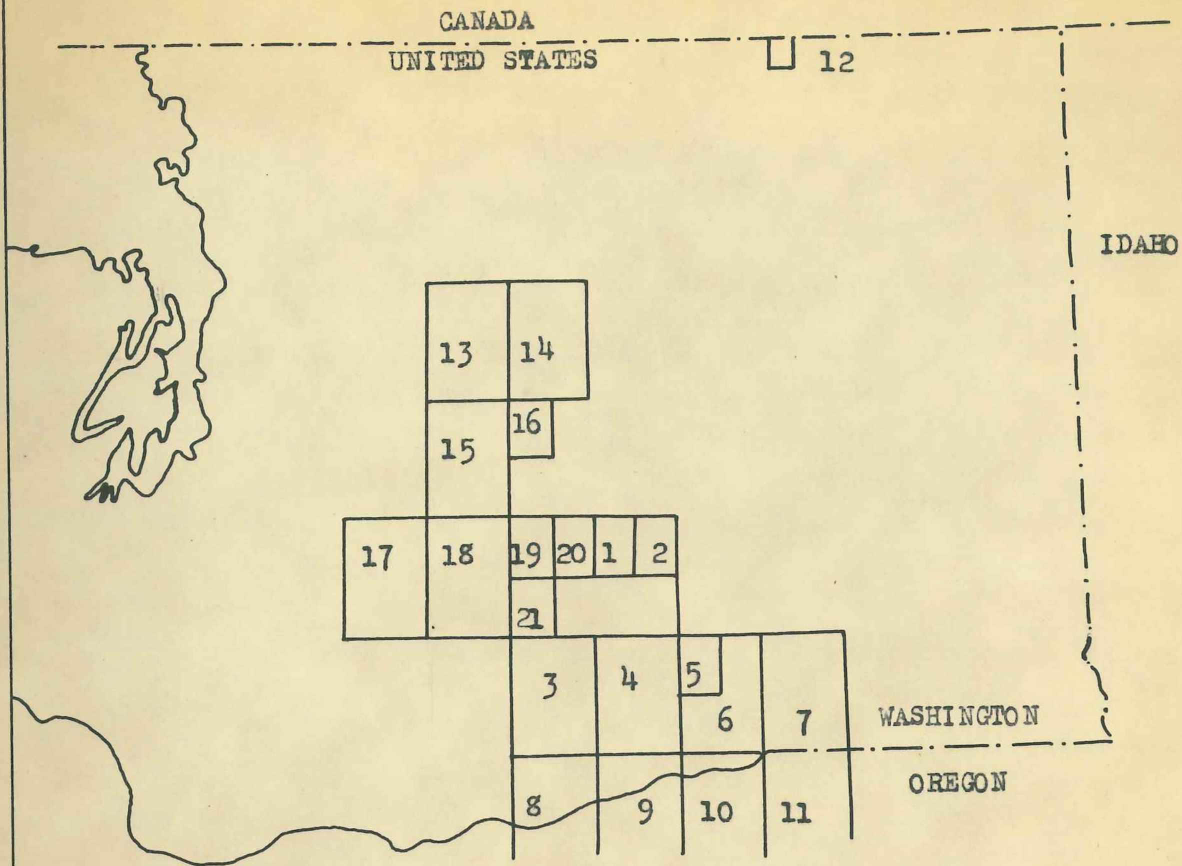
Geologic information not acknowledged in the text was contributed by Mr. J.D. Arthur, formerly Chief Geologist at McNary

Dam; Mr. J.S. Gobble and Mr. L.S. Jones of the Walla Walla District Corps of Engineers, and by Dr. W.A.G. Bennett of the Washington State Division of Mines and Geology. Mrs. L.E. Mark reviewed the manuscript for grammatical structure. My parents Mr. and Mrs. Carl F. Laval provided much assistance and encouragement.

G E N E R A L   G E O L O G Y

The rocks of the southwestern part of the Columbia Basin include a part of the widespread Columbia River basalt, together with sedimentary intercalations, and several hundred feet of overlying sediments called the Ellensburg and Ringold formations. In the mountains surrounding the Basin older Tertiary and pre-Tertiary rocks appear. These record a long and complex history and influenced the development of the Basin. The geology of the Cascade Mountains and of western Washington is fairly well known and very closely related to that of the Basin. Ancient northwest-southeast structural trends are recorded in the foliation of the pre-Tertiary metamorphic rocks of the Cascades, and early Tertiary northwest-southeast folding is known to have preceded the formation of a surface of mature relief upon which the Columbia River basalt was extruded.

The basalt extends into the larger modern valleys around the edges of the Basin and can be traced down the gorge of the Columbia River into western Washington and Oregon. Late Tertiary folding of all the rocks developed the structures which are plainly displayed in the canyons of the Yakima and Columbia



1 to 11-Thesis area quadrangles.
12-Kettle River-Toroda Creek district; Dobell, 1955.
13-Chiwaukum quadrangle; Page, 1939; C.L. Willis, 1950, 1953.
14-Chelan quadrangle; Waters, 1932.
15-Mount Stuart quadrangle; Smith, 1904.
16-Wenatchee quadrangle; Chappell, 1936.
17-Mount Aix quadrangle; W.C. Warren, 1941; Abbott, 1953.
18-Ellensburg quadrangle; Smith, 1901, 1903.
19-Badger Pocket quadrangle; Mackin, 1946, 1947; Gray, 1955; Kojan, 1955.
20-Boylston quadrangle; Alto, 1955.
21-Yakima East quadrangle; Waters, 1955.

Figure 3; Index map showing principal localities mentioned in text.

Rivers. Latest Tertiary and probably Quaternary uplift of the Cascade Mountains has completed the structural development to date.

The present topography has been formed under the influences of structure, differential rock resistance and the formation of slopes graded to local base levels. Loessial soil mantles many of the uplands, and fluvio-glacial silt and sand deposits are extensive in the lower valleys. Ice rafted erratics are common up to about 1,200 feet elevation.

S T R A T I G R A P H Y

GENERAL

In this section of the Columbia Basin five litho-stratigraphic units are of primary significance. These are from oldest to youngest: the Yakima basalt, the Selah formation, the Wenas basalt formation, the Ellensburg formation, and the Ringold formation. The Yakima basalt is an accumulation of great sheets of once very fluid plateau or flood lava of unknown total thickness. Individual flows show much variation in gross aspect from place to place, but retain their general petrographic characteristics and can therefore be correlated in the field. The Selah and Ellensburg formations are essentially sedimentary and both consist of lithologies which record andesitic volcanic activity in the general area of the present Cascade mountains as well as erosion in the area of present Columbia River drainage. The Wenas basalt consists of flood basalt separated from the Yakima basalt by the

Selah formation sediments over most of the area. The Ringold formation consists largely of fine-grained clastics containing Ellensburg type and other volcanic elements together with conglomerates similar to some of those in the Ellensburg.

In general the stratigraphic nomenclature has developed rather informally, and few type localities or type sections have been specifically designated; so that it is desirable to review the history of the nomenclature and to define the stratigraphic units.

The oldest formation, the Yakima basalt, was named and informally defined by Smith (1901, 1903 A) after detailed geological mapping in the Ellensburg quadrangle and vicinity. Earlier, Russell (1893) had included Smith's Yakima basalt in the Columbia lava, which he later (1901) named the Columbia River lava. Russell's Columbia River lava included several lava "sheets" exposed over some 200,000 square miles of the Columbia Plateau in Washington and Oregon and in the Snake River Plains of Idaho. Merriam (1901) proposed that the Columbia lava should be restricted to the part most prominent along the Columbia River. He found this part between the Mascall and the John Day formations in the John Day Basin of Oregon and considered it of Miocene age.

Since that time the term "Columbia River lava" has been generally superseded by "Columbia River basalt", which seems to have been introduced by Buwalda (1923). Columbia River basalt is generally used in Merriam's sense to refer to the "Miocene" part of Russell's Columbia River lava. According to Wilmarth

(1938) the United States Geological Survey uses the term for lavas of Tertiary age in the general area of Russell's work. In this thesis "Columbia River basalt" will refer to the whole Yakima basalt-Wenas basalt sequence including interbedded sediments and to the general correlatives of this sequence in other areas. It is therefore only a generalized lithologic term.

Smith (1901, 1903A) pointed out the fact that Russell's Columbia River lava included lavas of several different ages and defined the Yakima basalt as the Miocene part. He mapped the Yakima as a unit in the Ellensburg and Mount Stuart quadrangles and stated (1904) that the Yakima extends beyond the boundaries of the State of Washington.

Above the Yakima basalt is the Selah formation, a sedimentary unit previously named the Selah tuff member of the Ellensburg formation by Mackin (1947). Mackin's type locality is at Selah Butte (Locality A). The Selah is a mappable unit of much stratigraphic importance and is therefore regarded as a formation. Previously this unit had a rather anomolous stratigraphic position owing to Smith's having included it in the Ellensburg formation, but also having indicated the intervening Wenas basalt to be a formation (1903A, p.2). Smith mapped the Selah as "Ellensburg beds below the Wenas basalt".

The Wenas basalt was named and mapped by Smith (1903A), who both included it in the Ellensburg formation and indicated it to be a separate formation. Mackin (1947) suggested it be considered a member of the Ellensburg formation, but recently (1955A) would give it formational rank. It has a distinctive general lithology and is separable in the field from the Yakima basalt even where the Selah formation is absent.

The Ellensburg formation, as used here, includes the part of Smith's Ellensburg (1901, 1903A) lies above the Wenas basalt. It is a sedimentary unit of distinctive lithologies whose stratigraphic top has never been defined.

The Ringold formation was named by Merriam and Buwalda (1917), who found the beds in the White Bluffs of the Columbia River north of Pasco to be of Pleistocene age and not part of the Ellensburg formation as formerly thought.

DATING OF THE FORMATIONS

Precise dating of the rocks with the possible exception of the Ringold formation at its type locality has not been possible because: the rocks are all of continental sedimentary or volcanic origin and the time scales for the marine and continental Tertiary of the Pacific Coast region are not in alignment; fossils are rather rare with the exception of fossil flora at certain localities; the Miocene-Pliocene boundary is a world-wide problem.

The marine and continental time scale misalignment has been discussed by Durham, Jahns and Savage (1954) in connection with the historical geology of southern California, where marine and continental fossiliferous sediments interfinger so that a comparison of dating methods is possible. They demonstrate that the mammalian Miocene-Pliocene boundary is well down in the marine Miocene. This same sort of misalignment seems evident in comparing the later marine Tertiary history of western Washington and Oregon evolved by Weaver (1937) with the generally accepted dating of the later Tertiary history of eastern Washington and Oregon. The latter is typified by Water's (1955A) suggested timing for the rocks and events in the Yakima East quadrangle. A link between the two is provided by Lowry and Baldwin (1952), who, in summarizing the geology of the lower Columbia River valley, make tacit use of the marine scale for dating the Columbia River basalt and the continental scale for dating the younger formations. Figure 4 illustrates these conditions in somewhat over-simplified form. The implied time transgression of the Mio-Pliocene diastrophism from west to east may be a function of the time misalignment. According to Weaver the resultant structures affected both western and eastern Washington.

Paleontological dating in the Columbia Basin has been almost limited to floral evidence from the Ellensburg and related formations such as the Latah. This has usually resulted in middle or late Miocene datings. In recent years there has been a tendency to discount paleobotanical dating, which is summarized by Savage (1955) as follows.

> It may be concluded that plant chronology has been based on earlier terminologies which in turn were based on dates provided by mammals or invertebrates contained in correlative sediments. This statement belittles the role of fossil plants in geoghronological assignments, but cannot belittle the role of plants in paleoecological or paleoclimatological assignments.

If paleobotanical evidence is to be elimated from serious consideration, the only worthwhile fossil evidence from the western Columbia Basin by which the Ellensburg formation and the Yakima basalt can be dated seems to be limited to the Hipparion discoveries of Russell (1893), Merriam and Buwalda (1918) and

		Southwest Washington and northwest Oregon (Weaver, 1937)	Portland, Oregon and vicinity--Columbia River Gorge (Lowry and Baldwin, 1952)	South-central Washington (1. Merriam and Buwalda, 1917 2. Waters, 1955A)
AGE		Marine scale	Marine and continental scales	Continental scale
Recent			Alluvium	Alluvium
Pleistocene		Satsop formation	Portland gravels and sands	Fluvio-glacial deposits Ringold formation
		Diastrophism	Diastrophism	
Pliocene	Upper	Marine formations --differential warping.	Portland Hills silt ? — ? — ?	
	Middle		Troutdale formation--warping	
	Lower		Unconformity-diastrophism	Ellensburg formation--diastrophism (2)
Miocene	Upper	Diastrophism	Laterization of Columbia River basalt	Ellensburg (2) formation Yakima basalt
	Middle	Astoria formation interfingered with Columbia River basalt.	Columbia River basalt	
	Lower			

Figure 4: Simplified Chronological summary based on previous work.

C.R. Warren (1940A) and to recent vertebrate and invertebrate finds mentioned by Waters (1955A). All of these indicate a Pliocene age for the Ellensburg and upper Yakima, according to the vertebrate chronology.

The age of the Yakima and the Ellensburg according to the marine chronology depends on correlation of the Yakima basalt with the Columbia River basalt of western Washington and Oregon. According to Weaver (1937), the Columbia River basalt is interbedded there with the marine Astoria formation of middle Miocene age. The deposition of the Astoria was terminated by diastrophism in the "lower part of the upper third of the Miocene". This diastrophism resulted in folds trending north 60° to 75° west that may be traced from western to eastern Washington. In the later Miocene and during the Pliocene marine sediments were deposited in local troughs and were folded to some extent.

The Selah-Wenas-basal Ellensburg sequence is essentially conformable, but the thickest Ellensburg sections occupy structural depressions. By analogy with western Washington it would appear that the Yakima basalt is of middle to late Miocene age on the marine scale and the Ellensburg is of late Miocene and early Pliocene age on that scale. The Selah and Wenas formations, of course have intermediate age positions.

The only fossils found by this writer were some seed hulls from a pumicite bed in the Selah formation southeast of Locality 1, near Sentinel Gap. Dr. M.K. Elias (1955) of the Nebraska State Geological Survey determined that the hulls were from <u>Celtis</u>

willistoni, a variety of hackberry, and said that they were probably of Miocene age. The better preserved fossil material is deposited in the Paleontology Museum, Department of Geology, University of Washington as Lot No. 25. The locality is recorded as U.W. Locality [A-46.] = A-75

In any case the whole Yakima-Ellensburg sequence appears to have accumulated without notable time breaks, therefore no precise dating is possible without much more evidence than is now available. Furthermore as Glaessner (1953) points out, the Miocene-Pliocene boundary is one of the most unsettled time-stratigraphic problems in existence from a world-wide standpoint.

The Ringold formation at its type locality, the White Bluffs, seems to have been satisfactorily dated as Pleistocene by Merriam and Buwalda (1918) on vertebrate evidence. Corroboration of this dating is afforded by Strand and Hough (1952), who would extend the Ringold into the late Pleistocene.

YAKIMA BASALT

Smith (1903A), who defined the Yakima basalt, mapped it as a unit. He mentions the possibility of there being ten or more flows exposed in the canyon of the Yakima River between Yakima and Ellensburg, where about 2,000 feet of basalt may be seen. A typical flow is described as being black, aphanitic, non-porphyritic, jointed into columns in the main body and having a vesicular top.

Although Smith did not designate a type locality for the

Yakima and did not describe a type section, he plainly considered the basalt to be a formation. In that sense the Yakima has usually been described by later workers, although some confusion has existed as to its boundaries and as to its relation to the Columbia River basalt. The Yakima basalt is regarded by this writer as a formation in order to follow the usage of Smith. The formation is divided into several members which are mappable units in themselves. The members consist of individual lava flows, sequences of flows with the same lithology and of sedimentary interbeds between flows.

In the areas studied the Yakima basalt is the "basement rock". The total thickness of the basalt under the Columbia Basin has never been determined. According to Taylor (1948) a drill hole penetrated 4,570 feet into the basalt from the top of the Frenchman Hills without leaving the formation. It is only at the margins of the Basin and in the surrounding mountains that the basalt may be seen to rest unconformably upon older rocks. But at those places, as far as is known, only the upper flows are to be seen. The total thickness of lava in the central portions of the Basin may be well in excess of 5,000 feet.

The Columbia River basalt flows, in general, are of the type usually called plateau or flood basalt. Individual flows are commonly called sheets, because their internal structures indicate that they spread as sheets of very fluid lava. These structures also show that the sheets consolidated almost entirely after all movement had ceased. Therefore such features as the ropy surfaces and clinker associated with the Hawaiian type pahoehoe and aa flows are only locally well developed in the Columbia River flows.

The extent of individual flows of the Columbia River basalt was noted for many miles along canyon walls by Russell and other early workers. Recently Waters (1955B) has reported a flow in northeastern Oregon and adjacent parts of Washington and Idaho to be 360 to 480 feet thick and traceable in deep canyons for 120 miles north-south and 50 miles east-west. It is evident that the flows are continuous stratigraphic units, but until recent years it was not believed possible to trace individual flows beyond canyon exposures.

The field correlation of the upper several hundred feet of Yakima flows on a secure basis has been largely possible because of two porphyritic basalt members. Porphyritic basalt was mentioned by Russell (1901) and by Warren (1940A), but the possibilities opened for field mapping were not realized until William D. Irwin (cited in Mackin, 1946 and in Wallace et al, 1950) made use of porphyritic flows in working out the stratigraphy and structure of the Grand Coulee District for the Bureau of Reclamation. Later, Mackin (1946, 1947) described and mapped the same porphyritic units in connection with the Squaw Creek and Quincy-Burke diatomite deposits. Gray (1955) has traced these units from the vicinity of Yakima to Moses Coulee, a distance of about 60 miles.

Field identification of the members of the Yakima basalt depends primarily on lithology. In the case of lava flows this involves the type and degree of crystallization of the groundmass in the main body of the flow and the presence or absence of phenocrysts. These features have considerable variation in most flows, but remain rather constant in gross aspect. Additional means for flow identification are provided by total thickness, type of jointing, weathering, vesicularity, and general position in the stratigraphic column. Accurate identification of interbedded sediments usually depends upon the identification of the enclosing basalt flows, because the lithologies of the sediments can change in detail within short lateral and vertical distances.

Flow correlation is most successful where a good knowledge of the local stratigraphy can be obtained, because the details vary from place to place. With such knowledge it is possible to trace non-porphyritic as well as porphyritic flows. Sedimentary interbeds and petrified wood zones can be correlated in conjunction with associated lava flows. Microscopic examination is seldom necessary for flow correlation, but can well be of value with reference to local details of stratigraphy.

The Yakima basalt, as well as the Columbia River basalt in general, is a real example of "layer cake" stratigraphy. Each flow and interbed is a layer of the cake and the Ellensburg formation is the frosting. Each flow is a time-stratigraphic unit whose variations record not only internal changes due to progressive crystallization, but record the environment of its formation. The time involved in the extrusion of a flow was probably on the order of the days, weeks, or months recorded for modern Icelandic and Hawaiian flows. The flows on the Columbia Basin.

are, of course, much larger than any known modern terrestrial flows, but their evident extreme original fluidity suggests that they can hardly have taken an appreciably longer time for extrusion.

It is not always possible to determine whether a "flow" represents a separate phase of extrusion or is a flow unit which has broken forth from a partly consolidated flow front in the manner described by Nichols (1936). In canyon exposures the intertonguing and merging of units which make up some of the thicker flows is evident. In addition there are what might be called jointing units where a flow consists of several types of jointing which are intertongued or arranged in continuous tiers.

For descriptive purposes the exposed Yakima basalt may be grouped into two division: the lower units, including the Vantage member and the flows beneath it; and the upper units, including the members above the Vantage. The reason for this division is that the Vantage member and the units beneath it outcrop only at Saddle Mountains in the areas studied, whereas the upper units are exposed throughout the areas.

<u>THE LOWER UNITS</u>: The lower units are well exposed at Sentinel Gap, where the Columbia River cuts through Saddle Mountains, and at Frenchman Hills Gap to the north. At least the upper flows are exposed in the Yakima River canyon between Ellensburg and Yakima, and according to Mackin (1955B), at Umtanum Ridge south of Priest Rapids.

The following descriptions draw upon Galster's (1955) work for general relations between Frenchman Hills Gap and Sentinel

TABLE I__ COMPARATIVE NOMENCLATURE OF STRATIGRAPHIC UNITS

AGE	Russell (1893) Cent. Wash.	Russell (1900-1901)	Smith (1901,1903) Ellensburg qd.	Waring (1913) S.-cent. Wash.	Merriam, Buwalda (1917)	Twiss (1933) Saddle Mts.	Mackin (1946, 1947) Squaw Cr.-Burke	Mason (1953) Cent. Wash.	Alto (1955) Boylston qd.	Gray (1955) Central Wash.	Waters (1955) Yakima E. qd.	Mackin (1955) Priest Rapids	This Thesis South-cent. Wash.
Pleistocene					Ringold formation	Crab Creek beds-Ringold formation		Ringold formation					Ringold formation?
Upper Miocene to lower Pliocene	John Day System	Ellensburg sandstone	Ellensburg formation	Ellensburg formation	(Ellensburg formation)*	(Ellensburg formation)*	Ellensburg formation: Ellensburg formation	Ellensburg formation: Upper member		Ellensburg formation: Ellensburg formation	Ellensburg formation: Ellensburg formation	(Ellensburg formation)*	Ellensburg formation
			Wenas basalt	Wenas basalt		(Wenas?) basalt	Wenas basalt member	Wenas basalt member		Wenas basalt-top flows	Wenas basalt flow	Wenas basalt	Wenas basalt formation
			Ellensburg beds beneath the Wenas basalt	Lower member of the Ellensburg formation		Beverly formation	Selah tuff member	Lower member--Prosser member Columbia River ba.		Ellensburg formation	Sediments below the Wenas flow	Selah formation	Selah formation
	Columbia lava	Columbia River lava	Yakima basalt	Yakima basalt		Columbia River basalt	Yakima basalt: One or two flows	Yakima basalt--Columbia River basalt	Columbia River lava	Yakima basalt: Non-porphyritic flows	Yakima basalt: Flow	Yakima basalt: Priest Rapids basalt	Yakima basalt: Priest Rapids basalt member
							(diatomite)*			Upper diatomite		Burke diatomite	(Burke diatomite member)*
							Porphyritic flow		Unit 6	Upper porphyritic flow		Roza porphyritic flow	Roza porphyritic basalt member
							Squaw Creek diatomite			Lower diatomite — Non-porph. flows	Diatomite	Squaw Cr. diat.	Squaw Cr. mem.
									Unit 5		Flow	Sentinel Gap complex	Frenchman Springs basalt member
							Underlying porphyritic flow		Unit 4	Lower porphyritic flow	Flows	Frenchman Springs group	
									Unit 3 (interbed)	Museum sandstone interbed		Vantage interbed	Vantage member
							Main body of Yakima basalt		Unit 2 (Museum flow)	Museum platform flow		Museum flow	Museum flow
									Unit 1	Gray, vesicular flow		Rocky Coulee flows	Flow F
												Dry Gulch flow	Flow E
												Cave complex	Flow D
												Skookumchuck flow	Flow C
												Confusion flow	Flow B
													Flow A

Note: Tabulation omits glacial melt-water deposits, alluvium, etc.

* Indicates unit not observed or not specifically described.

Gap and upon the writer's measured section at Sentinel Gap for details.

Flows A and B: Flow B outcrops in the deepest part of Sentinel Gap on the east side of the river and at Frenchman Hills Gap. At Sentinel Gap there appears to be another flow (flow A) below flow B, but it is not clearly exposed. Flow B is composed of blue-black, aphanitic, finely porphyritic basalt with very good columnar jointing at the base. Higher up the rock tends to weather to a deep red and the jointing has blocky and "fan" structure. A thick vesicular zone at the top is in well marked contact with the flow above. At Sentinel Gap the flow is about 220 feet thick.

Flow C: Flow C consists of several flow units marked by zones of vesicular basalt, and clinker or flow breccia. Some of the vesicles are large and elongate horizontally, which, together with the clinker, suggests that the flow was rather viscous when it reached this locality. The rock is dark gray, aphanitic, and locally finely porphyritic. It weathers mostly to shades of gray. The top of the flow is more massively jointed than the main body and tends to form a bench. The flow is about 205 feet thick.

Flow D: Flow D appears to be one unit nearly 200 feet thick. At Sentinel Gap it has several varieties of jointing in roughly layered arrangement. Typically the rock is dark blue-gray, aphanitic, or very fine-grained and weathers to a deep red. Near the middle of the flow is a rather massively columnar, sheeted zone a few feet thick, which is slightly porphyritic and tends to form a narrow bench. At Frenchman Hills Gap the flow has a pillow-palagonite zone with many weathering cavities.

Flow E: The massive columnar jointing in the basal several feet of this red-weathering, ledge forming unit contrasts strongly with the flows above and below. At the measured section the flow is about 35 feet thick, but due to several feet of original relief at the top of the flow, this is possibly a minimum thickness for the vicinity. The rock is blue-black, very fine-grained and finely porphyritic.

Flow F: Flow F is very nearly 200 feet thick at both Sentinel Gap and Frenchman Hills Gap. The basal part tends to be massively columnar but does not necessarily form a prominent outcrop. Above the basal twenty-five or thirty feet the whole flow is a series of intertonguing units, so that any particular measured section is only a general representation of the flow as a whole. The rock is dark gray, aphanitic, or very fine-grained, and has plagioclase phenocrysts about two millimeters long scattered sparsely throughout. The basal part, especially, has some phenocrysts up to five millimeters long. Roughly cylindrical segregations of vesicles are common.

Museum flow: The Museum flow was named informally by Mackin for the exposures beneath the "Museum platform" at the Gingko Petrified Forest State Park near Vantage. In the basal 20 to 60 feet, the flow is very massively columnar and forms an unusually resistant unit. The flow forms platforms and ledges between

Vantage and Sentinel Gap on both sides of the Columbia River. At the top of the flow is an extremely vesicular zone, which varies considerably in thickness and is non-resistant. The total thickness of about 90 feet at the measured section is probably typical.

The rock is dark gray to blue-gray, aphanitic to fine-grained, and weathers to a conspicuous deep red. Plagioclase phenocrysts up to five millimeters long are scattered sparsely throughout and locally may approach one per square foot of outcrop.

Vantage member: This widespread sedimentary unit was named informally by Mackin and has since been described by several other workers. Its known range is from the Yakima River gorge south of Ellensburg (Kojan, 1955) to Moses Coulee on the northeast (Gray, 1955) and to Umtanum Ridge on the south (Mackin, 1955 B). It may be present beneath the surface at Wallula Gap, where well bailings at the Lester Blair ranch indicate an interbed presumably near the stratigraphic position of the Vantage.

The thickness of the member in the vicinity of Sentinel Gap, varies from about ten to forty feet in response to surface irregularities of the Museum flow and probably to differential deposition and erosion by the agent of agencies of deposition. Alto (1955) suggests that differential warping during deposition of the Vantage may have caused variations in the depositional thickness.

The Vantage has two lithologies. The cross-bedded sandstones at Sentinel Gap are formed of medium and coarse angular grains of quartz and variable amounts of feldspars, quartzite, and micas in a tuffaceous matrix. Above the sandstone is bentonic tuff which may be traced together with interbedded sandstones composed of quartz, plagioclase, and volcanic glass, from Vantage westward into the Badger Pocket quadrangle. South of Ellensburg in the Yakima River canyon the Vantage is a pebbly sandstone with the hornblende andesite lighology of the Ellensburg formation. Near Smyrna on the north flank of Saddle Mountains the member is a fine-grained sandstone of hornblende andesite lithology. The andesitic clastics indicate an opening phase of the eruptions which culminated during the deposition of the Ellensburg formation. The median geographic position of the quartzose sandstones at Sentinel Gap suggests an early attempt at establishment of drainage over a part of the basalt plain.

THE UPPER UNITS: The flows above the Vantage interbed are comparatively well known, because erosion has exposed them in gullies on the flanks of the ridges as well as in the main canyons. Their varied lithologies and the presence of several sedimentary interbeds make them comparatively easy to trace.

Frenchman Springs basalt member: The Frenchman Springs basalt is a group of flows informally named by Mackin for the occurrency at Frenchman Springs alcove a few miles northeast of Vantage. The flows are characterized by feldspar phenocrysts up to one inch or more in diameter with roughly rounded outlines and a shattered appearance on broken surfaces. Most of the phenocrysts consist of several plagioclase crystals clotted together and some consist of plagioclase and pyroxene.

Typically the phenocrysts appear on the order of one per square foot of outcrop, but show much variation in their distribution. In some places they are very abundant and in others it is difficult to find them. This variation can usually be seen within the individual flows or flow units of the member. In particular the Sentinel Gap flow, the upper flow at Sentinel Gap, has very rare phenocrysts. The groundmass of the rock is typically dark gray to black, and aphanitic, but the central and lower parts of the thicker flows are commonly very fine-grained. Columnar jointing up to five feet thick or even thicker is typical except for the Sentinel Gap flow, which is jointed into small irregular blocks. The flows weather to shades of dark gray and dark red-brown.

The known extent of the Frenchman Springs basalt is from the Badger Pocket quadrangle (Mackin, 1947), southward to Toppenish Ridge, eastward to Wallula Gap, and northward to Moses Coulee (Gray, 1955). Therefore the member has a known north-south extent of more than seventy miles. Its total extent may be much greater than this, because the minimum recorded thickness where the base is exposed is 230 feet (Gray, 1955). The greatest known thickness is over 500 feet at Sentinel Gap, where the member consists of four flows.

At Frenchman Springs and in the general vicinity of Vantage, the lowermost flow of the member has a basal pillow-palagonite phase of markedly varying development from place to place. This flow has been called the Gingko, because the petrified wood at the Gingko State Park occurs in the pillow-palagonite. Sentinel

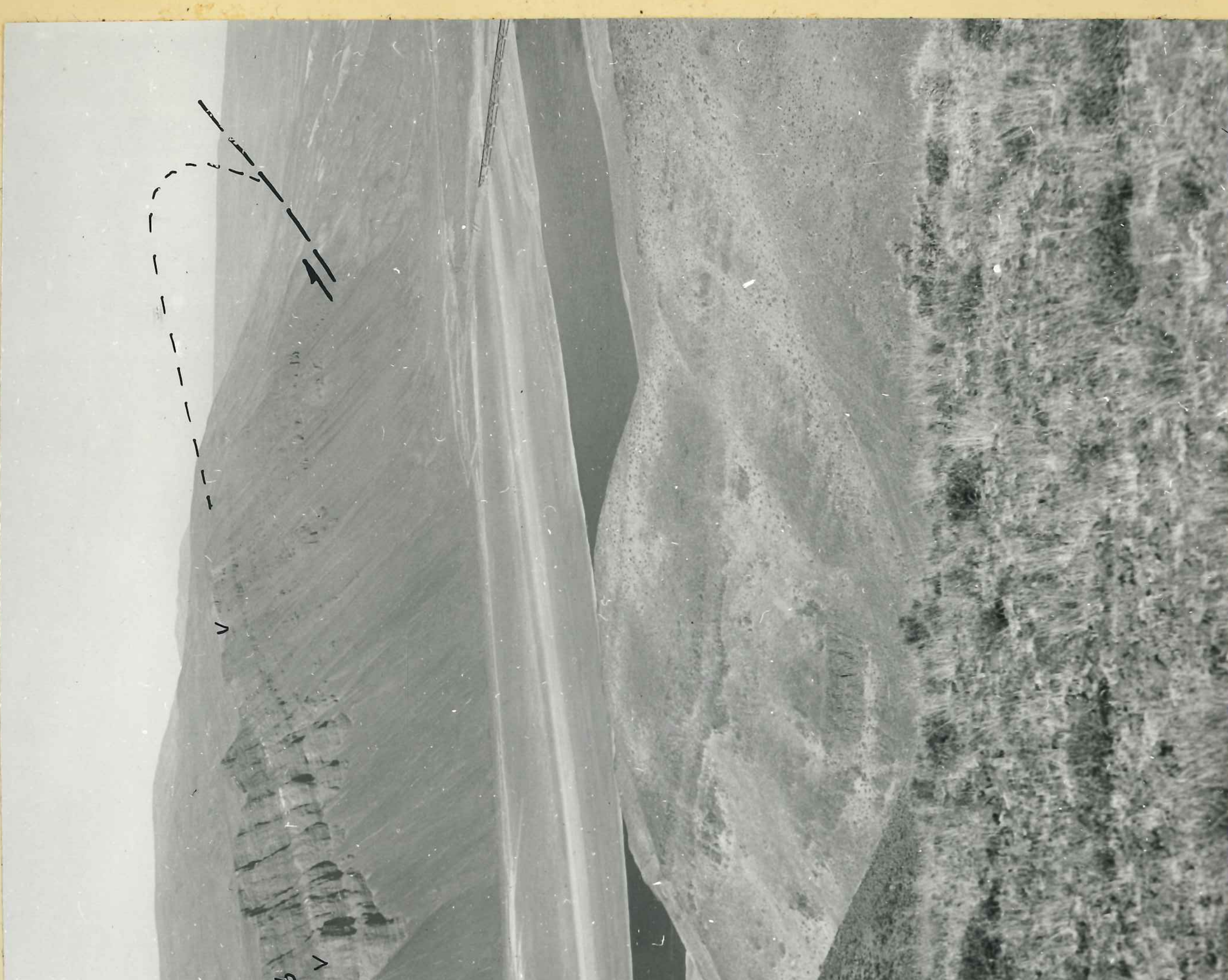


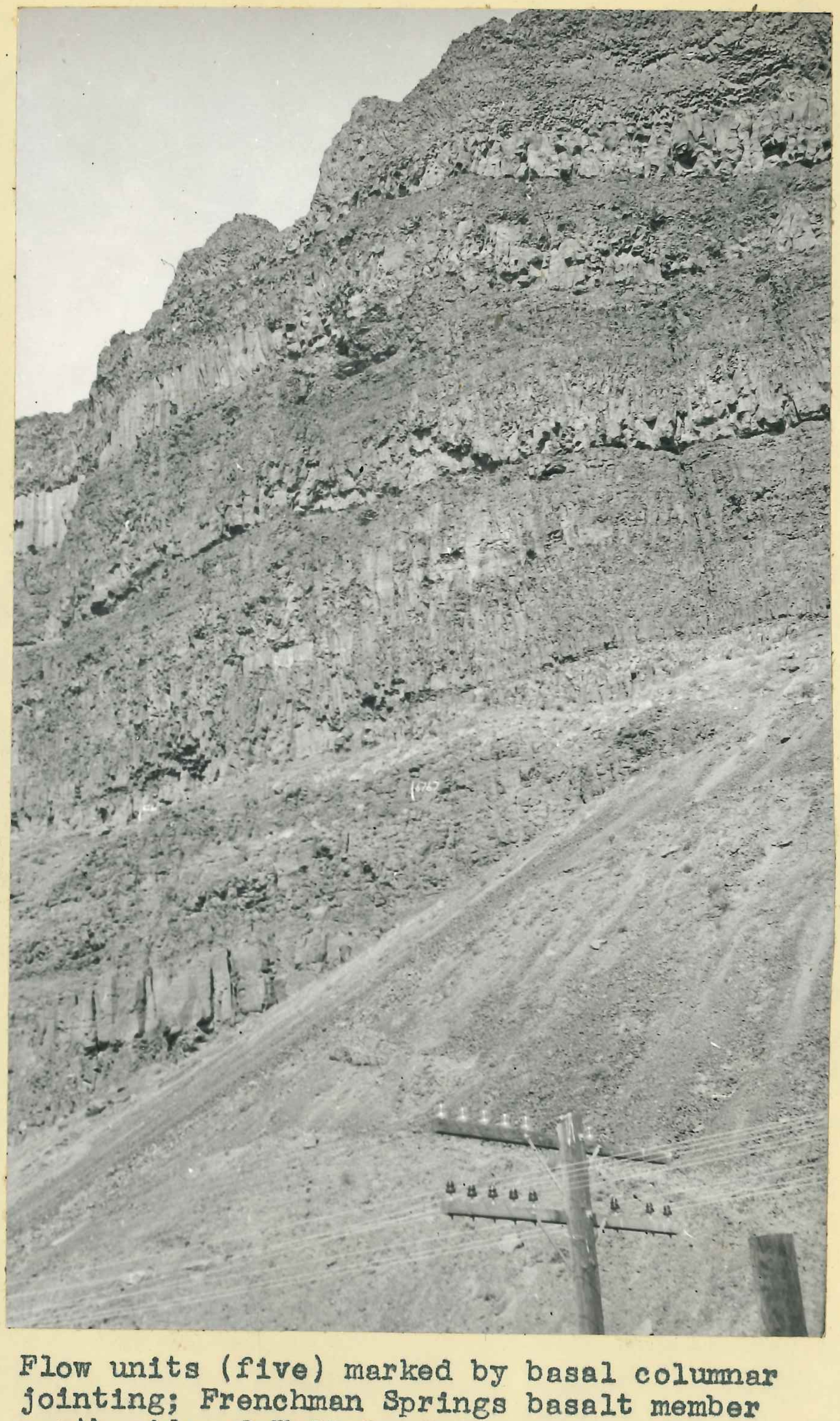
PLATE I: View westward across Sentinel Gap (Map Area I). "V" is Vantage member at top of lower Yakima basalt units. "Fsb" is Frenchman Springs basalt. Elements of structure indicated.

Gap is the only area studied where the pillow-palagonite occurs. Here it is poorly exposed and appears to be developed, not at the base of the lower flow, but several feet above the base. The relation is best seen on the west side of the gap above the Vantage member, which outcrops as a light colored band along the north rim of Saddle Mountains. Probably the palagonite was formed at the base of the flow in the manner described by Fuller (1931), when it encountered water or wet Vantage sediments. Possibly the palagonite complex was underrun by molten lava after the water had been dried up.

At Wallula Gap the exposed part of the member consists of several flows and intertonguing flow units totalling over 400 feet in thickness. At Locality 8 in the Horse Heaven Hills two flows are exposed, but to the west only part of one flow was observed.

Between Frenchman Springs and Saddle mountains the Frenchman Springs basalt is capped by the Sentinel Gap flow (cf. Sentinel Gap complex, Mackin, 1955A). In the vicinity of Vantage this flow is about 200 feet thick, and the basal part consists of a pillow-palagonite complex with forset structure dipping northward. According to Fuller (1931) this type of structure indicates that the flow advanced from the southward. Both northward and southward the flow thins so that it is not actually present at Frenchman Springs and is about 130 feet thick at Sentinel Gap. According to Mackin (1955 B) this flow may have formed a dam, which impounded the lake in which the Squaw Creek diatomite accumulated.

PLATE II



Flow units (five) marked by basal columnar jointing; Frenchman Springs basalt member north side of Wallula Gap near Locality 16. Note irregular forms of some of the jointing units.

The vesicular top of the upper flow at Locality 8 is crowded with feldspar phenocrysts, but the main body of the flow has very few. This condition was observed at several places and may be genetically related to the vesiculation of the flow top. In this particular place the segregation of the crystals was greatly aided by the formation of a slab pahoehoe crust, which gathered up the phenocrysts as they arrived at the flow top.

Another type of phenocryst segregation is that in which they are most abundant in platy zones or near the bottom of a flow. Many flows and flow units with good columnar jointing show this type of segregation. Possibly it is brought about by overturn of the top of the flow or unit during advance or even by convective overturn of the phenocryst-rich flow top.

Squaw Creek member: The Squaw Creek member is a sedimentary unit originally described by Mackin (1947). At the type locality in the Badger Pocket quadrangle and at Roza Gap (Locality B) the member consists of diatomite and quartzose silts and sands.

A questionable occurrence of this member is at Locality 3 on Toppenish Ridge. Here a few feet of fine-grained sandy tuff of hornblende andesite lithology represents the stratigraphic equivalent of the Squaw Creek. Probably this interbed has no actual connection in space with the diatomite beds. It apparently represents a shower of volcanic ash somewhat worked by running water.

Roza porphyritic basalt member: The Roza porphyritic basalt was named informally by Mackin (1955 A), because of the exposures opposite the mouth of Roza Creek, a tributary of the Yakima River. This is probably the most easily recognized member of the Yakima basalt. The rock is typically fine-grained, well crystallized basalt, porphyritic, and finely vesicular throughout. The phenocrysts are single and composite plagioclase feldspar crystals, in part associated with pyroxene crystals, and ordinarily average about one fourth inch in diameter. They range up to one half inch or more in diameter like many of those in the Frenchman Springs flows. Unlike the Frenchman Springs phenocrysts, those in the Roza are generally distributed rather evenly throughout on the order of several per square foot of outcrop.

The flow weathers to red-brown and is jointed into bluff-forming columns in the main body. It can be seen in the Upper Grand Coulee and has been traced by Gray (1955) from Moses Coulee to the vicinity of Selah Gap (Locality A). It outcrops at Union Gap and at several places in the Horse Heaven Hills.

The Roza porphyritic flow is possibly more uniform in thickness as well as lithology than any other flow of the Yakima basalt studied. From Gray's Moses Coulee locality to Sentinel Gap, the thickness appears to vary from seventy to one hundred-ten feet. In part the greater thickness at Sentinel Gap seems due to an upper flow unit which was not found anywhere else At the western localities (3, B, C) the thickness varies from seventy to one hundred-sixty feet. In the Horse Heaven Hills the flow thins gradually and to the east of Locality 9 disappears. Apparently all of the variations in thickness of this flow are the result of very gradual thickenings and thinnings.

Burke diatomite member: The Burke diatomite was not observed at the localities studied, although some petrified wood occurs at its stratigraphic level at several localities. It was named by Mackin (1955 A) for the occurrences in the Quincy-Burke area (Mackin, 1946) east of Vantage and has been reported by Gray (1955) in the Squaw Creek area (Locality C) and at a locality on Saddle mountains east of Sentinel Gap.

Priest Rapids basalt member: The Priest Rapids basalt is another member named informally by Mackin (1955 A). At the type locality near the hamlet of Priest Rapids (Locality D), he describes four flows or flow units totaling about two hundred feet in thickness. At other localities the member consists of two to five flows, all with the same general lithology, and one major sedimentary interbed. The basalt is typically so well crystallized that the groundmass, although very fine or fine-grained by the usual standards, is coarse-grained in comparison to that of most of the other flows. Plagioclase phenocrysts up to one or two millimeters long are common, and in places there are single crystals several millimeters long and clots up to one-half inch in diameter, reminiscent of those in the Frenchman Springs flows, although not so abundant.

Very massive columns, as much as eight or ten feet in diameter, are characteristically developed in the thicker flows. At the bottoms of such flows cross-jointing tends to form plates and slabs at all angles. Thinner flows are ordinarily jointed into columns about three or four feet in diameter. The tops of the flows tend to be very vesicular, sheeted and crumbly. In places the upper part of the vesicular zone is altered to a dark green, brittle, clay-like material, which seems to have contributed to the sedimentary Selah formation. At other localities thick clinker zones are developed at the flow tops. The weathering color is typically a conspicuous red-brown.

The Priest Rapids flows differ from the Roza porphyritic flow in their general lack of large phenocrysts and in their tendency to form more massive columns. They differ from the Wenas basalt in their generally better crystallization and more massive jointing.

The exact relations of the type Priest Rapids flows to those at other localities are not known. At the type locality Mackin found evidence of the two lower flows having accumulated in rapid succession. They may be units of a larger flow, in which case there are possibly three individual flows. At Sentinel Gap, about ten miles to the north, the member consists of only two flows, although the total thickness is about the same as at Priest Rapids. Farther east on Saddle Mountains near Smyrna, there are two flows. Apparently in the area bounded by these three localities, the member consists of both single and multiple unit flows.

In the Horse Heaven Plateau area the member is well exposed at several localities. Here it can be divided into the basal flows, the Mabton interbed, the Umatilla flow, and the Sillusi flow from the base upward. If it had been possible to map all these divisions of the member with certainty everywhere they would have been regarded as separate members of the Yakima basalt. This was not possible, so it seems best in view of the present knowledge of the stratigraphy, to designate these as subordinate units.

The basal Priest Rapids flows outcrop at several localities on Toppenish Ridge and in the Horse Heaven Plateau area. Plagioclase phenocrysts up to five millimeters in diameter or even larger are sparsely distributed through the flows and are locally common. Their distribution seems to be erratic, so that porphyritic texture is only locally reliable for field correlation. In this connection it is possible that the peculiar disappearance of the Roza porphyritic flow ("upper porphyritic flow") described by Gray (1955) at Selah Gap may be explained by substituting porphyritic basal Priest Rapids for Frenchman Springs basalt. This change has been made on Plate XXXIII, resulting in a more natural picture insofar as the Roza flow is concerned. However, the substitution accentuates the strangely abrupt cut-off of the entire Priest Rapids member between localities A and B.

The basal Priest Rapids flows are best exposed in the vicinities of Localities 7 and 17. At both of these localities there are three basal flows or flow units. At Locality 7 flow Number 1, the lowermost, is separated from Number 2 by a few feet of petrified wood and opal, which appears to establish a time lapse. Flow Number 2 is only thirty-five feet thick and vesicular throughout, so it may well be a unit of flow Number 3. At Locality 17 in Wallula Gap, there are again three basal flows or flow units. All three have clinkery tops and locally have clinkery bottoms. The clinker development, together with a paucity of vesicularity in the solid lava beneath, and the irregular relief at the tops of the flows suggest that they were very viscous when they arrived at this vicinity. A few miles to the northeast at Locality 16, there are no basal flows. This suggests that they terminated rather abruptly in the intervening distance.

At Locality 8 the basal Priest Rapids consist of only one porphyritic flow eight feet thick. The thinning of over two hundred feet in a distance of six miles between Localities 7 and 8 is possibly due to structural conditions, that will be discussed later, rather than to proximity to a "margin" of the flows.

The Mabton interbed outcrops above the basal Priest Rapids at several localities on Toppenish Ridge and on the Horse Heaven Hills and Plateau. It is the basis for separating the basal and upper flows of the member. The best outcrops are in gullies south and southwest of Mabton on the north flank of the Horse Heaven Hills west of the road to Alderdale and Roosevelt. This general area is regarded as the type locality, and the type section is described in Appendix A, Locality 7. Here the interbed consists of seventy-five feet of tuffaceous sands, showing some evidence of fluviatile bedding, and of massive tuffs, evidently representing showers of volcanic ash. Farther east at Locality 12, and to the south at Locality 19, the interbed is largely cross-laminated sandstone overlain by bentonitic tuffs. Geologists of the U.S. Army Corps of Engineers found the same general conditions during exploratory drilling at McNary Dam site (Locality 18). At McNary Dam and at Locality 19, near Alderdale, small pebbles are associated with the sandstones. The general

PLATE III

1. Umatilla flow with curved massive jointing at McNary Dam excavation.

2. Massively jointed Umatilla flow over clinker of cobble-sized scoria at top of basal Priest Rapids flow near Locality 17.

lithology of the Mabton is andesitic like that of the Ellensburg formation. The Mabton may be the stratigraphic equivalent of the Burke diatomite as a result of transgressive or simultaneous deposition on the Roza member and the basal Priest Rapids.

The upper part of the Priest Rapids member consists of two flows in the Horse Heaven Hills district. These two flows may correspond wholly or in part to Mackin's type Priest Rapids at Priest Rapids (Locality D) and to the two flows which Gray (1955) reports at Selah Gap (Locality A). The two flows which may be traced over the Horse Heaven area are well exposed in the vicinity of McNary Dam (Locality 18) and on the nearby flanks of Sillusi Butte. The lower flow forms Umatilla Rapids in the Columbia River and is accordingly called the Umatilla flow. The upper flow is called the Sillusi flow, because of the exposures on the south face of Sillusi Butte along the right of way of the Spokane, Portland and Seattle Railway. Both flows can be seen in the walls of Wallula Gap upstream from McNary Dam.

The Umatilla flow at its type locality shows a considerable variation in thickness and internal structure, caused by the development of a clinker zone up to sixty feet or more in thickness at the top. Clinker is likewise well developed at the top of the probable Umatilla flow at Locality 3 on Toppenish Ridge. Elsewhere the flow top is a normal vesicular zone in which the vesicles are generally nearly spherical, indicating that they formed after movement of the lava had nearly, if not entirely ceased. The main body of the flow has the typical massive columnar jointing at all localities studied. Near the base of the flow this jointing commonly is intersected by a confusion of slabs and plates at all angles, so that the columnar structure is all but lost to view. Where the flow has been strongly flexed, as on the flanks of Toppenish Ridge, the rock is broken into angular fragments a few inches in diamter with no perceptible relation to the original contraction jointing. At such places the weathering colors tend to be limonitic yellow and greenish rather than the usual red-brown.

The Sillusi flow is similar in general appearance to the Umatilla, but is thinner and generally not as well crystallized. It tends to have fairly massive columnar jointing, which makes it a resistant unit. In the vicinity of McNary Dam, the top of the flow is clinker up to twenty feet thick. About one mile east of the dam and at the possible occurrence of the flow at Locality 1 (Sentinel Gap), the vesicular top is altered to dark green, rather soft material, which seems to be some sort of deuteric alteration product.

Umatilla flow clinker: Although clinker is not uncommon in the Yakima basalt, it is ordinarily a minor feature of the flow tops. The thick clinker of the Umatilla flow was therefore studied in some detail in excavations at McNary Dam site and in highway and railway cuts in Walluaa Gap. It consists of red, purple, and gray scoria, both vesicular and non-vesicular, in a matrix of impure silica gel. The scoria fragments range in diameter from a fraction of an inch to several feet, and have almost every conceivable shape. Many fragments are roughly rounded, both from having been tumbled along on the advancing lava, and from having been partly remelted by gas fluxing.

According to MacDonald (1953) the formation of clinker at the tops of the Hawaiian flows is a function of the transformation of pahoehoe flows with ropy crusts into aa lava in which the flow becomes channelized between masses of granulated scoria or clinker and slowly advances under a cover of clinker. The transformation is supposed to be caused by gradual loss of gases from the moving lava, accompanied by falling temperature, so that the lava becomes a very viscous granulated mush. At this stage the crust at the top of the flow becomes a mass of spinose fragments which break from the parent crust into a rubble, which is carried along on top of the flow and tends to accumulate on either side of the lava channel. At the flow front the molten lava slowly rolls over the clinker which falls from the front, and occasionally tongues of more fluid lava may break from the main flow.

The Umatilla flow, of course, accumulated as a lava flood under very different conditions from those of the Hawaiian flows. However, the Umatilla clinker seems to have developed in response to loss of gases and to granulation of the lava; so it seems proper to refer to the Umatilla as an aa flow where clinker is significantly developed. Loss of gases from the lava is indicated by the large amount of non-vesicular scoria in the clinker and by the sparseness or lack of vesicles in the solid basalt below the clinker. Where the solid basalt is vesicular, the vesicles are generally large and drawn out horizontally, because of movement when the lava was very viscous. Granulation of the lava during movement is indicated by the aphanitic groundmass

PLATE IV: Autoinjective dike in Umatilla flow clinker between Localities 17 and 18, north side of Wallula Gap. Dike rises from massive part of flow concealed just below track level. Pick handle is three feet long.

throughout the flow in contrast to the relatively coarse crystallinity at most of the localities where there is little or no clinker. Another evidence of granulation is the sparseness of glass in the groundmass of the solid lava at the top of the flow and in the clinker fragments.

Autoinjective dikes from the solid basalt penetrate the Umatilla clinker. Dikes of this type are well exposed in railway cuts on the north side of the Columbia River about three miles west of Locality 17. In this vicinity dikes of various widths up to 15 or 20 feet, can be seen to emerge from the top of the solid basalt and to penetrate nearly to the top of the clinker. None was observed to have reached the top. The larger dikes commonly branch out in the clinker and all taper to a blunt ending. They are formed of non-vesicular basalt, have flow banding and rarely contain cognate inclusions. Apparently they represent comparatively mobile lava squeezed from the viscous mass below.

In the Locality 3 vicinity on Toppenish Ridge an accumulation of clinker over one hundred feet thick is at the top of a flow, which probably is the Umatilla. The clinker is not as ideally exposed as at Wallula Gap, but shows much the same features. The reasons for believing that this flow is the Umatilla are: the thickness of the clinker is approximately that of the probable Sillusi flow at nearby Locality 5 and at Locality 7, and roughly corresponds to the thickness of the possible Sillusi correlative described by Gray (1955) at Selah Gap; the flow at Locality 3 overlies a tuffaceous interbed, apparently the Mabton. The thick clinker zone evidently formed an island over which the Sillusi flow could not lap.

Clinker up to seventy-five feet thick is present at Locality 12 over what may be the Umatilla flow. In this vicinity the exposures are not continuous, but suggest that only one Priest Rapids flow about 275 feet thick lies above the Mabton interbed. The situation may be similar to that at Locality 3.

All of these thick accumulations of clinker seem to be related to the presence of water on or in the terrain over which the lava advanced. The water is particularly manifested in the silica-gel which forms ten to twenty-five per cent or even more of the clinker volume at all localities. In addition as much as ten or fifteen feet of the basalt at the base of the Umatilla (?) flow at Toppenish Ridge is glassy or has been replaced by opal and agate which retain amygdaloidal structure. At McNary Dam and vicinity drill cores and excavations disclosed black and green opal linings in joint cracks and large masses in fault zones in what was called the "Main Flow" below the clinker.

These observations suggest that a flow which is in a condition to form clinker will be greatly assisted in this formation by the presence of water. All of the cited occurrences of thick clinker are at or near places where the Mabton interbed was found, which indicates that the water was contained in the sediments or in ponds or streams on the surface. Apparently the chilling effect of the water and the steam which was produced from it accelerated the granulation of the lava, so that as it continued to move, clinker accumulated on a grand scale. There may have been phreatic explosions locally.

The steam leached silica and other solubles from the porous clinker mass and from the base of the flow, and upon sufficient cooling, the silica was deposited as a hydrated gel. In the confinement of fissures in the cooled lava and, at the base of the flow, the steam pressure was apparently great enough and the temperature high enough to form a concentrated silica-gel or opal. In the clinker an open system existed, so that the steam became cooled before the leachings were highly concentrated. Therefore the gel which fills the voids in the clinker is mostly a very hydrated substance. Excavations at McNary Dam and vicinity were cut through a great deal of clinker containing this type of gel. When fresh and damp it was white, tan, or dark green in color and had the consistency of cool paraffin. On drying it became brittle and fractured or disintegrated. Associated with this gel are palagonitic substances and minerals such as calcite and zeolites, which are all of approximately contemporaneous origin.

Natural outcroppings of clinker tend to be very ragged and spiny, because the gel weathers away easily. In bluffs and artificial cuts the crumbling of the gel leaves a porous mass of scoria, which, in many places, resembles a cobble conglomerate.

The foregoing observations indicate that the formation of clinker in the flows studied is somewhat analogous to the formation of the pillow-palagonite complexes. The processes differ in that pillow-palagonite seems to have been entirely the result of the chilling of a flow by water, whereas the formation of clinker was merely assisted by the presence of extraneous water.

The pillow-palagonites of the Columbia Plateau have formed from lavas which could be chilled to glass, whereas the lavas which formed clinker appear to have been in a state very near to solidification before they encountered surface water.

CONDITIONS OF YAKIMA BASALT ACCUMULATION: The Yakima basalt flows have left some records concerning the development of the Columbia Plateau. Each flow, for the most part, was formed from very fluid lava and tended to create a nearly flat initial surface; therefore, the original distributions and thicknesses of the flows were influenced by structural warping as well as initial slopes.

Time required for accumulation: The paleontological evidence previously discussed does not offer a means for measuring the time lapse represented in the accumulation of the nearly 2,000 feet of Yakima basalt exposed to view at Sentinel Gap. However, indirect evidence is afforded by the lack of any appreciable interflow weathering. Such weathering would be expected on the basis of the rather humid climate postulated by Chaney (1940) for the general Columbia Plateau region during the Miocene and Pliocene, if any great time had lapsed between eruptions.

The deep weathering of the uppermost Columbia River basalt flows in the general vicinity of Portland, Oregon, has been mentioned, together with the views of Lowry and Baldwin (1952) that this weathering took place during much of late Miocene time. Scheid (1947) reports similar weathering in the vicinity of Spokane, Washington. He finds that his "Excelsior surface" was covered by a few lava flows. He postulates, however, that the Excelsior weathering may have been contemporaneous with that of the Portland area.

Although soil zones are commonly mentioned in the geological literature of the western part of the Columbia Basin, no real evidence of such development was found in the field. If any are present in the examined areas, they are evidently covered by the exposed rocks. The Mabton interbed in the vicinity of Locality 12 does have several feet of red alteration at its top. This alteration may represent a soil zone; but, if so, it is a zone that was evidently not developed everywhere on the interbed. It is more likely that the red alteration was formed by some type of optalic metamorphism induced by the overlying lava flow. The red tops of some of the flows are not evidence, of course, of their weathering, but rather are primary oxidation features.

Nowhere was there any evidence that vegetation had formed on the interbeds or on the flows. The only type of petrified wood seen was in the form of tangled logs and limbs, obviously floated into place. Insofar as these observations are concerned, there is no basis for believing that the wood represents forests that grew between eruptions of basalt only to be covered by the lava. Rather the forests probably grew beyond the areas reached by the lava for the most part. However, Waters (1955 A) reports fossil rooted tree stumps in the Yakima East quadrangle. The diatomite beds described by Mackin (1946, 1947) and Waters (1955A) also indicate a lapse of time between lava outpourings.

The conclusion is that if the climate during Yakima basalt time was conducive to weathering, the flows to be seen at Sentinel Gap and the other localities studied were accumulated during a comparatively short interval of time. Perhaps an interval of only a few hundred years was involved. If, however, the climate was semi-arid, as at present, so that weathering was a slow process, the time for accumulation may have been much longer.

Method of flow advance: Individual flows consist of one or more flow units. Where intertonguing of flow units is visible, it is possible to gain an idea of the manner in which they advanced. Flow C at Sentinel Gap, and at least the middle part of the Frenchman Springs member at Wallula Gap, are illustrative of multi-unit flows. It is not hard to visualize these flows advancing as a series of flared-out wedges spreading ahead of the main wave of lava. However, in the case of a flow which seems to consist of only one unit, it is not so easy to visualize the advance, especially where that flow is two hundred or more feet thick. Here, it seems almost necessary to postulate a single gush of lava of very low viscosity. If such a flow actually did advance in a series of units, the lava was evidently able to assimilate them into an apparently massive flow. The possibility of such assimilation does suggest itself in the prominent partings parallel to the top and bottom surfaces of some flows. Particularly where these partings outline intertonguing lenses of basalt, the analogy with flow units is striking.

Topography of the Yakima basalt surfaces of accumulation: According to the views of Bailey Willis (1887) and others who have worked at the northerly margins of the Columbia Basin, the Columbia River basalt flows advanced northward against the regional slope into valleys which formed a drainage pattern radiating from the present Basin area. At that time the northern Cascade Mountains and the Okanogan Highland had a mature relief. Supposedly this area remained a relative highland throughout Columbia River basalt time.

To the south in the Columbia River gorge through the Cascade Mountains, the lavas are interbedded with marine sediments. Therefore, it seems that a regional southerly and southwesterly slope from the Okanogan and Cascade Mountain areas and a westerly regional slope through the Columbia Gorge area existed at that time. This means that if the lava flows of the western Columbia Basin came from the southeast, as is usually supposed, they advanced against the regional slope in flowing northward, whereas they could more easily have flowed westward down what is now the Columbia River valley. It would seem that the distribution of the flows was determined by local factors as well as regional slopes. Some of these factors are expressed in the distributions and thicknesses of the flows and interbeds plotted on Plate XXXIII

The Roza porphyritic flow is the oldest that is exposed over a large area in its entirety. The thickness of the member at the various localities shown on the diagram plus Gray's (1955) Moses Coulee locality indicates that its thickest development is along a northeast-trending zone roughly blocked out by Localities 3, B, Moses Coulee, and 1. This suggests that the flow accumulated in a shallow trough, which may have been created by structural warping, or may have simply been the surface expression of the Frenchman Springs member.

The Roza flow appears to have consolidated from a very fluid lava everywhere that it was observed. Molten lava, of course, is not a true liquid, but the thicker parts of the flow, at least, probably tended to form a nearly level upper surface. The variations in the thickness of the flow about its margins may give some indications of the constructional slopes formed by an individual flow. The general rate of thickening or thinning of the Roza flow between points such as Localities 1 and 9, where a significant change is recorded, is on the order of two feet per mile, both east-west and north-south. The more extreme thinning between Localities 7 and 9, a matter of forty feet in nine miles, is at the rate of nearly four and one-half feet per mile. The difference of two and one-half feet between these two figures seems to be a measure of the surface slope of the Roza flow near its margins.

The rate of thinning of the Roza flow is two to four and one-half feet per mile and is probably close to the minimum, whereas the variations in the thicknesses of the Umatilla flow of up to fifteen feet per mile are probably close to the maximum, even discounting its clinker build-up. The effects of the flow margin slopes in producing depressions are evident in such members as the Burke diatomite, whose fifty feet thickness at Locality C corresponds very nearly to the forty feet of thinning of the Roza flow between there and Sentinel Gap.

Structural warping during Yakima basalt accumulation: Constructional slopes were not unmodified during Yakima time. The interbedded Columbia River lavas and marine sediments in the

Columbia River Gorge indicate subsidence concurrent with flow accumulation. In the Columbia Basin, the bottom of the Yakima basalt is probably several thousand feet below sea level at present. The amount of comparatively recent subsidence involved is impossible to evaluate, but it hardly seems possible for several thousand feet of basalt to have stood above sea level while two hundred miles away the basalt was at or below sea level. Such a situation would have resulted in a regional slope much greater than the slopes indicated in the preceding section, and would almost surely have had drastic effects on the distribution of the lava flows.

It is generally considered that the basement rocks were basined because of the weight of the accumulating lava, or for other reasons; consequently, the surface of the accumulating lava may never have stood much above sea level. In this connection Newcomb's estimate that the surface of the lava in the Pasco Basin may have been at 2,500 feet above sea level at the close of accumulation, is probably an extreme maximum.

Along with the broad downwarping, some local warping seems to have been developing. The evidence for this is largely contained in the Priest Rapids member. At Locality 20, the Mabton interbed and the flows above it combined are about three hundred feet thick, but are about four hundred sixty feet at Locality 9. In addition the Selah formation and the Wenas basalt formation at Locality 20 are unusually thin. At Localities 13 and 1 the Priest Rapids above the basal flows of the member is even thinner than at Locality 20. These scattered observations suggest that the Horse Heaven Plateau had a positive tendency during Priest Rapids time, and that a shallow basin outlined by Localities A, 3, 7, and 12 was filled with the thicker part of the Priest Rapids. Another basin may have existed in the vicinity of Localities 18 and 19.

It is possible that some of the major structures of the Columbia Basin were beginning to develop in Priest Rapids time. The presence of fluviatile sediments in the Mabton inter-bed at Localities 7 and 12, at the north edge of the Horse Heaven Hills, and at Localities 18 and 19, at the south edge of the Horse Heaven Plateau, may record ancestral Yakima and Columbia River drainage.

SELAH FORMATION

The Selah formation is a sedimentary unit which incidentally includes some basalt of Wenas lithology. It lies between the Yakima basalt and the Wenas basalt formations. It outcrops over most of the area studied except in the eastern part of the Horse Heaven Plateau. Well logs cited by Newcomb (1948, 1951) indicate that the formation or its correlatives may exist in the Walla Walla Basin. Its thickness varies from over two hundred feet at Sentinel Gap, Roza Gap and Toppenish Ridge to five or ten feet in the hills south of Kennewick, the easternmost place where it was observed.

The lithology of the Selah is very similar to that of the Ellensburg formation, which originally (Smith, 1903 A) included the Selah. In the western part of the Ellensburg quadrangle Smith shows the Selah joining the Ellensburg directly, due to the disappearance of the elsewhere intervening Wenas basalt. Waters (1955 A), who also mapped the Selah as part of the Ellensburg formation, shows a similar situation on his map of the Yakima East quadrangle.

In view of the similarity of general lithologies, and in view of the local vertical and lateral continuities, the Selah and Ellensburg formations and the Prosser interbed of the Wenas basalt formation together constitute a lithosome. This type of lithologic unit has been proposed by Wheeler and Mallory (1954) to include the vertical and lateral variations of a stratigraphic unit with essentially the same lithology. A lithosome by definitition is a purely lithologic unit, which may comprise a member or a formation or several members or formations, which may or may not interfinger with other formal stratigraphic units. The discussion of the Selah formation will, then, apply except for details to the Ellensburg formation. The Selah-Ellensburg lithosome will be simply called the sedimentary lithosome. Opposed to the sedimentary lithosome is the lava lithosome composed of the Yakima and Wenas basalt formations and the lavas in the Selah and Ellensburg formations.

LITHOLOGY OF THE SELAH FORMATION: The Selah formation consists of four lithologies, all of which, except possibly Number 4, have been found in the Ellensburg formation. These are as follows in the approximate order of decreasing abundance: 1) andesitic detritus, including both fluviatile and aeolian sediments; 2) quartzitic conglomerates and related sandstones; 3) basalt flows of Wenas lithology; 4) claystones and siltstones derived from altered basalt.

<u>Andesitic detritus:</u> The andesitic detritus consists of sandstones, conglomerates and siltstones of fluviatile deposition, and of pumicites of aeolian deposition. Smith (1903 A) stated that the beds in the Ellensburg quadrangle consist of pebbles and grains of hornblende andesite composition and fragments of pumice and ash of the same composition. Remarkably enough, although the beds were deposited on basalt, it is only rarely that basalt is aa constituent. Coombs' (1941) petrographical studies of the more typical occurrences in the Ellensburg and Mount Aix quadrangles showed that the mineralogy of the sands is limited to the light and heavy constituents of the andesite. The writer expanded this subject somewhat (1948), and has incorporated some of the observations made at that time into this work.

The source areas of much of the detritus are evidently in the Cascade Mountains where hornblende andesites have been reported by Smith (1904) in the Mount Stuart quadrangle, by Page (1939) and C.L. Willis (1950) in the Chiwaukum quadrangle, by Chappel (1936) in the Wenatchee quadrangle, and by Abbott (1953) in the Mount Aix quadrangle. The latter would seem the source of most of the detritus in the Naches valley-lower Yakima valley district because of the large boulders in the bluffs near Nile Creek. The coarse detritus and beds of pumice near Ellensburg and the comparatively coarse material at Sentinel Gap may have had their origin in the Mount Stuart area or farther north. Possibly some of the material at Sentinel Gap came from northeastern Washington, where Pardee (1918) and Dobell (1955) have reported

Miocene (?) hornblende andesites. No specific studies have been made to solve this problem.

In the areas studied, the fluviatile deposits are dominant in the west but become subordinate to the aeolian material in the southeast. The fluviatile beds consist of sandstones and siltstones and are locally pebbly in the Yakima valley area and more notably so in the Sentinel Gap beds, owing no doubt to the latter being closer to a source of supply. In general, the strong lensing and channeling structures so common to the Ellensburg formation in the Yakima area are not typical of the Selah anywhere and become even less common to the southeast, where the stream or streams of deposition evidently lost velocity. Weaker lensing and cross-bedding effects are present however, so it is not possible to trace any one bed for an appreciable distance even where the exposures are continuous. Ordinarily the Selah has so little resistance to erosion that its position is marked by hogbacks or bluffs of the overlying Wenas basalt.

The cementation of the fluviatile beds varies from strong to poor and seems to be a function of the amount of volcanic glass present. Beds which are comparatively glass-rich are generally well cemented, probably owing to some sort of natural pozzuolanic reaction. Beds which are glass-poor are rarely cemented unless by iron oxide or lime. This variation in glass content and cementation is apparent at Locality 5, 5A, where loose and firm sands of the same grain size alternate.

Pumicite beds are a rather conspicuous lithologic type in the Selah. It was on the basis of their occurrence that Mason

(1953) sought to classify parts of the Selah as the "Prosser member of the Columbia River basalt", a classification not used here. The pumicites are of two types: coarse and fine-grained. The coarser grained consists of blue-gray glass shards with a submetallic luster, which has induced some workers to call it silvery-gray tuff. This type of pumicite generally has a crenulated, cross-laminated structure, although some beds are massive. The cross-laminated structure is very similar to that to be seen in present day deposits of drift sand and silt along the Columbia River. It was evidently developed when the pumicite was drifted along the ground by the wind after its journey through the air. The massive beds were probably deposited in ponds. Grains of pumicite are common in the fluviatile beds, because some of the ash fell in streams. The other type of pumicite is very fine-grained, generally massively bedded and commonly altered to a bentonitic condition. In many places this material is somewhat gritty because of included grains of feldspar. This pumicite is possibly the major constituent of the Selah formation east of Prosser. Its outcrops tend to be rather free of vegetation, probably as a result of the bentonitic alteration which promotes a run-off of the scanty rainfall.

Both types of pumicites have a moderate to poor degree of cementation. The coarser-grained pumicite is typically porous and friable, whereas the fine-grained type is soft and clay-like when damp, and brittle and much fractured when dry. Very commonly the presence of the fine-grained type, not only in the Selah formation but also in the other sedimentary units, may be recognized by a characteristic soft, light gray soil with many polygonal cracks extending downward for as much as two or three feet. Where this soil has formed the vegetation is ordinarily scanty. It may be caused by the swelling of the bentonitic material during periods of moistening in a process somewhat analogous to frost heaving.

Quartzitic conglomerate: This is the type of conglomerate which has been commonly called Hood River conglomerate. It consists of pebbles and cobbles of basalt and quartzite, together with various amounts of andesite, plutonics, metamorphics, and miscellaneous volcanics. The sandmatrix is typically formed of hornblende andesite constituents with the addition of non-volcanic quartz and non-volcanic feldspar. In places there are quartzose, micaceous sands associated with the conglomerates.

The Hood River conglomerate proper is a sedimentary formation named by Buwalda and Moore (1930). They found that it lies upon the Columbia River basalt and is interbedded with the basalt. They regarded the Hood River as a correlative of the Dalles and Ellensburg formations. Warren (1941 A, B) traced the Hood River type conglomerate over a large area in south-central Washington and concluded that it represented the shifting course of the ancestral Columbia River.

Insofar as south-central Washington is concerned, the name "Hood River" cannot be well applied to a formation or a member of a formation because the exact relationships of the conglomerate at Hood River, Oregon, the type locality of Buwalda and Moore, to the other "Hood River" beds are not known. Hood River type conglomerates occur in both the Selah and Ellensburg formations. In order to consider the conglomerates as members of those formations, the conglomerates would require names other than Hood River to avoid stratigraphic confusion. This does not seem practical at present; therefore the conglomerates are simply termed quartzitic (cf. "quartzite-bearing conglomerate" of Waters, 1955 A). However it should be noted that, although the yellowish weathering quartzite pebbles are the constituents most arresting to the eye, they vary considerably in their abundance and may even be absent locally.

The only studied locality where quartzitic conglomerate occurs in the Selah formation is Sentinel Gap (Locality 1). There the conglomerate forms a thick deposit at the base of the formation. Higher in the section quartzitic conglomerates are interbedded with andesitic sediments. The two lithologies are intermixed in some beds. Quartzitic conglomerate has been reported in the Selah formation or its correlatives at Priest Rapids (Mackin, 1955 A), at several localities on the Rattlesnake Hills and Yakima Ridge, and at Alder Ridge several miles west of Locality 19 (Mason, 1953).

Some of the reported occurrences of so-called Hood River conglomerate in the Selah were not corroborated in the field. For example, at Locality 5-5A on Toppenish Ridge, both Warren (1941 A) and Mason (1953) report quartzitic conglomerate below the Wenas basalt. This actually consists of lag gravels from the Ellensburg formation, which exists only as a remnant of tuffaceous soil with scattered pebbles on the Wenas. In places quartzite pebbles have streamed down the slopes and become superficially embedded in bentonitic sediments.

The quartzitic conglomerates in the Selah formation represent the same type of sedimentation as those in the Ellensburg formation. In general the conglomerates are the bed-load deposits of a large stream, presumably the ancestral Columbia River. The deposits indicate that the Columbia shifted over a wide area as it began to establish its course over the Columbia Basin.

Basalt flows in the Selah formation: Basalt of the Wenas type occurs in the Selah formation at Sentinel Gap, Toppenish Ridge, and Roza Gap. On the south flank of Saddle Mountain, at the east side of Sentinel Gap (Locality 1), the basalt in the Selah formation wedges down from a thickness of about sixty or more feet on the east to three feet in the first gully east of the Columbia River valley. The flow pushed into pumicite with a snow plow action and was covered by more pumicite. About one and one-half miles to the east the flow thickens and the overlying sediments thin and disappear, so that the flow is in contact with the Wenas basalt and becomes a part of that formation.

At Locality 5-5A on Toppenish Ridge, a small remnant of Wenas type basalt caps a portion of the Selah formation. The remnant is cut off by erosion from the Selah on each side, but evidently once filled a depression, possibly a channel cut by the stream which deposited the sediments. The relations indicate that this remnant of basalt was at one time covered by Selah sediments. Because the Selah sediments here are of types which could have been deposited within a very short period of time,

PLATE V: West to east view across south end of Sentinel Gap. In foreground Wenas basalt (W) fills channel in Yakima basalt (Y). Across Gap Selah formation (light gray) two hundred feet thick separates Wenas and Yakima.

this flow remnant may have been an advance unit of one of the Wenas formation flows.

Sediments derived from altered basalt: At several places the Selah rests on dark green, softened Priest Rapids basalt retaining vesicular structure. This same sort of alteration was observed at the top of the Wenas basalt locally. Apparently the same type of material is represented in the Selah formation by dark green claystones or siltstones, which are brittle where dry and full of slickensides where damp. Mason (1953) thought some of these beds were thin lava flows weathered in place to clay. Such an origin does not seem possible, because the associated sediments show no evidence of weathering, except of a superficial nature; and thin tongues of basalt which were observed to be intercalated with sediments are not altered as described above.

In places, for example, about one mile upstream from McNary Dam (Locality 18) on the north side of the Columbia River, this alteration material is possibly twenty feet thick at the top of the Sillusi flow and may have been transported for a short distance in part. However, no positive evidence was seen anywhere that the material directly overlying hard lava had been eroded. On the other hand, the absence of this material in most places may be due, in some measure, to its having been removed before it could be covered by the succeeding lava flow or sediments.

Possibly this material originated by deuteric alteration of clinker or clinkery vesicular basalt. The inherent porosity and original fragmentation of these phases of lava flows would allow ready access to chemical attack and would promote easy removal by running water. Some of the clinker fragments exposed in new excavations at McNary Dam were in a very similar physical state, although probably in a chemical state of higher oxidation. The green coloration of the altered basalt and the claystones indicates a state of reduction which is incompatible with a theory of formation by weathering of basalt.

CONDITIONS OF SELAH FORMATION ACCUMULATION: The Selah formation seems to have been deposited essentially as a fan-like blanket of andesitic detritus from the west and north, modified by deposits of quartzitic conglomerate from the north. Contemporaneous with at least the later stages of Selah deposition, Wenas type lava was spreading over the sediments and being covered by them. Eventually there was a slowing in the rate of andesitic sedimentation or an increase in the rate of lava outpouring that caused the Wenas basalt to spread as a nearly continuous blanket.

During Selah time there seems to have been a regional slope of a very moderate degree toward the southeast and the south. An indication of this slope is provided by comparing the thickness of the formation at Roza Gap (Locality A), where it is about three hundred feet thick, with that at Ward Gap (Locality 9), the southeasternmost extent of significant amounts of fluviatile material, where it is forty-seven feet thick. The straight-line distance between these two points is about forty-five miles. If it is assumed that the surface of the Yakima basalt was a level plain at that time, the restored surface gradient of the Selah was something like six feet per mile.

That conditions were not altogether that simple is indicated by the fact, that the Selah, a few miles west of Yakima in the Naches valley bluffs, is only a few feet thick. Even more striking is the evidence of contemporaneous warping at Sentinel Gap. At that place the evidence for warping indicates that the andesitic sediments were not merely deposited in the crease between the regional slopes and the advancing basalt, as commonly postulated in the past, but accumulated in a structural sag that may have been a forerunner of the present structural saddle. Somewhat similar circumstances seem to have controlled the deposition of the thicker sections at the Yakima valley locations. These are all located on the flanks of structural depressions. The pumicites, of course, were not limited to deposition by streams but were controlled more by the strength of the prevailing winds.

WENAS BASALT FORMATION

Smith (1903 A) defined the Wenas basalt as overlying the Yakima basalt and "separated from it by a varying thickness of Ellensburg sandstone." He stated the two basalts to be very similar, but that their separation was necessary on stratigraphic and structural grounds. At the general type locality in the Wenas Creek valley, Smith found the Wenas to be about one hundred feet thick and in two flows. He reported three flows at other localities. The total thickness of the Wenas in the Ellensburg quadrangle attains a maximum of over two hundred feet, but in the western part of the quadrangle Smith shows the Wenas thinning and disappearing.

PLATE VI

1. Wenas basalt formation in bluff at north side Columbia River valley east of Locality 18.

2. Yakima basalt flows on north side of Wallula Gap east of Locality 16.

FLOWS: In the areas examined by this writer the Wenas appears to represent a continuous formation consisting of one or two flows, and locally a sedimentary interbed. Typically the basalt is dark gray or black, has an aphanitic or glassy groundmass, and may be sparsely to moderately porphyritic. Thick flows, as at Locality 16, may be better crystallized in their basal portions and have a blue-gray or blue-green color on freshly broken surfaces. Generally the flows are jointed into sinuous columns about six or eight inches in diameter, intersected by joints roughly parallel to the base of the flow. This jointing causes the rock to break into blocks about six or eight inches in diameter with conchoidal surfaces. This type of jointing is called blocky, diced, or brickbat. The typical jointing, together with the black, dense groundmass, are the criteria for field recognition of the Wenas type flows. The usual weathering to shades of gray or yellow-brown contrasts with that of the Priest Rapids flows.

The thicker flows are usually more massively columnar in the basal portions and may be sheeted. The upper vesicular zone also tends to have a good columnar structure and may be very massively jointed. The top of the upper flow at Locality 14 exemplifies the latter condition. There and at localities to the west in the Horse Heaven Hills vicinity, the lower flow in particular consists largely of irregularly shaped tongues with the blocky structure described above, and of tongues with columns about one foot in diameter broken into blocks by basal jointing. In Wallula Gap, and especially in the vicinity of

Sillusi Butte (Locality 18), the Wenas has well developed sinuous partings parallel to the base of the flow, which continue for several hundred feet in outcrop. They apparently represent shrinkage zones parallel to the top and bottom of the flow. Possibly they outline flow units, which were nearly assimilated into a massive flow.

Round vesicles about one-eighth inch in diameter are commonly dispersed through the flows. The vesicles locally constitute about fifty per cent of the rock volume at the flow tops. In places the vesicles are irregularly oblate and an inch or more in length.

As Waters (1955 A) points out, Wenas type flows occur in what is here called the Selah formation and also in the Ellensburg formation. During field mapping the writer used continuity of outcrop as the basis for selecting the Wenas as a formation and arbitrarily relegating flows of similar lithology to the Selah and Ellensburg formations. The Wenas basalt formation, as mapped, consists of a continuous lower flow, which is the sole representative of the formation in most places, and a thinner upper flow, which is best developed in the Prosser-Kiona area (Localities 10 to 13). East of there, the upper flow thins so that it is not present at Wallula Gap, but the lower flow thickens somewhat in compensation. A thin upper flow or unit may be present at Sillusi Butte near the 1,017 feet summit. At the east side of Sentinel Gap, the upper flow was mapped as the Wenas formation, whereas the lower flow was placed in the Selah formation. About three miles east of the Gap, where the lower flow comes in contact with the upper flow, the former was mapped as part of the Wenas formation via the arbitrary cut-off of Wheeler and Mallory (1953).

On the west side of Sentinel Gap, there are apparently no Selah sediments below the Wenas, but the Wenas rests unconformably on the upper two members of the Yakima basalt. The Wenas is in part pillowy and fills and rises above a channel-like depression in the Yakima. The relations suggest that either slightly subsequent to, or during Selah deposition, the Yakima basalt was upwarped and eroded here. In all probability the Columbia River did the eroding. A similar Wenas basalt channel filling at Priest Rapids is reported by Mackin (1955 A).

At Wallula Gap (Localities 16, 17, 18) the Wenas lies directly on the Priest Rapids member in apparent conformity due to non-deposition of the Selah formation.

Clinker in the Wenas basalt: Clinker up to sixty feet thick occurs at the top of the lower Wenas flow in the vicinity of Chandler (Locality 12). The clinker is composed of red and gray scoria from pebble to cobble size, more or less rounded in general outline, and both vesicular and non-vesicular. The scoria are clotted together and partly surrounded by a matrix of smaller fragments and light tan silica gel. In most of the outcrops, the silica gel has weathered away, so that the clinker stands in crags with a spongy texture. Probably because of the porosity, the clinker is resistant to weathering and topographically prominent. This is shown south of Chandler, where the rocks are overturned at the north base of the Horse Heaven Hills, the clinker stands in nearly vertical walls.

The clinker is also fairly well developed farther to the east in the Rattlesnake Hills extensions south of Kennewick. Some of the Wenas outcrops in the eastern part of Toppenish Ridge show a little clinkery basalt at the top of the flow. The clinker in the eastern area may be genetically related to the thinning of the flow over the Horse Heaven Hills area. Loss of gas as a contributing factor is suggested by the vesicular zone beneath the clinker being thinner than usual, and a general lack lack of vesicles in the main part of the flow where clinker was observed.

PROSSER INTERBED: In the Prosser-Chandler area (Localities 10, 11, 12) two Wenas flows are well developed and separated by the Prosser interbed. The interbed is a sedimentary unit representing part of the sedimentary lithosome. The type locality is Locality 10 (Appendix A), where some forty-five feet of pumicite and tuffaceous sediments may be seen between two flows of Wenas basalt. The same two flows may be traced a few miles to the west to Locality 9 at Ward Gap, where no sediments intervene, and possibly to Locality 7, south of Mabton, where about twenty feet of Wenas type basalt is interbedded with the basal part of the Ellensburg formation. This basalt may simply be an "overflow" from the mapped Wenas, as it evidently occupies a channeled-out depression in quartzitic conglomerate.

The Prosser interbed is identical, at least at its type locality, with Mason's (1953, locality 14) "Prosser member of the Columbia River basalt", except for variations in the interpretation of the sediments exposed there. This was apparently also Mason's type locality. He interpreted the sediments to be interbedded between the Yakima basalt and the Wenas basalt. In the vicinity of Roza Gap his "Prosser member" is interbedded with what he called the "lower member of the Ellensburg formation" (Selah formation). It seems undesirable to use the term "Prosser member" in Mason's sense, because of this stratigraphic confusion.

The locality along and near Highway 30 (8E), south of Prosser at the crest of the Horse Heaven Hills, presents especially good exposures of the sediments. As their intercalation between two flows of Wenas basalt is evident, the term "Prosser interbed" is used here to designate the beds as a sedimentary unit of the Wenas basalt formation. The Wenas flow above the Prosser is called the upper flow and the one below is called the lower flow. Plate XXXIII illustrates these conditions and indicates that west of Ward Gap the upper flow may either thin and disappear or may reappear at various localities in the Ellensburg formation.

The Prosser interbed is a link between the Selah and Ellensburg formations. Its lithology is very similar to that of the Selah, and consists largely of pumicites and fine-grained sandstones. Near Kiona, some impure diatomite, finely comminuted because of tectonic shearing, is associated with opal in the Prosser. At Localities 14 and 15, a few feet of pumicite between the two Wenas flows represents the stratigraphic equivalent of the Prosser, but may never have been spacially connected with the type Prosser. The Prosser interbed is a part of the Ellensburg lithosome separated locally from the Ellensburg formation by a nearly continuous sheet of Wenas basalt. Its conditions of deposition were essentially those of the southeastern parts of the Selah and Ellensburg formations.

CONDITIONS OF WENAS BASALT FORMATION ACCUMULATION: The Wenas as a formation is in a sense the complement of the Selah formation. Where the Selah is thin or absent the Wenas tends to be thick, and vice versa. This relationship is probably due to the Wenas having advanced in a general westward direction against the regional slope of the Selah. Exceptions to this complementary arrangement, such as the thick development of both formations at Roza Gap and Selah Gap, and their thinning at Locality 20 on the Horse Heaven Plateau, are evidently due to the presence of local topographic and structural swells and basins.

The Wenas may also be considered a part of the lava lithosome. The Wenas part of the lithosome includes not only the formation but also the basalt of Wenas lithology intercalated in the Selah and Ellensburg formations. The isolated exposures of basalt in these formations suggest that flow units from the Wenas filled local channels and basins in the sediments. Locality 1 at Sentinel Gap is an outstanding example of this. "Local flows" such as Water's (1955 A) Elephant Mountain flow and Selah Butte flow may be other examples of the same sort, separated from the Yakima basalt by various thicknesses of sediments.

In view of the evident rapidity of sedimentation shown by the Ellensburg lithosome beds, it is not improbable that all the Wenas lithology basalt is the product of two flows produced during one or two periods of eruption. Sedimentation and structural warping probably forced the advancing lava to send out local flow units while the main bodies of lava were building the continuous sheets which form the Wenas basalt formation.

ELLENSBURG FORMATION

The Ellensburg formation was defined by Smith (1903 A) as volcanic sediments of foreign origin, typically displaying fluviatile cross-bedding, deposited on the Yakima basalt. As previously mentioned, he rather cryptically included the Wenas basalt in the formation, thereby dividing it into two sedimentary parts. Mackin (1947) and Waters (1955 A) followed Smith in considering the sediments above and below the Wenas basalt to be members of the Ellensburg, but they departed from Smith's informal classification in considering the Wenas basalt to be a member of the Ellensburg.

In the areas studied the Ellensburg formation represents two general conditions of sedimentation: the original or volcanic phase and the tectonic phase. The original sediments include fluviatile and aeolian andesitic clastics and are intercalated with Wenas type basalt flows or flow units. The tectonic phase sediments consist of mixtures of andesitic and basaltic clastics, largely of local origin.

Field exposures of the Ellensburg formation permit examination only of the basal three or four hundred feet at best in the areas studied. Toppenish Ridge and Snipes Mountain present the best exposures, but even at these localities the exposures are largely limited to artificial cuts because of the retiring

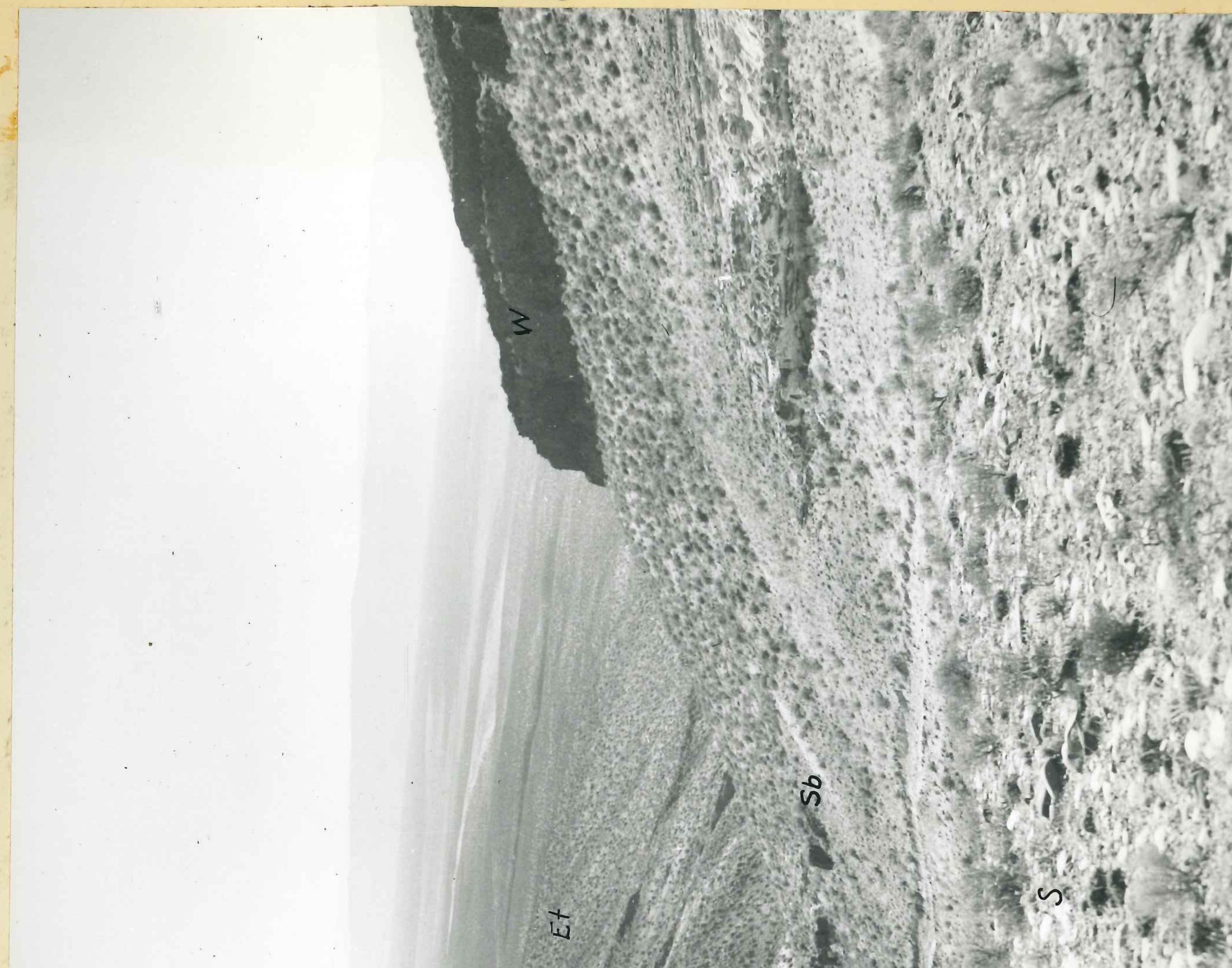


PLATE VII: South flank of Saddle Mountains, Locality 1. Et, tectonic phase Ellensburg; W, Wenas basalt formation; S, Selah formation; Sb, basalt in Selah formation (symbol is at local termination of flow); quartzitic conglomerate cobbles in foreground; pumicite beds at right. Rocks dip south.

nature of the sediments under conditions of natural weathering. The formation may be much thicker in the lower Yakima River valley area than the exposures indicate. Smith (1903 A) describes about 1,500 feet of Ellensburg formation in the Naches River valley bluffs west of Yakima.

<u>ORIGINAL SEDIMENTATION:</u> The original or volcanic phase sediments essentially represent a continuation of the types of sedimentation that produced the Selah formation. In general, the sediments of this phase are finer-grained in the areas studied than those to the north and west in the vicinity of Yakima. They were brought to the places of deposition from outside sources with no essential contributions from local areas.

<u>Andesitic sediments:</u> The andesitic sediments consist essentially of sandstones, siltstones, and pumicite. Conglomerate beds were observed at Toppenish Ridge and Snipes Mountain, but not farther east, although pebbly sandstones are common throughout. Like the typical Ellensburg beds of the Yakima area, those of the areas studied have the hornblende andesite lithology. However, admixed quartz grains commonly form a significant percentage of the sands as a result of contamination by non-volcanic sediments.

The andesitic sediments described here are limited to the lower Yakima valley area. The stream-born clastics show the same types of cross-bedding, lensing, and channeling effects as the Ellensburg beds farther northwest, but these structures are more subdued. With distance eastward, the strong stream-bedding effects gradually give way to more even bedding and, at the same time, the grain size decreases.

The pumicites in the Ellensburg formation are of the same types as those in the Selah formation and the Prosser interbed. Medium-grained, glassy pumicite was observed at Snipes Mountain and at a small abandoned quarry southeast of Prosser. East of Mabton, the andesitic sediments are very poorly exposed, but seem to consist largely of very fine-grained pumicite, in part bentonitic.

Quartzitic conglomerate: The quartzitic conglomerates in the Ellensburg formation are of the same type as those discussed under the Selah formation and represent the same type of sedimentation. The conglomerate is well exposed at the base of the formation on the higher parts of Snipes Mountain, and may be observed where interbedded with the andesitic sediments in the clay works pit southeast of Granger, and in a quarry at the east end of Toppenish Ridge. At other localities the exposures are less satisfactory, the conglomerate being largely traceable by quartzite pebble float. This float must be regarded with caution in field mapping because the quartzite pebbles linger as lag gravel long after the other pebbles and finer clastics have been removed.

Where the conglomerate is formed of pebbles in good contact with each other, it tends to form hogbacks or mesas depending upon its attitude. Excellent examples of these topographic expressions may be seen along the south side of the eastern portion of Toppenish Ridge. In this vicinity the conglomerate base has a gradual stratigraphic rise to the eastward caused by the intervention of andesitic sediments between it and the

Wenas basalt. At the east end of Toppenish Ridge the conglomerate is about three hundred feet stratigraphically above the Wenas basalt formation and is interbedded with andesitic sediments, so that it is not topographically prominent. To the east, across the Yakima River valley at Snipes Mountain, a strong conglomerate unit about one hundred feet thick lies directly upon the Wenas basalt along the crest of the higher part of the ridge. In turn this conglomerate becomes interbedded with andesitic sediments at the east and west ends of Snipes Mountain.

Other localities were found where quartzitic conglomerate with little andesitic admixture forms part of the Ellensburg formation, such as both flanks of Toppenish Ridge near U.S. Highway 97, and the north base of the Horse Heaven Hills south of Mabton (Locality 7). At all of these localities the conglomerate is in the basal part of the Ellensburg formation, either directly upon or not far above the Wenas basalt. East of Prosser, scattered pebbles of quartzite on the north slope of the Horse Heaven Hills suggest the presence of conglomerate, but no outcrop was seen. Very likely the pebbles are residual, or may in part have been ice-rafted during the Pleistocene epoch.

Basalt flows in the Ellensburg formation: The flows in the Ellensburg are all of the Wenas type. They form a small part of the formation and apparently fill channels and other depressions in the sediments. On the north flank of Toppenish Ridge at Locality 4, a small flow remnant is intercalated in Ellensburg sediments. South of Mabton, at the lower gravel quarry

PLATE VIII

1. Wenas basalt at Locality 18. Jointing is typical of many Wenas outcrops.

2. Prosser interbed pumicite (coarser-grained type) at Locality 10.

west of the road to Roosevelt and Alderdale, about twenty feet of basalt is intercalated in Ellensburg sediments. These occurrences probably represent Wenas flow units in the sense of Nichol's descriptions. They could have been formed by mutual damming and diversion of the spreading basalt and the rapidly accumulating Ellensburg sediments. The basalt would have tended to fill channeled-out sections on the alluvial blanket. Something of this kind seems evident at one locality on Snipes Mountain, where a very few feet of vesicular basalt is in the basal few feet of the Ellensburg formation.

TECTONIC PHASE SEDIMENTS: The tectonic phase sediments consist of andesitic and basaltic clastics. They are found on the north flanks of the Horse Heaven Hills and on the slopes of Saddle Mountains. Possibly they exist elsewhere in the areas studied, but could not be identified. At both of the above areas the relations indicate sedimentation concurrent with the stripping of basalt and sediments from the ridges.

Tectonic phase Ellensburg of the Horse Heaven Hills: Deposits of this phase were observed at Localities 7, 8 and 9. The clearest exposures are in the vicinity of Locality 7 southwest of Mabton on the north slopes of the Horse Heaven Hills.

Here the basal few hundred feet of Ellensburg consists of interbedded andesitic sediments and quartzitic conglomerates dipping steeply to the north. The conglomerate beds form hogbacks, which can be traced in nearly straight line patterns across the topography. Farther to the north are rather poorly exposed beds of what appear to be reworked andesitic material mixed with fragments of basalt. The basalt is in the form of pebbles, cobbles, boulders and huge anular blocks. The larger gragments are in massed accumulations in the tuffaceous material. The masses of basalt are very similar to those which can be seen to have accumulated in the present gullies which score the face of the Hills. These modern accumulations are moraine-like heaps near the foot of the ridge, where the occasional torrents capable of transporting such coarse debris suddenly lost velocity and carrying capacity.

A similar situation seems to be recorded in the older debris where in the midst of the fine-grained tuffaceous material are large heaps of basalt cobbles and boulders whose surfaces are slightly to moderately rounded. The surface profiles of these foothill ridges of debris, if projected to the south, appear to parallel roughly the general profile of the main ridge face, but to rise above it in smooth curves. This profile relationship can be observed between the main ridge in the Yakima basalt and the foothills of Ellensburg debris where east-west transverse valleys and gullies isolate some of the debris in mesas. An outstanding example is the roughly triangular shaped mesa defined by the closed 1,250 feet contour line about six miles southwest of Mabton.

The structural relationship between the debris Ellensburg and the basal Ellensburg is not entirely clear because of the lack of contact exposures, but it is virtually certain that at least part of the debris has an unconformable relationship, to the steeply dipping basal beds. This suggested unconformity, together with the lithology of the debris, indicates that it is in large measure a result of the erosion of basalt and sediments from the north flank of the Horse Heaven Hills.

The inclusion of this debris in the Ellensburg formation is based on the following deductions. Andesitic material comprises the bulk of the deposits. There is no evidence for the existence of the Ellensburg farther south on this section of the Horse Heaven plateau or even on the north crest of the Hills where the Wenas basalt outcrops. If the formation had been deposited in these places, there would almost certainly be evidence today in the form of pebbles from the quartzitic conglomerate. Therefore, it is deduced that the Ellensburg debris was deposited in a structural basin between the rising Horse Heaven Hills and Rattlesnake Hills concurrently with the erosion of the ridges. The large size of much of the basalt fragments and the fact that Frenchman Springs basalt is included indicate that erosion had bitten deeply into the north face of the Horse Heaven Hills at that time. This depth of erosion suggests that the Ellensburg formation and the Selah formation had been substantially if not entirely stripped from the north face of the Horse Heaven Hills at that time. This part of the Ellensburg appears to consist of slope wash together with original type material.

Similar conditions in the Yakima East quadrangle have been described by Waters (1955 A). He found that pediments had been formed on the slopes of the rising anticlinal ridges while the Ellensburg formation was being deposited. In the process of pediment formation basalt was eroded fromthe ridges and included in the Ellensburg sediments along with reworked andesitic material. At present the erosional processes are forming new pediments and dissecting old ones.

Tectonic phase Ellensburg of Saddle Mountains: At Locality 1 the Ellensburg consists of andesitic sands, silts, and basaltic gravels. The sands and silts are of nearly typical Ellensburg composition although they contain quartz and are rather less rich in glass and less cemented than is usual. Basaltic gravels make up the bulk of the beds. The rather slight degree of rounding of the basalt pebbles as compared to those in the Selah formation at the same place, and the lack of strong current bedding suggests that these beds were in large measure locally derived from reworked Ellensburg sediments and basalt bedrock. The beds here appear to be conformable on Wenas basalt with a low southward dip.

About a mile east of Sentinel Mountain on the north crest of Saddle Mountains are tuffaceous silts, sands, and conglomerates of slightly to moderately rounded basalt pebbles in a tuffaceous andesitic sand and silt matrix containing quartz. These beds rest in structural valleys on the surface of the Wenas basalt. The structural valleys trend north and south and are subordinate to the main east-west uplift. The sediments attain a maximum thickness of possibly two hundred feet or more. Below the Ellensburg beds the Wenas basalt and the Selah formations form prominent outcrop bands. Farther east the Ellensburg thickens and forms badland pinnacles.

PLATE IX: View of north face of Saddle Mountains, eastern part of Beverly quadrangle. Tectonic phase Ellensburg beds (Et) on Wenas basalt (W) fill synclinal valley transverse to main anticlinal axis. S is Selah formation; Y is Yakima basalt.

Still farther east in the vicinity of Smyrna (Map area II) similar sediments about five hundred feet thick underlie a broad topographic bench north of the crest of Saddle Mountains and south of Crab Creek. These sediments have been called the Crab Creek beds by Twiss (1933), who correlated them with the Ringold formation.

Near Smyrna the beds dip 5° to 9° northward, the upper beds having the steepest inclination. They consist of loosely cemented tuffaceous sands and silts of rather typical Ellensburg composition except for the comparatively low content of volcanic glass and of basaltic conglomerates similar to those at the ridge crest east of Sentinel Mountain. The structural conditions are somewhat complex and will be discussed later, but the evidence afforded by lithology and structure suggests that here are sediments formed from Ellensburg and basalt eroded from Saddle Mountains during the initial deformation of the Ellensburg and the basalts. As this sort of sedimentation does not fit the usual view on the formation of the Ringold formation and does not, therefore, fit Twiss's views on the age of the Crab Creek beds, the sediments are best referred to the Ellensburg.

Farther east along the north front of Saddle Mountain, especially in the vicinity of Corfu, the same sort of relation may be seen. In this vicinity Mason (1953) has described an unconformity between the Yakima and Wenas basalts and the "Ringold formation". Such an unconformity exists, but here also the sediments dip with the basalt to the north, although at a much lesser angle. The sedimentary material here contains little basalt debris and consists largely of Ellensburg lithology sands and silts. Apparently these sediments also belong to what may be called the tectonic phase of the Ellensburg formation, especially if, as most workers have assumed, the Ringold was deposited after the deformation of the Ellensburg formation.

Basaltic gravel west of Kiona: Slightly over two miles nearly due west of Kiona (between Localities 12 and 13), a county road passes over the crest of the Horse Heaven Hills through a topographic and structural saddle where a large pit has been excavated in basaltic gravel. The gravel is entirely of fairly well rounded basalt pebbles and cobbles in a silty matrix, but in part the texture is openwork. The bedding is foreset and dips steeply to the northwest. The deposit is probably at least fifty feet thick and lies on the upper Wenas flow. Apparently the Wenas was eroded by the stream which carried the gravel, but the amount of erosion is not determinable, owing to poor exposures of the bedrock.

This was the only deposit of pure basaltic gravel found at an elevation above the upper limit of Pleistocene scabland gravels. It apparently represents the bed load deposit of a rather large stream which flowed in a structural sag during the up-arching of the Horse Heaven Hills, long before they had attained their present elevation. It is included in the Ellensburg description because of its stratigraphic position.

CONDITIONS OF ELLENSBURG ACCUMULATION: In general, the Ellensburg represents a continuation of the sedimentation processes that produced the Selah formation and the Prosser interbed.

However, the Ellensburg also records an intensification and localization of the warping movements that had begun during accumulation of the Yakima basalt. These intensified movements produced basins in which the thickest sections of the formation are preserved today and anticlinal ridges from which sediments and basalt were stripped and deposited in the basins.

Because the Ellensburg formation represents a culmination of processes which had been evolving for a long time, it is convenient to discuss the accumulation of the whole sedimentary lithosome. The discussion will include the deposition of the pre-Selah interbeds, although they may have never had any actual connection in space with the lithosome. The lithosome proper includes the Selah formation, the Prosser interbed, and the Ellensburg formation.

CONDITIONS OF SEDIMENTARY LITHOSOME ACCUMULATION

With the advent of andesitic volcanism, at least as early as Vantage member time and very probably before that, regional slopes toward the center of the Columbia Basin had come into existence. The andesitic detritus from the west was carried southeastward by streams which probably had courses nearly parallel to those of the major drainage lines of today. At first the andesitic eruptions evidently lacked intensity, and the streams probably lacked carrying capacity; consequently, coarse detritus in the Vantage member has been found only near Ellensburg. The finer detritus, however, reached a widespread area comparable to that of the Selah and Ellensburg formations. Whether the pre-Selah interbeds are spacially connected anywhere with the present-day ranges of the Ellensburg and Selah formations is not known, but it is possible that they were originally continuous vertically with the Ellensburg lithosome in the source areas.

The Vantage member, the Squaw Creek member, the Mabton interbed, the Burke diatomite, and the various petrified wood horizons all testify to the sedimentation processes which were going on during the time that the Yakima basalt was accumulating. At the same time that the eruptions were contributing andesitic sediments, the Columbia River was beginning to develop its drainage pattern after the disruption of the previous drainage by the lava flows. The earliest known traces of this drainage, with the possible exception of petrified wood accumulations, are the cross-bedded quartz sandstones of the Vantage member at and near Sentinel Gap. That this drainage may have established a temporary course in the vicinity of Sentinel Gap is suggested by the sandstone there in contrast with the Ellensburg lithology of the Vantage to the east on Saddle Mountains and west in the Yakima River gorge south of Ellensburg. The river at that time was apparently much smaller than the present Columbia as evidenced by the lack of coarse clastics associated with the quartz sands.

The picture in pre-Selah time, then involves outbursts of explosive andesitic volcanism, which contributed thin sheets of detritus while diatomite was forming in ponded areas and the ancestral Columbia River and perhaps tributary streams were depositing sediments derived from the older formations to the northward. The sedimentation appears to have taken place in localized basins formed by the encroachment of lava flows against the regional slope, in surface irregularities on the individual flows, and in structural sags. Much, if not most, of the pre-Mabton interbed andesitic sediments were derived from showers of volcanic ash, which fell in ponds or were reworked and deposited in streamways. There is no evidence to support the existence of the Yakima River drainage in an integrated form at that time.

With the advent of Priest Rapids accumulation, regional warping had become more localized, with the result that the flows and the Mabton interbed show considerable variations in thickness from place to place. In these variations can be seen the beginnings of the structures which exist today, superimposed on the structure of the Columbia Basin as a whole. The Mabton interbed, in addition, contains sandstones which may represent deposits of the ancestral Columbia River.

In Selah time, the andesitic eruptions intensified and probably became less intermittent than formerly. The structural warpings also intensified and became more localized, but the deposition of andesitic detritus was still controlled largely by the supply from the west and the regional slopes. At this time showers of volcanic ash became larger, so that ash or pumicite accumulated between stream courses in large quantities. In addition much ash fell directly along stream courses and was incorporated into the stream-laid sediments.

Along with this increased volcanic activity, the Columbia River drainage system began to develop in earnest, so that its

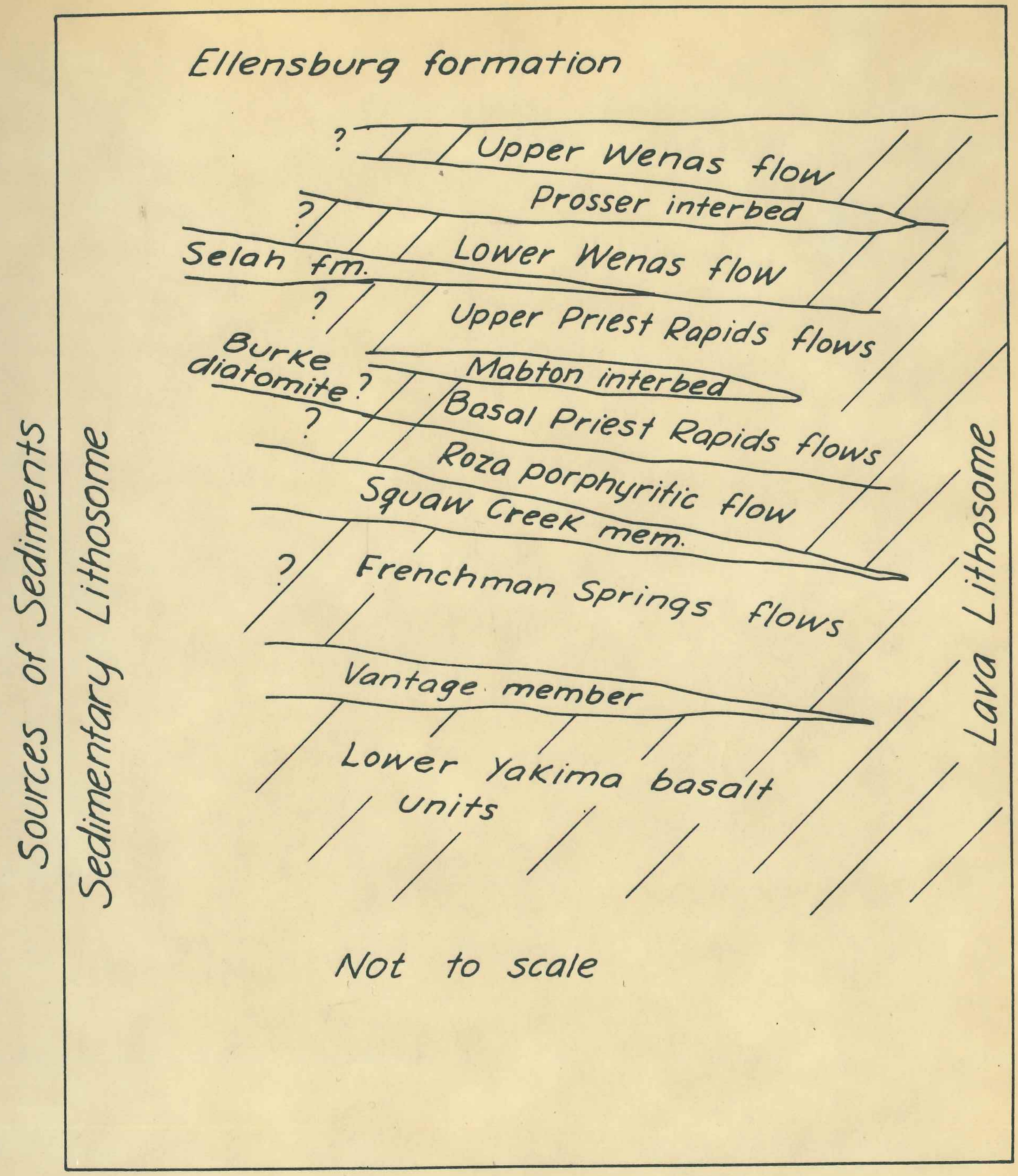


Figure 5: Diagrammatic representation of sedimentary and lava lithosomes.

carrying and erosive power became significant. The result was the quartzitic conglomerate. It is generally agreed that the conglomerate records erosion in the northern Rocky Mountains, but it may also represent erosion in the Cascade Mountain area. According to Waters (1955 A), quartzitic conglomerates and quartz-rich sands are found almost everywhere in south-central Washington near the base of the Ellensburg formation or its stratigraphic equivalents. This suggests that some of the conglomerate was deposited by streams tributary to the Columbia. The sources of much of the conglomerate may be such formations as the Eocene Swauk near Wenatchee in which quartzitic conglomerate has been reported by Coombs (1952).

Some of the conglomerate may have been deposited by the Yakima River. For example, between Localities 3 and 4 on the north flank of Toppenish Ridge, nearly vertical beds of conglomerate interbedded with andesitic sediments have two lithologies. One lithology is the quartzitic type; the other is non-quartzitic. In it about one half of the pebbles are hornblende andesite and the remainder are basalt, "greenstone" types, volcanics, and granitics which resemble some of the rock types of the northern Cascade Mountains. This conglomerate seems to occupy a large channel cut in quartzitic conglomerate and andesitic sediments. In any event the conglomerate in general represents the bed load deposits of a vigorous stream or of several streams. Where the pebbles consist of rock types now being carried by the Columbia River with very little or no andesitic admixture, there is little doubt that the ancestral Columbia River was the depositional stream. At Sentinel Gap, the river had an established course somewhat prior to the deposition of the Selah formation. Evidence of this is the conglomerates at the base of the Selah formation, which outcrop for about three miles east of the Gap, less clearly exposed gravels and pebbles on the west side of the Gap, and the channel occupied by the Wenas basalt on the west side of the Gap. Such evidence suggests that the present structural sag at Sentinel Gap has been in existence for a long time. The river seems to have crossed Saddle Mountains in the lowest gap available. Perhaps the crossing was in part directed by the growth of a fan of andesitic detritus from the west; almost certainly floods of andesitic detritus forced the river to shift its course at times.

The conglomerates in the Selah formation at Priest Rapids (Mackin, 1955 A) suggest that the river followed a southerly course. Perhaps this Selah course trended southeastward below Priest Rapids. At or near the base of the Ellensburg formation, compact quartzitic conglomerates near Union Gap, at Toppenish Ridge, Snipes Mountain, and south of Mabton (Locality 7) indicate a shifting course of the Columbia at a higher stratigraphic level. Possibly the Wenas flows pushed the river westward from its Selah course. This is suggested by thick Wenas at Localities 14, 16, and 18, the Wenas type flows interbedded with quartzitic conglomerate and andesitic sediments in the Rattlesnake Hills (Mason, 1953).

Whether the river ever crossed the Horse Heaven anticline in the vicinity of Satus Pass (Warren, 1941 B) is conjectural.

Waters (1955 A) reports quartzitic conglomerate to overlie Yakima basalt on both flanks of the Horse Heaven anticline west of Mabton, but he did not find any in Warren's Satus Pass "windgap". From the vicinity of Mabton eastward, there is no evidence of quartzitic conglomerate on the Horse Heaven upland. The basaltic gravel near Kiona was the only gravel seen by this writer at the crest of the Horse Heaven Hills, and it was probably deposited by a stream tributary to the Columbia.

Therefore, the Columbia River either crossed the site of the Horse Heaven Hills west of Mabton and was diverted to a more easterly course as Warren suggested, or the river never had an established course across this section of the Hills. In the latter case, the river may have used the Wallula Gap structural sag crossing continuously in post-Yakima basalt time except for possible temporary diversion elsewhere across the Horse Heaven Hills by advancing flows of Wenas basalt. The evidence for nearly continuous structural warping during accumulation of the upper Yakima basalt and the Ellensburg lithosome suggests that the river primarily followed a structural course.

During the post-quartzitic conglomerate part of Ellensburg formation accumulation, the Columbia probably had essentially its present course, and the Yakima River spread andesitic detritus together with reworked quartzitic conglomerate. The bulk of the sediments was deposited in synclinal troughs between the growing anticlinal ridges. Most of the Yakima River sedimentation in the areas studied took place west of Chandler (locality 12), in the basin between the Rattlesnake Hills and the Horse

PLATE X

1. View westward from Locality 4 of north side of Toppenish Ridge. Wenas basalt in foreground, Selah outcrop (light gray) left and center.

2. View of Locality 5 from the west. Wenas basalt caps Selah formation (light gray) in middle distance. Small dark ridge capping at left is basalt remnant once interbedded with Selah.

Heaven Hills. The Columbia River and tributaries from the west deposited sediments on the north side of Saddle Mountains. As the ridges grew higher, sediments and basalt from their flanks were eroded and partly deposited on the slopes.

RINGOLD FORMATION

Lime cemented gravels on the south slope of Saddle Mountains east of Sentinel Gap may represent the Ringold formation. These gravels (see Locality 1, Appendix A) are very similar to the quartzitic conglomerate in general lithology and are quite evidently a Columbia River product. The beds directly overlie the Wenas basalt with probable unconformity, and the top of the deposit forms a terrace between 900 to 1,000 feet elevation. The material and manner of cementation are very similar to that of the gravels exposed in the Ringold formation north of Pasco and to material which was encountered near the base of the formation in the vicinity of Pasco and Kennewick during test drilling and excavations for levee foundations in connection with the Army Engineers' McNary Dam Project. The relations both at Sentinel Gap and in the Pasco Basin suggest the bed load deposits of the Columbia River. At Sentinel Gap the bed load deposits cover a terrace cut on the Wenas basalt and laterally into the Ellensburg formation.

The best exposures and the type area of the Ringold are largely within the confines of the Hanford Project of the United States Atomic Energy Commission. The restrictions of this area make it difficult to determine the relation of the type Ringold with other deposits that have been assumed to be Ringold correlatives. Near Ringold the beds consist of sands, silts, and clays. The sands consist (Laval, 1948) of quartz and andesitic materials. The grains are much more worn and altered than those in typical Ellensburg sands, and the glass content is lower. Apparently the material largely represents weathered and reworked Ellensburg lithosome material.

The type Ringold was assumed by Merriam and Buwalda (1918) to be unconformable upon folded Ellensburg formation. Jenkins (1924) described such an unconformity in the type area. These relations indicate that the type Ringold was deposited either after the deformation of the Ellensburg was complete, or during the deformation, but certainly after it had been substantially completed. The accepted Pleistocene age for the Ringold would indicate the former. If this is true, then the basining which allowed the beds to accumulate was possibly a by-product of regional epeirogeny. On this basis and other evidences discussed under the Ellensburg formation, it would appear that beds associated with folding of the east-west ridges, as opposed to later warpings of lesser intensity in the areas studied, cannot be assigned to the Ringold formation but must be regarded as Ellensburg formation or its correlatives unless special classifications are to be made.

The Ringold was not observed in locations other than the Pasco Basin and (?) Sentinel Gap, and no evidence was found to support Culver's (1937) contention that a large part of the Ellensburg formation should be regarded as Ringold. Rather it is thought that various Ringold "correlatives" should be regarded as tectonic phase Ellensburg formation.

The Ringold appears to be a result of renewed of reaccentuated downwarping of the Pasco Basin in early Pleistocene time or possibly in later Pliocene time. The "basal" conglomerate in the vicinity of Pasco suggests that the Columbia River had been at, or nearly at, grade previously. The clays in the Ringold at Pasco and near Ringold suggest that some ponding of the Columbia took place, but most of the sedimentation, according to McKnight (1923) was fluviatile. There is no evidence for enough ponding of the Columbia River to cause it to be dammed behind the site of Wallula Gap in the Horse Heaven Hills, as suggested by Flint (1938 A) and by Warren (1941 B). Instead it appears that the Gap was in existence as both a topographic and structural feature long before Ringold sedimentation and that the river continued to flow through it during Ringold time. Otherwise high level deposits of Ringold should exist in the Horse Heaven Hills south of Kennewick, but they are not known. The Ringold seems to represent renewed or continued sedimentation after the vigorous tectonism of Ellensburg time. It may be a part of the sedimentary lithosome, but it is not so considered here because continuous Ellensburg-Ringold deposition cannot be proved at present.

YOUNGER QUATERNARY DEPOSITS

Deposits younger than the Ringold formation consist of fluvio-glacial sediments, a thick mantle of loessial soil in the Horse Heaven Hills, high level and recent alluviums of the Columbia and Yakima Rivers, and in many places drift sand and small deposits of volcanic ash or pumicite.

The fluvio-glacial deposits are of little direct interest as far as structural studies are concerned. They consist of basalt gravels derived from the Columbia Plateau by the Spokane floods of Bretz (1925) and Allison (1933), and of the Touchet beds of Flint (1938B) and of Columbia River type gravels and ice-rafted erratics associated with the Touchet beds. In general these deposits serve to mask and obscure the bed rock.

The ice-rafted erratics which were scattered about by the ponding of the Columbia River introduce a source of confusion in interpreting the bedrock below elevations of approximately 1,200 feet in the Yakima and Columbia valleys. The erratic material consists of sands, gravels, and large angular blocks. The sands and gravels can introduce errors in geological mapping because they greatly resemble weathered quartzitic conglomerate. The large blocks are no problem where they consist of obviously foreign types, such as limestone or granite. But large blocks of basalt, such as those near the crest of Snipes Mountain, where they were apparently stranded along the shore of a very temporary lake, can resemble basalt bedrock.

Basalt or scabland gravels may be seen in some of the gullies tributary to Wallula Gap and have been encountered in well drilling near the mouth of the Walla Walla River at the entrance to the Gap. Some of the high gravels in the Gap may have been derived from the erosion of the scabland channels, which may be seen high up in the walls of the Gap and in the edges of the plateaus on either side.

In the vicinity of Pasco and Kennewick are thick deposits of Columbia River gravels which form two terraces, the higher one reaching an elevation of slightly over six hundred feet. They are both evidently of Pleistocene age and the lowermost at least is no doubt of Wisconsin age. It is molded into huge bars that record a river much larger than the present Columbia and was evidently formed by the river when it was much enlarged by glacial melt waters. Similar types of gravel are to be seen farther downstream in the Umatilla basin. Openwork gravel of Columbia River lithology forms the south abutment of McNary dam and forms a large fill terrace beneath a scabland terrace cut in basalt.

High level river gravels form thick deposits in the abandoned valley along the north side of the Horse Heaven Hills between Kiona and Badger (Plate XXIX). At the western end of the valley are quarry exposures of Columbia River type gravels, perhaps one hundred feet thick overlain by Touchet beds which form terraces on both sides of the valley. The valley floor near Kiona is about one hundred feet above the Yakima River and is cut through the Touchet beds, the older gravels, and into bedrock. The exact significance of these gravels was not determined, but they may be genetically related to the higher terrace south of Kennewick.

A blanket of loessial soil over two hundred feet thick in places, mantles the Horse Heaven Plateau, and in not so well developed form, many of the other uplands. Much of it may correspond to the Palouse soil of eastern Washington. The soil of the Horse Heaven upland has been eroded by melt water floods below 1,200 feet elevation, and is therefore probably older than Wisconsin age. Culver (1936) has suggested that much of the loess may have originated from the deflation of the Ringold formation in glacial times.

In the valleys, and especially in the Pasco and Umatilla Basin areas, are extensive deposits of drift sand. Characteristically, these are arranged in longitudinal dunes whose axes trend northeast-southwest because of the prevailing winds. The drift material has been derived from all of the sedimentary rocks of the area. Associated with these drifts are small deposits of volcanic ash.

P E T R O G R A P H Y A N D P E T R O L O G Y

The lava flows were examined in thin section, and the sediments were examined under both the binocular and the petrographic microscope. The upper units of the Yakima basalt and the Selah, Wenas, and Ellensburg formations received the most attention because of their widespread distributions.

LAVA FLOWS

Under this heading will be considered the Yakima basalt flows and all of the Wenas type flows. The flows are all tholeiitic (Kennedy, 1933) and have nearly the same general composition. They all contain plagioclase, pigeonite, magnetite and glass. Olivine is generally rare or absent but appears sparsely in the Sillusi flow and is a major constituent of the

Wenas type flows at some localities. Orthopyroxene was identified only in a palagonitic sideromelane breccia from the base of the Frenchman Springs basalt.

Typical textures are diabasic, intersertal, and hyalo-ophitic. All of these may be found in a single flow, but the better crystallized parts are generally diabasic or intersertal. Most of the flows are at least finely porphyritic or microporphyritic, and several (see Stratigraphy and Appendix A) are megaporphyritic. The larger megaphenocrysts are largely formed of glomeroporphyritic clots of plagioclase or of plagioclase together with pigeonite or olivine.

On the basis of anorthite content of the plagioclase, the flows can be classified as basalts, basaltic andesites, and rarely as andesites. The determinable plagioclase crystals range in composition from about An_{30} to An_{70}. In any one thin section the bulk average of the plagioclase will probably range from An_{45} to An_{55}. This average is very difficult to ascertain because of the difficulty of properly sampling the large phenocrysts and of identifying groundmass microlites. Andesitic composition is represented by Flow C at Locality 1 and the Umatilla flow at Localities 7 and 18. Basaltic composition is represented by Flow D at Locality 1. The other flows or parts of flows are borderline examples. The Wenas flows represent another variation in that several thin sections from the Wenas basalt formation and from the Wenas type basalt in the Selah and Ellensburg formations have two or three per cent of olivine as small phenocrysts and an indeterminable amount of groundmass olivine. Available chemical analyses (Washington, 1922; Campbell, 1950) indicate the Columbia River basalts to be of tholeiitic basalt and tholeiitic andesite composition. Detailed petrographic work and chemical analyses related to particular flows are needed.

COMPOSITION OF THE FLOWS: Because of the variations in composition of the flows, both vertically and laterally, it seems desirable to describe the individual components rather than to attempt detailed descriptions of each flow. With few exceptions each of the components was found in all of the flows. The particular characteristics of individual flows or groupings of flows can be described best with reference to their constituents.

Plagioclase: The plagioclase was determined by means of the conventional extinction angle curves. More accurate results might have been obtained in determining the larger crystals by means of index of refraction oils, but some difficulty would have been experienced in connection with the smaller crystals. The methods used seemed to give consistent results. In view of the work of Köhler (1949) and others on high and low temperature plagioclases, the standard low temperature curves may be in error by several per cent with relation to volcanic plagioclases. This problem has not yet been resolved and is not a critical factor here except that the determined anorthite contents may be somewhat higher than those which would have resulted from the use of "high temperature" data.

Three generations of plagioclase are almost invariably present. The oldest crystals have compositions of about An_{70}

to An_{55} and form the large phenocrysts of the porphyritic flows. The crystals tend to be euhedral, but are nearly all corroded to various degrees, so that in some of the flows only small remnants remain. Individual crystals have a length to width ratio of about 2:1 or 3:1 and range in length from about two to ten millimeters. Many of the phenocrysts are formed of several crystals which appear to have grown in contact with one another. This form of growth may be due in part to some type of twinning. In contrast with these compound phenocrysts are glomeroporphyritic clots of plagioclase, or of plagioclase and pyroxene, in which the individuals plainly became welded together after growth had been completed.

The older crystals have albite and Carlsbad twinning and many of them are zoned. Three types of zoning were observed. Most common are oscillatory zoning with little variation in extinction angles and normal zoning in which the greatest variations noted were An_{70} cores and An_{40} rims. Reverse zoning in which the rim is slightly more calcic than the core is very rare. Most of the zoned crystals have cores occupying about one-half of the crystal volume, whose rounded outlines indicate resorption of the original crystal. Many of the cores are crowded with inclusions of dark brown tachylyte.

Large crystals of this type are characteristic of the Frenchman Springs and Roza porphyritic flows. They are common in some phases of the Priest Rapids flows and rare to common in flow F, the Museum flow, and the Wenas type flows. In the flows below F, they are common to abundant but are so corroded that they form only very small phenocrysts or are no larger than the groundmass crystals.

Plagioclase of generally intermediate size and normally of composition An_{55} (range, An_{45} to An_{55}) represents a second generation. The crystals are on the order of one to two millimeters long, are euhedral, tend to be rather stubby, and rarely are zoned. Corrosion has penetrated many of them at one end along cleavage cracks and less commonly on more than one side, but is by no means as extensive as in the older phenocrysts. Inclusions of tachylytic glass arranged parallel to the elongation of the crystals are common. Where the older type of plagioclase is not present, the second generation crystals form small but easily recognizable phenocrysts.

The youngest plagioclase crystals are laths and microlites of An_{30} to An_{50} composition. They are elongate and range in length from less than one-tenth millimeter to about one-half millimeter and exceptionally to one millimeter. Most of the crystals are subhedral and many have ragged ends. No zoning was observed. In well crystallized phases of the flows, this generation of plagioclase ordinarily forms twenty to fifty per cent of the rock volume. The most notable development of this generation of plagioclase is in the Umatilla flow at Localities 7 and 18 and in flow C at Locality 1. At all of these localities the plagioclase consists of laths of approximately An_{35} composition and phenocrysts up to one or two millimeters long of An_{45} composition.

Pyroxene: Nearly all of the pyroxene which could be identified is pigeonite, whose apparent optic angle varies from about 0° to nearly 30°. The pigeonite occurs as euhedral and subhedral grains and phenocrysts up to five millimeters long and as clusters of small anhedra. The phenocrysts and larger grains are generally somewhat corroded and commonly are clotted together with plagioclase. In some thin sections there appear to be two generations of large pigeonite grains, as evidenced by differential corrosion and the associations with the older plagioclase crystals.

One pigeonite phenocryst in a section from the Wenas basalt is zoned so that the narrow rim has a somewhat larger extinction angle than the core. According to data given by Winchell (1946, p. 221) this may indicate that the rim has a somewhat higher iron content than the core. The zoning of augite to pigeonite mentioned by Waters (1955 A, B) was not observed. In some thin sections the larger pigeonite crystals have apparent optic angles of 25° to 30°, whereas the groundmass anhedra have apparent optic angles of very nearly 0°, insofar as measurements could be made. This relationship does not seem to be consistent, however, and according to Winchell (1946) may be found within individual crystals. Some of the phenocrysts are weakly pleochroic in shades of brown.

In the groundmass of the flows the pyroxene is typically crystallized into clusters of tiny anhedra intimately associated with magnetite and interstitial glass. In the Umatilla flow at Locality 7, some of this groundmass pyroxene appears to be augite. Other than this the anhedra are apparently pigeonite, but are commonly too small for positive identification.

Orthopyroxene was identified only in thin sections from the pillow-palagonite complex at the base of the Frenchman Springs basalt near Vantage. Slightly resorbed crystals of weakly pleochroic hypersthene (?) are scattered about in sideromelane breccia together with pigeonite and plagioclase. The hypersthene (?) crystals attain lengths of perhaps one half millimeter but are too sparse for positive identification.

Olivine: The only definitely identified olivine was found in the Sillusi flow at Localities 16 and 18 and in the Wenas basalt and Wenas lithology flows at several localities. Most of the olivine forms sparse phenocrysts up to three millimeters in diameter, some of which are in glomeroporphyritic clots with plagioclase. Corrosion of the olivine is generally very marked, but reaction rims of very small pyroxene (?) crystals are rather uncommon. Some of the crystals are so corroded to very small remnants that they are part of the groundmass material, but apparently are of the same generation as the larger grains. The olivine has an apparent 2V of approximately 80^{o} and a negative optic sign, indicating that it is comparatively rich in iron.

Magnetite: Most, possibly all, of the opaque oxides are magnetite. The better formed crystals are octahedral, but most have irregular angular outlines. In some sections the oxides tend to be elongate, perhaps because of available room for crystallization or perhaps because of chemical composition. Published chemical analyses of the Columbia River basalts indicate an appreciable titanium content; however, ilmenite could not be identified optically in thin section. Very likely the magnetite is titaniferous. In some thin sections the magnetite appears to be in two generations, the older being enclosed in early pyroxene.

Glass: Sideromelane, tachylyte and an interstitial gray-brown glass were observed in all the flows. Sideromelane is megascopically black and opaque but is clear yellow in thin section except where weathered to red-brown. It occurs as interstitial patches in nearly all of the thin sections and is a major constituent of pillow-palagonite complexes. Peacock and Fuller (1928) define sideromelane as "ideal" basaltic glass produced by sudden chilling of molten lava. The sideromelane in the studied thin sections seems to have approximately the same index of refraction (n=1.583) as Peacock and Fuller's sample from Moses Coulee. According to George (1924) this indicates basaltic composition, which would be expected for glass formed by rapid chilling of lava.

The interstitial sideromelane is somewhat puzzling in this respect because it has the appearance of a residual product. If it had formed after the main crystallization of the lava, it might be expected to have the composition of the residual melt, which would be deficient in calcium. Perhaps much of the interstitial sideromelane formed during second generation crystallization, when expanding volatiles streamed through the lava and cooled it locally. Very commonly the glass has been partly devitrified, so that under crossed nichols a spherulitic structure is apparent. Except for pillow-palagonite complexes, sideromelane ordinarily comprises not more than two or three per cent of the rock volume.

Tachylyte is a black, opaque or brown, nearly opaque glass full of tiny crystals and dust of magnetite. The thinner parts of the Wenas flows commonly consist of fifty per cent or more of this glass. The brown phase forms irregularly rounded inclusions in first and second generation plagioclase. Groundmass occurrences of tachylyte differ from those of sideromelane in that the tachylyte includes two or three generations of mineral grains and, therefore, was formed from the comparatively rapid chilling of an iron-rich residium.

Interstitial gray-brown glass is essentially a groundmass constituent. It has a refractive index noticeably lower than that of the thin section mounting media. Data published by George (1924) puts the composition of this glass in the andesitic range. Because this glass is a residual product of progressive crystallization of the lavas and contains various amounts of microlites and crystallites of plagioclase, magnetite, and unidentifiable minerals, its composition probably has a considerable variation. It ordinarily seems to comprise about five per cent of a flow, but some thin sections have much more than that proportion very finely disseminated. In places this glass has a gradational contact with sideromelane, which suggests that it is in part a product of sideromelane devitrification.

Groundmass: In addition to glass the groundmasses of the finer-grained lava contain microlites and crystallites. Some of these are identifiable as feldspar, magnetite, zircon (?) and spinel. The finer-grained phases of the Umatilla flow in particular have considerable very fine-grained anhedral material with low interference colors. Much of this can be identified as plagioclase under high magnification, and some of the grains appear to be sodic plagioclase on the basis of negative relief. The twinning is not developed well enough to permit a definite identification. Some of this material may be zeolitic. The coarser-grained portions of the flows do not have any appreciable amount of fine-grained groundmass except in the interstitial glass.

Accessories: Rods and needles of apatite, tiny rutile crystals, and feldspar microlites are included in the first and second generation plagioclases. Other needle-like inclusions could not be identified. Groundmass accessories have already been mentioned.

Alteration Products: Chlorophaeite (Peacock and Fuller, 1928), in its red-brown oxidized form exists as partial replacements of pigeonite and as vesicle linings. Possibly some of the material identified as devitrified sideromelane is actually chlorophaeite.

Palagonite (Peacock and Fuller, 1928) is most notably present in the pillow-palagonite phases of the Frenchman Springs member. Nearly every flow, however, has palagonitic phases where the lava was leached by steam either at the base of the flow or in clinkery phases at the top.

PLATE XI PHOTOMICROGRAPHS

1.

2.

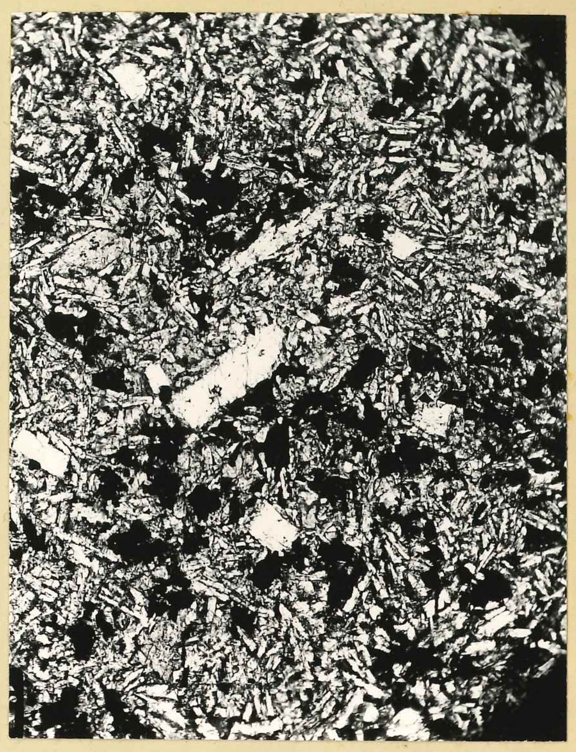
3.

4.

See p. 107 for explanation.

PLATE XII PHOTOMICROGRAPHS

1.



2.

3.

4.

See p. 107 for explanation.

PLATE XIII PHOTOMICROGRAPHS

1.

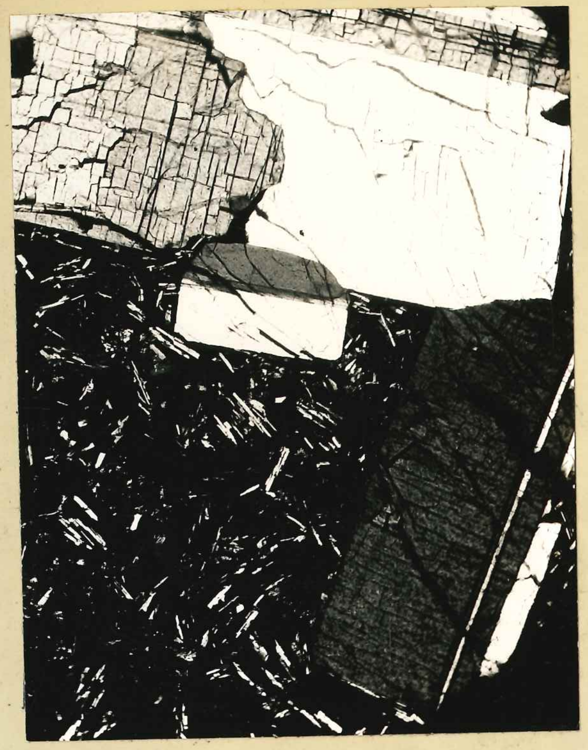
2.

3.

4.

See p. 108 for explanation.

PLATE XIV PHOTOMICROGRAPHS



1.

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See p. 108 for explanation.

EXPLANATION OF PLATES XI AND XII, PHOTOMICROGRAPHS

PLATE XI

1. Wenas lithology flow (near base) in Selah formation, Locality 1. Corroded large labradorite and olivine phenocrysts in hyalo-ophitic groundmass of An_{45} (medium-size) and An_{35} plagioclase, pigeonite anhedra, magnetite and tachylyte (opaque), a few olivine grains. Plane light, X20.
2. Same as 1, crossed nicols, X20.
3. Wenas basalt formation (near base), Locality 18. Corroded labradorite (core filled with glass inclusions) and olivine phenocrysts in hyalo-ophitic groundmass of labradorite (smaller phenocrysts), andesine, pigeonite anhedra, magnetite, tachylyte, a little olivine. Plane light, X20.
4. Sillusi flow (near base), Locality 13. Labradorite microphenocrysts (flow oriented?) in diabasic groundmass of An_{50} plagioclase, pigeonite anhedra, magnetite, sideromelane. Plane light, X20.

PLATE XII

1. Sillusi flow (near base), Locality 16. Labradorite microphenocrysts in intergranular groundmass of andesine, pigeonite anhedra, magnetite, sideromelane. Plane light, X20.
2. Umatilla flow (midway), Locality 18. Labradorite microphenocrysts in intergranular groundmass of andesine, pigeonite anhedra, magnetite, interstitial gray glass. Plane light, X20.
3. Umatilla (?) flow (near base), Locality 1. Relatively coarse-grained intergranular mat of An_{60} plagioclase (large, corroded), An_{55} plagioclase (large, non-corroded), An_{45} plagioclase (smaller laths), pigeonite anhedra, magnetite, intersitial glass. Plane light, X20.
4. Same as 3, crossed nicols, X20.

EXPLANATION OF PLATES XIII AND XIV

PLATE XIII

1. Umatilla flow (near base), Locality 3. Labradorite microphenocrysts in well crystallized, intergranular mat of andesine- labradorite, pigeonite anhedra, magnetite, interstitial glass. Plane light, X20.
2. Basal Priest Rapids basalt (typical), Locality 17. Part of a labradorite clot (rather rare) and labradorite microphenocrysts in intersertal groundmass of calcic andesine, pigeonite, glass. Plane light, X20.
3. Roza porphyritic flow (midway), Locality 7. Part of a labradorite clot in diabasic groundmass of labradorite and calcic andesine (smaller) laths, pigeonite anhedra, magnetite, tachylyte. Plane light, X20.
4. Same as 3, crossed nicols, X20.

PLATE XIV

1. Sentinel Gap flow (midway), Frenchman Springs basalt member, Locality 1. Part of labradorite clot (rare in this flow), in hyalo-ophitic groundmass of andesine, pigeonite, tachylyte, and magnetite. Crossed nicols, X20.
2. Frenchman Springs basalt member, flow No. 2 (basal part), Locality 1. Part of corroded labradorite clot in diabasic mat of labradorite, andesine, pigeonite anhedra, magnetite, sideromelane, and interstitial glass. Crossed nicols, X20.
3. Frenchman Springs basalt member, Locality 16. Part of corroded labradorite clot and a single labradorite crystal in diabasic groundmass of andesine, pigeonite anhedra, magnetite, interstitial glass. Plane light, X20.
4. Vantage member, Locality 1. Angular quartz and quartzite grains with many tiny inclusions, a large turbid microcline grain, a few mica flakes, tuffaceous matrix. Plane light, X20.

Silica in the form of opal and chalcedony fills vesicles and replaces some of the lava itself. The replacements exist at the bases of some of the flows where they evidently flowed into ponds or over wet sediments and are usually associated with glass. Some of the siliceous replacements have fluxion structure parallel to the base of the flow. Silica gel, a very hydrous form of opal, is abundant in the clinker phases of the flows and very commonly fills vesicles.

Weathering products, such as hematite and limonite, are widespread, but as the thin sections were made from the freshest material available and as the climatic conditions over most of the Columbia Plateau do not promote rapid weathering, the minerals are all very little or not at all weathered.

Mineral Paragenesis: The mutual relations of the various constituents and their physical aspects indicate a moderately complex history. The earliest generation of minerals is represented by olivine, labradorite and pigeonite crystals which are generally megaphenocrysts. These are no doubt intratelluric in origin and probably were formed in the magma reservoir. The corrosion of all of these crystals and the zoning of the plagioclase indicate that they were not in equilibrium with the melt during the main period of consolidation. Zoning of some of the plagioclase from cores of calcic labradorite to rims of andesine suggests that the reaction of the first generation crystals with the melt was nearly continuous throughout the course of consolidation of the lava. The actual order of crystallization of the

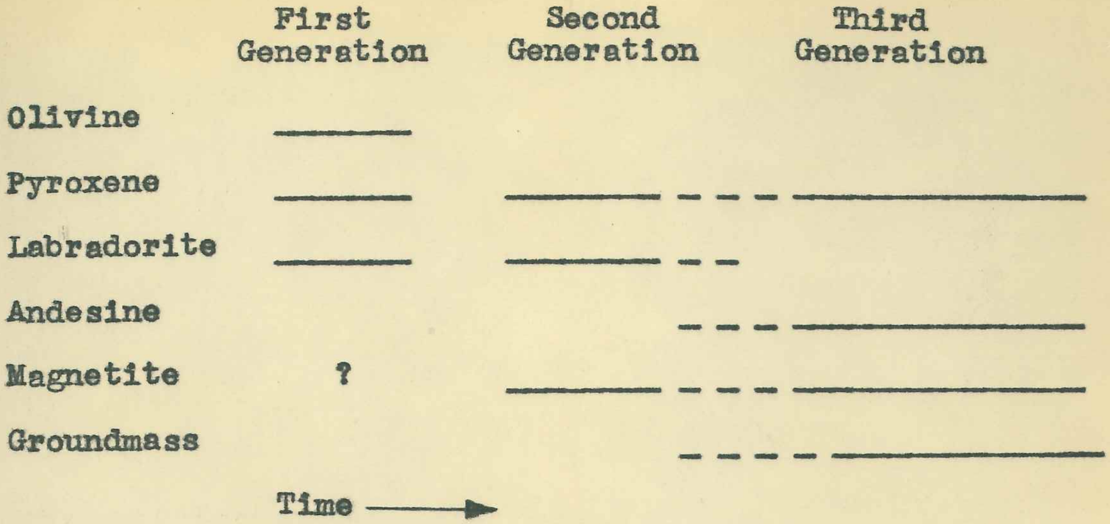


Figure 6: Diagrammatic representation of mineral paragenesis of the lava flows.

first generation minerals was probably olivine (where present), labradorite, pyroxene with overlap of at least labradorite and pyroxene.

The second generation crystals include sodic labradorite and calcic andesine, pigeonite and magnetite. The pigeonite and plagioclase of this generation show comparatively little corrosion but were evidently not in equilibrium with the melt during the final stage of consolidation. Magnetite crystals of this stage tend to be euhedral and larger than those of the final stage. Some of the magnetite included within second stage pyroxene may have crystallized during the later part of the first stage but is more likely contemporaneous with second stage pyroxene.

The second stage crystals were evidently formed when the volatile content of the flows was high and few centers of crystallization were in existence. In flows, such as the Priest Rapids at Sentinel Gap and the Roza porphyritic in general, the second stage crystals constitute the major part of the rocks. In these examples a high degree of vesicularity is apparent. On the other hand, flows, such as the Umatilla at McNary Dam, which became impoverished in volatiles, have a rather poor development of the second stage. Possibly the second stage began during the hypabyssal phase of eruption. It evidently continued as long as the lavas remained hot and fluid and retained a relatively high volatile content.

The third generation crystals include andesine, pyroxene and magnetite. Intersitial andesitic glass represents the final residium of this stage, and chlorophaeite represents the deuteric phase of this stage. Because most of the crystallization took place at many centers, the crystals are very small. In the flows which retained their volatiles during the final stages of crystallization, the third generation crystals have a much greater range in size than elsewhere. In most of the thin sections the final product of the third stage seems to be a mixture of pyroxene and magnetite together with interstitial glass containing tiny plagioclase crystals. However, in the finer-grained phases of the Priest Rapids flows, the final crystallization consists largely of plagioclase together with interstitial glass and relatively minor amounts of pyroxene and magnetite. The third generation crystallization overlapped the second stage, but the presence of round vesicles in most of the flows indicates that they were fluid when they arrived at their places of final consolidation; therefore, the third stage took place under essentially static conditions.

To a large degree the formation of crystals with differing compositions was a function of local differences in the composition of the melt. During the period of extrusion the lavas were probably agitated sufficiently to nearly homogenize the molten parts, but as they approached consolidation, mixing could no longer take place. Therefore, the second and third stage plagioclase crystals have a wide range of composition, and the final residium tends to be far out of chemical equilibrium with the basaltic melt expressed by the sideromelane of the suddenly chilled pillow-palagonites.

The first generation minerals represent high temperature crystallization. They are present in almost all of the thin sections, but vary in abundance and degree of corrosion. Their appearance as phenocrysts seems to be largely controlled by the degree of corrosion rather than simply by their rate of production. The degree of corrosion in turn was probably controlled by the length of time that the magma spent in the hypabyssal stage. For example, the corroded remnants of calcic labradorite crystals in flow D at Sentinel Gap comprise fully as much of the flow volume as the labradorite phenocrysts in the Roza porphyritic flow. The flow D magma may have halted at comparatively shallow depth for a long time, whereas the Roza magma may have been extruded from the source chamber in essentially one stage.

One of the outstanding problems in regard to mineral paragenesis is the association of corroded and zoned first generation plagioclase phenocrysts with An_{55} cores together with non-zoned and little corroded second generation An_{55} plagioclase. Possibly the first generation crystals were completely transformed from an earlier more calcic composition and because of their larger surface areas were more amenable to late stage zoning and corrosion than the second stage crystals.

Another problem is the almost complete lack of pyroxene other than pigeonite. According to Poldervaart and Hess (1951) basaltic magmas normally precipitate both calcium-poor and calcium-rich pyroxenes. The studied basalts seem to have crystallized under such conditions that the calcium was largely used to form plagioclase. Apparently the progressive withdrawal of plagioclase components left iron-rich residues from which pigeonite and magnetite crystallized. Rapid cooling of the lavas probably prevented the inversion of pigeonite to hypersthene, which Poldervaart and Hess find typical of slowly cooled basaltic magmas. In this connection the association of orthopyroxene with pigeonite in the quenched Frenchman Springs pillow lava is puzzling.

The Wenas flows with both olivine and pigeonite seem to have crystallized in more "normal" basaltic fashion. Possibly the olivine reflects a higher magnesium content than obtains in the older flows.

SEDIMENTS

In summary the sediments consist of hornblende andesite clastics derived largely from contemporaneous volcanism and of quartzose sediments derived from the erosion of consolidated rocks.

ANDESITIC SEDIMENTS: The pre-quartzitic conglomerate andesitic sediments consist of the hornblende andesite lithology typical of the "type" Ellensburg beds of the Yakima area. These pure andesitic sediments contain fragments of lithic andesite and pumice, and clusters and single grains of glass, plagioclase, hornblende, and magnetite. They also contain variable amounts of biotite and hypersthene, and traces of muscovite, zircon, high quartz, and foreign minerals.

Coarse-grained clastics: The lithic andesite pebbles consist of gray and pink, porphyritic hornblende andesite. The more porphyritic varieties contain euhedral crystals of plagioclase and hornblende up to a centimeter in length and smaller crystals of magnetite. The groundmass consists of fifty per cent or more of pumiceous glass containing smaller crystals of plagioclase, hornblende and magnetite. Pumice is comparatively scarce in most of the studied areas. It consists of nearly white, cellular, fibrous glass containing scattered crystals. Much more abundant are clusters of crystals and rather dense cream-colored and brown glass, which seems to represent an intermediate form between the lithic andesite and the true pumice.

Because most of the sediments consist of sand size or are easily disaggregated to that size, it is most convenient to study and to describe the sediments in terms of individual components. The essential components of the andesitic sediments have been described in some detail by Coombs (1941), but this writer will review them and describe other components and local variations.

<u>Glass:</u> Three forms of glass exist. One is the frothy glass of the pumice. The most abundant is the cream or pale brown glass. It may comprise from twenty-five to ninety per cent of the sand size material in a given bed. The refractive index of 1.52 to 1.53 indicates an andesitic composition according to George's data (1924), or even a dacitic composition according to the data of W.H. Mathews (in Williams, Turner and Gilbert, 1954). Much of this glass is slightly devitrified. It acted as a padding during sedimentation to protect the crystals from abrasion, and after deposition, formed an impermeable matrix which prevented appreciable weathering of the sediments. Most of the crystals are at least partly coated with this glass or bound together with it.

The second most abundant type of glass, and visually the most arresting, forms the angular shards of the pumicite beds. Under the microscope most of the shards are clear, although some are slightly devitrified. They exhibit a variety of fluted, grooved and keeled forms. Tiny inclusions of plagioclase, hornblende and magnetite are common. The refractive index of 1.52 indicates the genetic relationship of the shards to other andesitic material.

<u>Plagioclase:</u> The larger plagioclase crystals have compositions of Ab_{66} to Ab_{78} (Coombs, 1941). The crystals are euhedral to angular and show little or no rounding except in beds which have a very low glass content. Most of the plagioclase has albite twinning, and Carlsbad twinning and zoning are common. The tiny plagioclase inclusions in glass seem to be oligoclase. Plagioclase may comprise ten to ninety per cent of a bed.

Hornblende: The hornblende crystals are euhedral to subhedral, pleochroic from green to brown and commonly have oxidized rims. Some of the crystals are opaque. Hornblende comprises as much as ten per cent of the medium and fine-grained sand of some samples.

Magnetite: Shiny, black octahedra and dodecahedra of magnetite comprise as much as five per cent of a sample. It is strongly magnetic.

Hypersthene: Stubby green crystals of hypersthene are present in trace quantities in most samples. It may amount to three or four per cent of the heavy fraction of some samples.

Biotite: The biotite is dark brown in reflected light and pleochroic from yellow-green or green to dark brown in plane polarized light. It occurs as single flakes and "books" up to five millimeters in diameter. In the pure andesitic sediments of the Yakima valley, biotite rarely comprises more than traces of the sampled sands.

Trace minerals: Zircon, muscovite and "high" quartz may or may not be present in trace quantities. Minerals, such as clinozoisite and turbid unidentifiable minerals are rarely present. They may represent non-volcanic material or may be secondary alterations of the volcanic minerals.

QUARTZOSE SEDIMENTS: For petrographical purposes this division includes the quartzitic conglomerate and all the other quartz-bearing sediments. These include the Vantage member at Sentinel Gap and vicinity, the Mabton interbed, the quartzitic conglomerate and related sand beds, and the andesitic beds which are contaminated with non-volcanic detritus, including the Ringold formation.

In the field these sediments are usually identifiable because of their content of basalt, quartzite, plutonic and metamorphic pebbles. The microscope shows that the sand size constituents consist significantly or predominantly of angular fragments of clear colorless quartz. Apparently the bulk of this quartz is non-volcanic, but some of the grains, particularly in the Vantage member, are corroded and possibly of volcanic origin.

Aside from quartz, these fine-grained sediments have essentially the composition of the andesitic clastics. However, microcline, orthoclase, muscovite, biotite, and grains of quartzite and chert may be present. These are typically trace constituents, but do form as much as fifty per cent of samples from the Vantage member at Sentinel Gap. Biotite is much more abundant in the quartzitic conglomerate sands and associated andesitic beds especially at Sentinel Gap than in the pure andesitic detritus of the Yakima valley. It tends to be euhedral and to be partly coated with glass. In general the volcanic glass content of the sand matrix of the quartzitic conglomerate, and of sand lenses in the conglomerate, tends to be much lower than in the pure andesitic beds. This has resulted in greater original porosity and consequently somewhat greater weathering and cementation by iron oxide and calcium carbonate.

The Ringold (?) beds at Sentinel Gap are very similar in mineralogy to the quartzitic conglomerate beds there, but are almost wholly lacking in glass. Fine-grained Ringold sands from the vicinity of Ringold (Laval, 1948) contain high percentages of quartz, biotite, and muscovite. The grains are much more worn than those in typical Ellensburg formation sediments and seem to have been derived from reworked andesitic sediments or from the erosion of andesites. Much of the Ringold formation here consists of silty clays which may represent weathered, water-laid tuffs.

PETROLOGIC INTERPRETATIONS

The rocks of the western Columbia Basin show a general progression in time from pigeonite andesitic basalt interbedded with tuffaceous clastics to olivine bearing andesitic basalt and great volumes of hornblende andesite clastics. This progression suggests the possibility of petrologic correlation with Tertiary volcanic rocks which have somewhat anomalous stratigraphic positions in other areas. One possible correlative is the sequence of Fifes Peak andesite (W.C. Warren, 1941)-Yakima basalt-Deep Creek andesite (Pliocene?) of the Mount Aix quadrangle described by Abbott (1953). Somewhat farther afield are the interbedded hypersthene basalts and hornblende andesites of the Midway volcanics (lower Miocene?) of northeastern Washington (Dobell, 1955). Figure 7 summarizes Abbott's and Dobell's detailed petrographic descriptions and compares the petrologic sequences of the three areas.

The Fifes Peak andesite, the Yakima basalt of the Basin, and the Midway basalts all contain labradorite phenocrysts and groundmass andesine. Their classification as basalts or andesites depends upon the relative amounts of the various types of plagioclase

Mount Aix quadrangle (Abbot, 1953)	Western Columbia Basin (This thesis)	Kettle River, Northeastern Washington (Dobell, 1953)
Deep Creek andesite (hornblende andesite)	Ellensburg formation (hornblende andesite clastics)	Midway volcanics (hornblende
Yakima basalt (olivine bearing andesitic basalt)	Wenas basalt (olivine bearing andesitic basalt	and biotite
?		andesites interbedded with
Fifes Peak andesite (pigionite-hypersthene basaltic andesite or andesitic basalt with interbedded tuffs)	Yakima basalt (pigeonite andesitic basalt and basaltic andesite with interbedded tuffaceous material	hypersthene basalts)

Figure 7: Suggested petrologic correlations.

of the phenocrysts and that of the groundmass. Another evidence of kinship is the similarity of mafic content. Pigeonite and hypersthene, according to Poldervaart and Hess (1951) can be chemical equivalents.

The Yakima basalt of the Mount Aix quadrangle and the Wenas basalt of the Basin seem to be almost identical petrographically. Olivine bearing basalt is not described by Dobell, but an olivine bearing flow at or near the top of the Columbia River basalt in northeastern Washington is mentioned by Pardee (1918).

The hornblende andesites of the mountain areas suggest sources of andesitic clastics for the Basin sediments. In particular the Midway biotite andesites suggest a source of the abundant biotite in some of the Selah beds at Sentinel Gap.

The actuality of these suggested correlations can only be tested by tracing the rock units in the field. The vast areal extent of the lava flows of the western Plateau indicates that they may well extend to adjacent areas.

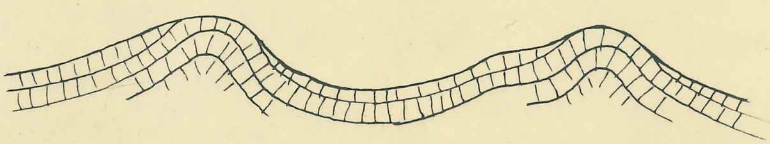
The above sequences suggest that differentiation or alteration of tholeiitic magma may have given rise to olivine bearing basalt and hornblende andesite as "end products". This possibility can be hardly more than a speculation until much detailed petrographic work has been accomplished, and it must be approached as Waters (1955 B) suggests with relation to the entire Cenozoic volcanic sequence. The association of Miocene or Pliocene basalts and basic andesites with hornblende andesites or dacites at several places in the eastern parts of the Cascade Mountains, in northeastern Washington and in eastern Oregon (Gilluly, 1937) seems to be more than coincidental. The interfingering of the Columbia River basalt with andesitic sediments such as the Selah, Ellensburg, Latah, and Payette formations over vast areas is a further indication of a great petrologic province.

STRUCTURAL GEOLOGY

GENERAL CHARACTERISTICS OF THE ANTICLINES

The structures mapped in the course of this study are part of a group of folds in a structural depression, the Columbia Basin. They illustrate anticlinal fold types in this depression, which is typified by very gentle structural slopes over most of its area. The concepts advanced for the origin of these structures range from the theory, commonly attributed to Russell (1893), that they are essentially fault blocks over which the basalt flows are draped, to the theory that they are essantially anticlinal folds formed by compression (Smith, 1903A, B; Waters, 1955A).

A. Russell's concept



B. Smith's and Waters' concept

Figure 8. Diagrams illustrating concepts on origin of Columbia Basin anticlines.

The anticlines examined resemble some of Russell's but more particularly Smith's types, and in some instances overturning and thrusting are significant. They have a wide variety of cross-sectional structures. In general they can be classified as:

(1) simple anticlines consisting of single convex upward flexures; (2) composite structures consisting of a broad arch with subsidiary flexures; (3) broad, monocline-like structures bounded on one or both sides by subsidiary flexures and locally thrust to the north.

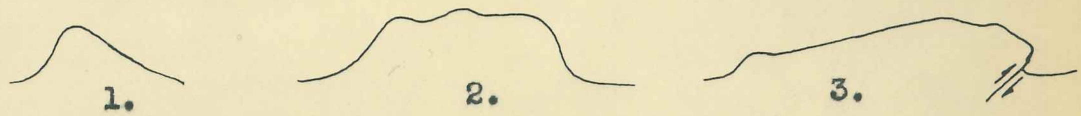


Figure 9. Anticlinal types (not to scale); see text.

DESCRIPTIONS OF ANTICLINES

<u>SNIPES MOUNTAIN:</u> Snipes Mountain (Plates XXIV, XXVI) is a prime example of a simple, doubly plunging anticline. The structure is asymmetric in cross-section with the southern limb the steeper. The structure is also somewhat asymmetric longitudinally as shown by the position of the axial culmination south of the letter "M" in the word Mountain (Plate XXIV) near the eastern end of the anticline.

At either end of the structurally higher part of the anticline marked by the Wenas basalt outcrop band, the southern limb steepens markedly. At the eastern end this limb is slightly overturned. At the western end it becomes vertical and has a subsidiary anticlinal flexure south of the main anticlinal axis.

TOPPENISH RIDGE: Toppenish Ridge (Plates XXIV, XXV) is a composite anticline in the form of a broad arch with subsidiary

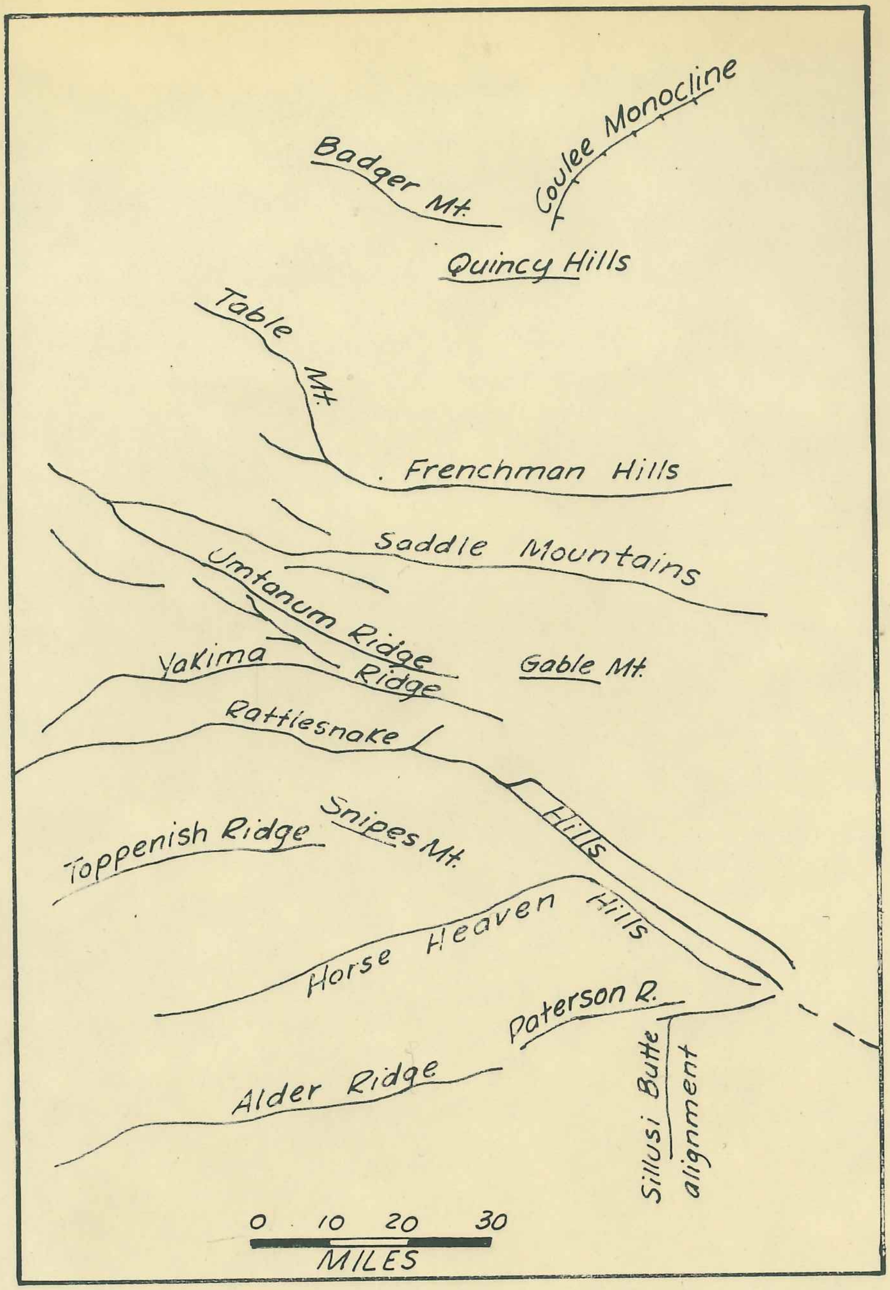


Figure 10: Anticlinal ridges of the Columbia Basin, central Washington.

anticlinal flexures. Because the exposures are somewhat better than average, it is possible to show the structure in detail.

In the western part of the mapped area the structure has the form of a square shouldered, flat-topped, roughly symmetrical arch with nearly vertical limbs and an undulatory crest zone as in sections A, B, C. This part of the structure plunges eastward to a saddle between sections C and D. West of the saddle a cross fault brings Wenas basalt in contact with Priest Rapids basalt. The fault displacement is believed to be essentially strike slip, although a dip slip component is indicated. East of the saddle, which is both structural and topographic, the structure rises as a rather rounded, broad arch with gentle undulations. In this eastern part, the northern limb of the structure assumes a low to moderate northward dip and maintains that general inclination to the eastern end of the exposed structure. In contrast to the northern limb the southern limb has a subsidiary, symmetrical anticlinal flexure that locally rises (section D) higher both structurally and topographically than the main arch to the north. Farther east (F,G) this subsidiary anticline is broken by a fault with a maximum throw of perhaps five hundred feet. This fault is apparently normal, because the inclinations, the lava flows, and sediments on either side of the fault zone are nearly the same, and no evidence of overturning or strike slip was observed. Farther east this faulted fold dies out and another subsidiary anticline locally overturned rises from the south limb of the composite structure.

PLATE XV: View eastward of north side of Toppenish Ridge from Locality 4. Wenas basalt dipping north forms hogbacks north of saddles cut in Selah formation. Rounded summit at extreme right is Locality 5.

In addition to the faults described above, which are apparently related to the rise of the Toppenish Ridge anticline, there is evidence of antithetic faulting by which the structural relief has been relatively lowered. In the vicinity of sections A and B on the north side of the ridge, large joint blocks of Priest Rapids basalt are strewn about on a low east-west trending ridge. No outcrop could be found, but the abundance of the blocks and the presence of the one lithology indicate disintegrated bedrock. The step-like south slope of the ridge suggests a fault or a series of faults by which the Priest Rapids basalt was raised relatively to abut the Ellensburg formation. A similar situation was observed on the north side of Toppenish Ridge between sections G and H. It is possible that a continuous east-west fault zone intersects the northern limb of Toppenish Ridge.

Faulting is suggested on the south flank of Toppenish Ridge in the vicinity of section B. In this area mesas of Selah formation capped by disintegrated Wenas lag are separated from the main south slopes by east-west valleys. In the field it appeared that the summit profiles of one or two of the mesas if projected northward would pass slightly above the profile of the main ridge. This discordance together with the east-west valleys suggests faulting by which the north block has been relatively depressed.

SADDLE MOUNTAINS: The Saddle Mountains anticline was studied in the vicinities of Sentinel Gap (Plates XXI, XXII) and Smyrna (Plate XXIII). The general structure resembles a monocline tilted to the south and with the north limb overturned and thrust to the northward in the areas examined. Farther east, as Calkins (1905) noted, the north limb is not overturned.

PLATE XVI: Map Area II, Saddle Mountains viewed from the north. Et, tectonic phase Ellensburg; Prb, Priest Rapids basalt ledge; V, Vantage member (overturned). Elements of structure indicated.

On the west side of Sentinel Gap (Plates XXI, XXII) the overturn of the north limb is evident, although much of the north slope of the mountain is covered by talus. Lower Yakima basalt units dip a few degrees southward from the summit almost to the base of the slope. In the easternmost exposure near the base of the slope one of the lower flows turns abruptly to an inclination slightly beyond the vertical within a north-south distance of about five hundred feet. About one-half mile west of the line of section A-A one of the lower flows is overturned to dip about 60° south. A short distance to the north the Priest Rapids basalt member and the Wenas and Selah formations dip 10° or 12° south toward the overturned lower Yakima units. These relations indicate a high angle thrust fault with a net slip of approximately 1,500 feet to perhaps 2,000 feet. The actual thrust zone was not observed. The probable continuation of the thrust on the east side of Sentinel Gap cannot be seen because talus and drift sand cover the lower north slope.

In the vicinity of Smyrna (Plate XXIII) there is an exposure of the thrust zone together with evidence of a tear fault. On the east side of the tear fault the Vantage member turns from the vertical to dip about 60° south. About one hundred yards south of the overturned Vantage member, the lava flow immediately underneath abruptly turns to the horizontal. To the north the entire vertically dipping succession of upper Yakima units, Selah formation, and Wenas basalt was traced to where shattered Wenas is in contact with the tectonic phase Ellensburg beds previously described (p. 78). The Wenas, Selah and Priest Rapids are overturned to dip south and, although the contact is not well exposed, can be seen to successively abut the tectonic Ellensburg. The relations indicate a thrust fault inclined about 45° south with a net slip of perhaps five hundred feet. The thrust zone is at least two hundred feet wide. In it the tectonic Ellensburg beds are closely sheared and the basalt flows and the Selah formation are dragged, slivered and sheared.

The tectonic Ellensburg beds lie unconformably on a ledge of Priest Rapids basalt which forms a bluff (see Plate XVI) for several miles along the north front of the mountain. At the studied locality the Selah and Wenas formations of the lower block of the thrust apparently were converted into tectonic breccia and removed or incorporated into the tectonic Ellensburg during the deformation.

Twiss (1933) has shown the existence of the overturn here, but probably because he mapped only Yakima basalt and "Crab Creek beds", (tectonic phase Ellensburg) he interpreted the thrust as a normal fault that dropped the "Crab Creek beds" against the Yakima basalt. He postulated an episode of normal faulting after the formation of the Saddle Mountains anticline.

A tear fault cuts the tectonic Ellensburg beds in a straight, nearly north-south course. The sediments on the east side are bedded, but those on the west side are closely sheared, so that pseudo-bedding structures have been developed roughly parallel to the nearly vertical fault. It is evident that the entire western block of tectonic Ellensburg was pushed over the Priest Rapids basalt. To the south the tear seems to die out. The maximum differential northward strike slip of the west block is probably on the order of five hundred feet.

The axis of the Saddle Mountains anticline undulates vertically. In the eastern part of the Beverly quadrangle these undulations form synclinal sags transverse to the main trend (Plate IX). A structural sag is suggested at Sentinel Gap where the lower Yakima basalt units show dip components toward the Columbia River.

HORSE HEAVEN PLATEAU: The Horse Heaven Plateau is the largest of the anticlinal structures studied and one of the largest anticlinal structures of the entire Columbia Basin. It was examined within the area approximately bounded by Mabton, Alderdale, and Wallula Gap, the Columbia River crossing. Within this area the structure resembles a monocline tilted to the south and flanked by sharply folded anticlines at the north and south margins. A major change in trend of the northern anticlines from east-northeast to west-northwest divides the structure into western and eastern segments. With reference to topography the term "Horse Heaven Plateau" is generally restricted to the long gentle slope to the south, while the high north rim of the Plateau, together with the northern flanking anticlines, is called the Horse Heaven Hills.

Western segment: The western segment is typified by the composite section (Plate XXXII) between the Mabton and Alderdale localities. Alder Ridge with its rather steeply inclined southern limb is the southern subsidiary anticline of the Horse Heaven structure comparable to the southern flexures of Toppenish Ridge.

The eastward plunge of Alder Ridge is plainly indicated by the topography of its continuation, Golgotha Butte. East of Golgotha Butte the main line of southern flexures is continued in Canoe Ridge and Paterson Ridge. A tendency for a secondary line of southern flexures to develop is shown in Crow Butte and in a probable rise from the southern limb of Golgotha Butte.

The Horse Heaven Plateau north of Alder Ridge has a gently undulating bedrock surface thickly mantled by loessial soil. Long undulations, such as the shallow structural trough occupied by the southeast trending part of Glade Creek, seem to be related to culminations and depressions along the rims of the plateau. At the north rim the plateau bends downward into the syncline followed by upper Glade Creek. East of Glade Creek this syncline is somewhat less pronounced and is broken into a series of depressions between culminations of the north flexure and the northern rim of the plateau.

The north subsidiary anticline of the western segment in the Mabton vicinity rises from the Glade Creek syncline, descends northward in a gentle structural slope, and turns down abruptly to a nearly vertical inclination at the base of the Horse Heaven Hills. Scabland exposures of the Priest Rapids basalt in the vicinity of Byron indicate that there is an equally abrupt upturn to, or slightly past, the horizontal farther north (Section CC Plate XXXII). At the Byron locality the tendency for the north limb of the north anticline to overturn is apparent. Farther east between Prosser and Chandler thrusting and tear faulting are evident, although not particularly well exposed. In addition to the usual cover, this section of the Horse Heavens is complicated by widespread slumping of the north slope. Partly because of the slumping, previous workers have thought it possible that the structure changes here from an asymmetric fold to an asymmetric faulted fold (Waring, 1913), or to a normal fault (Dennis, 1938).

The possibility of overturning and thrusting suggested by A.S. Cary (1954), on the basis of engineering geology studies, was substantiated by the writer's field mapping. Probably the most striking feature of the Horse Heaven thrust is the maintenance of the relatively even structural slope of the north flexure to the point of the abrupt break-over of the overturned limb. A sag in the axial area is not uncommon.

The maximum thrust displacement indicated by differentially displaced tear fault blocks and by a few exposures of the thrust zone along the Northern Pacific Railway near section E-E, Plate XXVII, is but a few hundred feet. At the latter locality brecciated Wenas, in part mixed with a debris of Selah formation, is thrust over much fractured Priest Rapids basalt in places and in others Priest Rapids is thrust over Wenas of the lower block. The base of the fault contact zone where it was observed consists of one to two feet of brecciated basalt and claylike "gouge". It dips 40° to 45° south.

Tear faulting of the upper thrust block is best evidenced by offset outcrop patterns in the overturned rock units. The major tear zones are not exposed but are represented by straight-line topographic alignments. Nearly vertical shear zones cut some of the thrust blocks between the major tears.

In the vicinity of Chandler (Plate XXVII), the north limb of the western segment is overturned to as much as 50° from the vertical. Thrusting (Section F-F) is suggested by this degree of overturn and by geological map patterns and straight-line gully lineaments indicative of tear faulting.

Eastern segment: The eastern segment of the Horse Heaven structure is complicated at the structural bend near Chandler. Angular bends in the map patterns show the conflict of the two trends. The eastern segment is the stronger element as shown by the maintenance on the Horse Heaven Plateau of southwestern slopes from the Horse Heaven Hills beyond the angle of the bend. Also a low anticline, breached near the Yakima River, continues the alignment of the eastern segment westward on the south flank of the Rattlesnake Hills.

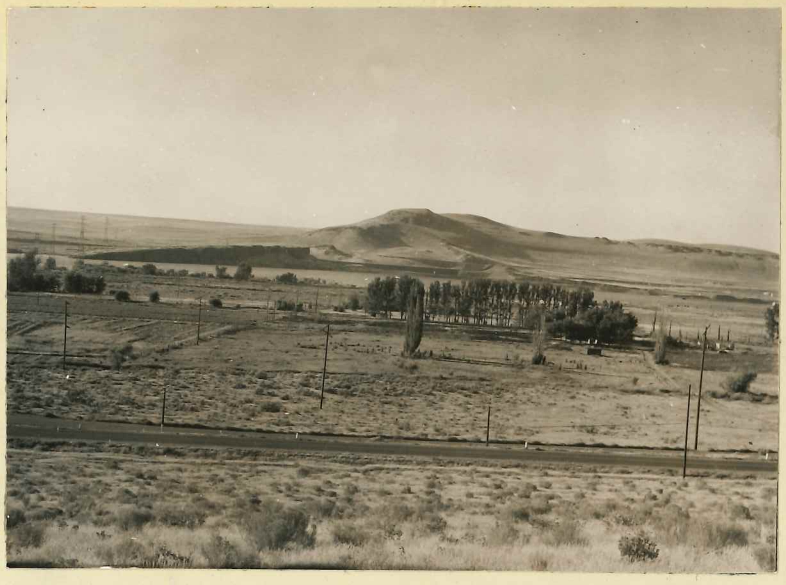
The north limb of the north flexure east of the bend loses the tendency to overturn and passes from a steep north dip to a gentle north dip in the vicinity of Kiona (Plate XXIX). The synclinal dip between the north rim of the Horse Heaven Plateau and the north flexure becomes less pronounced in the eastern segment and the Plateau itself narrows because the southern flexures converge toward the northern. The southern flexures keep their east-northeast trend, and a secondary line of flexures develops an en echelon alighment. This is shown in the merging of the eastern extension of Paterson Ridge (Fig. 8) with the south slope of the Plateau about three miles north of Sillusi Butte, and in the rise of a subsidiary anticline to the south to become the major southern flexure.

Sillusi Butte (Plate XXX) is part of a north-south anticlinal chain, which continues south of the Columbia River in the Umatilla Butte-Service Buttes alignment. Because the Sillusi Butte anticline plunges southward, the capping Wenas basalt dips below the level of the Columbia River. The more gradual rise to the south brings the Wenas to the surface in the Umatilla Butte anticline.

RATTLESNAKE HILLS-HORSE HEAVEN HILLS STRUCTURES: At the Chandler bend the Rattlesnake Hills approach the Horse Heaven Hills and farther east (Figure 8 and Plate XXXI) two Rattlesnake anticlinal alignments merge with the Horse Heaven uplift. The most obvious continuation of the Rattlesnake structure is the line of doubly plunging anticlines from Red Mountain to The Butte. South of Kennewick these anticlinal hills rise from the north slope of the Horse Heavens in a manner analogous to the rise of Toppenish Ridge from the north slope of the Horse Heaven Hills farther west.

A southern Rattlesnake alignment is topographically represented by Goose Hill (Plate XXIV). This alignment continues to the east-southeast in the 2,196 foot summit south of Kennewick and to the west-northwest in the main Rattlesnake Hills where they are offset to the south from the Red Mountain alignment. These conditions are illustrated by sections H-H and I-I, Plate XXXII. In H-H Red Mountain and Goose Hill are repsectively the northern and southern Rattlesnake structures and to the south are the typical Horse Heaven Hills structures. Section I through the 2,196 hill

PLATE XVII



1. Sillusi Butte anticline, Locality 18, from the south.

2. Horse Heaven Plateau from north end of Sillusi Butte. East-northeast anticlines extend to right. Horse Heaven Hills in distance.

shows the northern Rattlesnake fold, the 2,196 hill corresponding to the southern Rattlesnake fold, and farther south the topographic expression of the two Horse Heaven Hills folds. East of B.M. 2,196 the southern Rattlesnake structure nearly loses its identity in the general plunge and convergence toward the Wallula sag. Immediately east of Wallula Gap the structure seems to be a rather simple broad arch, but the northern crest may correspond to the southern Rattlesnake fold. On the west side of the Gap the northern Rattlesnake structure forms the small anticlinal hill east of The Butte. The convergence toward the Gap is very evident in the anticline's northwest-southeast alignment.

Transverse and normal faulting: In addition to the tear faulting associated with thrusting, the Horse Heaven-Rattlesnake structures afford evidence of transverse faulting because of rupturing of the northwest and southeast ends of the anticlinal folds. Fault breccia zones are exposed at the east and west ends of some of the northern Rattlesnake anticlines. They can rarely be traced for more than one hundred feet, but their north-south or northeast-southwest alignments suggest a genetic relationship to the anticlines. Apparently the rocks broke because of the abrupt rise of the anticlines from the surrounding gentle structural slopes. The possiblity of similar transverse faulting in the southern Rattlesnake folds is suggested by strong gully lineaments such as Zintel Canyon on either side of the 2,196 anticlinal hill.

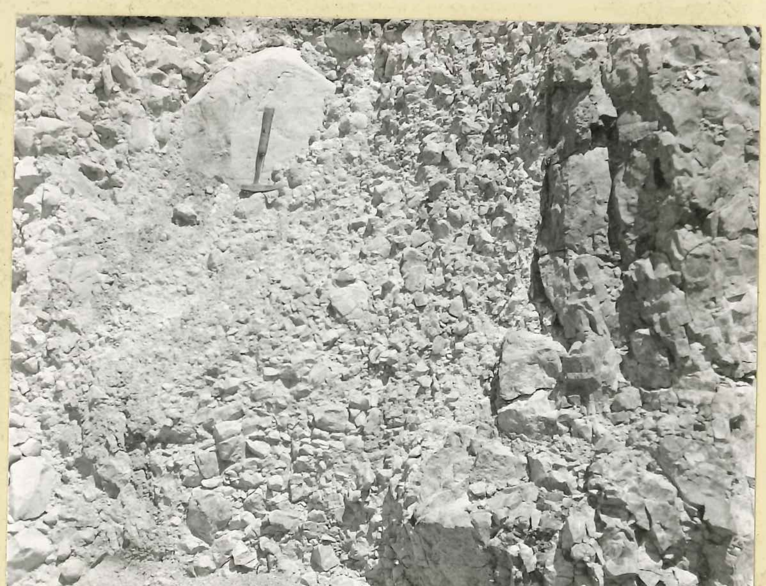
Antithetic normal faulting is particularly well displayed at the western end of The Butte (Plates XVIII and XXXI) where a nearly vertical fault zone is exposed in a quarry. On the north side of the fault the basal, massive part of the lower Wenas flow has been brought up relatively against the blocky, closely jointed upper part of the flow. The rock on the north side of the contact is brecciated, but large joint blocks in the breccia contrast with the much smaller joint blocks on the south. Many high angle shears intersecting the south block demonstrate a wide fault zone. The main contact dips about 75° south and a throw of about fifty feet is indicated. The fault zone may have a topographic expression in the prominent east-west gully at the east end of The Butte.

A zone of fault breccia as much as five hundred feet wide intersects the northwestern end of the small anticlinal hill east-southeast of The Butte. The fault zone trends north 65° west in line with the probable extension of The Butte fault. At this locality massively columnar lower Wenas flow on the north is in contact with blocky Wenas on the south. The fault throw is possibly over one hundred feet here. Although the basalt of the north block is massively columnar, it is topographically lower than the south block, making the fault line scarp obsequent. This apparent topographic reversal is probably due in large measure to the erosive effects of glacial melt water floods which have sculptured the entire hill. In consequence of this erosion, the faulting is probably of pre-Wisconsin age.

Antithetic faulting is also indicated at the western end of Red Mountain (Plate XXXIX, where a few exposures of a cemented breccia zone are aligned nearly parallel to the trend of the anticline. Here the Priest Rapids basalt (Sillusi flow) has

PLATE XVIII

1. General view of antithetic fault zone exposed at west end of The Butte, Locality 14.



2. Close-up view of antithetic fault at Locality 14. Pick leans on large columnar joint block in fault-brecciated lower Wenas flow. The closely jointed upper part of the lower flow is at the right.

been raised relatively on the north side, bringing it in contact with the Wenas basalt flows for a short distance. Sand drifts hide the possible extensions of the fault zone, but the alignment suggests that it may continue both to the southeast in the small Rattlesnake structures and to the northeast in the main Rattlesnake structure.

Another line of faulting exists at the northern front of the merged southern Rattlesnake-Horse Heaven Hills structures west of the north entrance to Wallula Gap. Here the exposures are not very satisfactory, but in the straight west-northwest trending valley south of Hover (Plate XXXI) a quarry exposes sheared blocky Wenas basalt, whereas on the ridge to the north there is massive, columnar basalt of the lower Wenas flow. A fault zone in which the northern block has been displaced relatively upward is indicated. The displacement may amount to one hundred feet or more depending upon whether the blocky basalt is part of the upper or lower Wenas flow. The fault probably dies out to the west where the gully turns southward. It was not in evidence at the base of the 2,196 hill.

On the east side of Wallula Gap, fault breccia scarps are prominent on the north face of the Horse Heaven Hills between the Gap and Vansycle Canyon. Lack of expoures to the north prevents determination of the type of displacement, but a continuation of the southern Rattlesnake-Horse Heaven fault is suggested.

SYNCLINES

The synclines, insofar as their structures can be seen, tend to have rather simple, broadly concave or nearly flat floors.

Plate XXXII illustrates some of the typical forms. The largest syncline, that of the lower Yakima valley west of Chandler, is filled with sediment. Perhaps its floor is smoothly concave upward similar to that of the Moxee Valley west of Yakima as illustrated by Smith (1901).

ROLE OF MINOR FAULTING AND JOINTING

Smith (1903A, B) recognized the important role played by original contraction joints that allowed the Yakima basalt to deform by means of minute slippages along the joint surfaces. Minor fault zones exposed in the Spokane, Portland and Seattle Railway cuts on the west side of Wallula Gap provide examples of the method by which the flows adjusted themselves to deformative strains. Many nearly vertical fault zones cut Frenchman Springs and Priest Rapids flows with no measurable displacement. Where the faults intersect blocky jointing, breccia zones two or three inches wide are present. These breccia zones can be traced downward into columnar rock where they merge with the jointing planes and disappear. As Waters (1955 A) points out, it is probably this sort of minute slippage between the original contraction joint blocks, together with bedding plane slippage, that allows the flows to accomodate most of the folding without notable brecciation or shearing.

In effect, the columnar and other contraction joints even though irregular, together with partings between jointing units, confer a high degree of bulk plasticity to the flows in spite of the very high compressive strength of individual solid blocks of basalt: therefore, the folds are quasi-competent. Also the original vertical jointing no doubt explains the rarity of large scale drag effects in high angle fault zones.

Much of the oblique cross-jointing of the flows is of tectonic origin. This is readily apparent at the break-over points of folds where the columnar phase of a given flow is shattered by close-spaced joints which are not present on the flanks of the fold. Even some of the massive columnar-type jointing may have been oriented in part by tectonic streses; for example, the Umatilla flow in the foundation excavations for McNary Dam was intersected by nearly vertical continuous joints trending roughly north-south. The continuity of this jointing suggested control by directed stress in addition to haphazard contractive tensions. Tectonic warping and local contraction settling are possible causes.

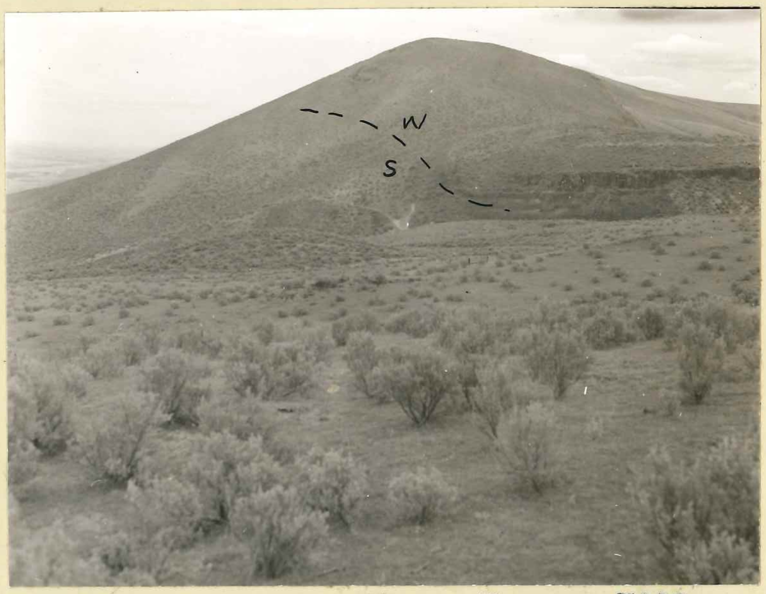
Besides the pre-Ellensburg tectonic warping suggested by stratigraphic relations, intraflow faulting in the Yakima basalt at Sentinel Gap (not mapped) and possibly at McNary Dam site testify to the deformation of the Yakima during its accumulation. At Mc Nary Dam a low angle fault which cuts the Umatilla flow does not seem to affect the Sillusi flow. The fault zone may have performed the role of a cooling surface because massive columns curve to meet it without evidence of drag.

STRUCTURAL TRENDS

Two structural trends, west-northwest and east-northeast (Figure 8 and Plate XX), are dominant in the areas studied. The eastern Horse Heaven Hills-Rattlesnake Hills alignment approximately marks the line of deflection between the two trends.

PLATE XIX

1. View eastward down fault zone valley southeast of Locality 15. Fault breccia scarps at north edge of Horse Heaven Hills across Columbia River may mark continuation of same fault zone.



2. Culmination in Horse Heaven Hills, Locality 9. General dip is south (right). Wenas basalt formation, W; Selah formation (light gray), S.

Nearly north-south subsidiary alignments are most clearly represented by the Sillusi Butte anticlinal chain. In addition, culminations of the axes of the major anticlines suggest other north-south alignments. North-south culminations are best developed in a series from Snipes Mountain nearly due north through the Rattlesnake Hills and the highest summits of Yakima Ridge, Umtanum Ridge and Saddle Mountains between the Yakima and Columbia Rivers. Another nearly north-south culmination alignment exists in the series from the highest summit of Saddle Mountains east of the Columbia River, the Gable Mountain anticline, and the low upwarp around which the Yakima River makes a U-shaped detour east of Chandler. Possibly this alignment is continued in the Frenchman Hills to the north and in the Sillusi Butte anticlinal chain to the south. Also worthy of note is the 2,196 feet summit of the Horse Heaven Hills close to the Wallula Gap sag.

GENESIS OF THE FOLDS

The general conclusion in regard to the genesis of the Columbia Basin folds is that they are related to the uplift of the mountains surrounding the Columbia Basin in the "Cascadian Revolution". Evidently the compressive forces which uplifted the mountains were transmitted laterally and caused the late Tertiary accumulation in the Columbia Basin to be folded. In the process the Basin gained its present conformation.

An indeterminate structural control is the structural detail of the rocks beneath the Yakima basalt because none are exposed in the thesis area. C.L. Willis (1950, 1953) suggests that the late Tertiary structures in the vicinity of the Chiwaukum quadrangle are more closely related to the pre-Tertiary structures than to the early Tertiary structures. Unfortunately geologic work in the Cascade Mountains immediately west of the folds studied has not revealed to date the exact relationships of late Tertiary orogenic structures to earlier Tertiary orogenic structures and very little pre-Tertiary rock is exposed.

Two possible modes of genesis are suggested: (1) folding of the Yakima basalt directly related to folds or faults in the basement rocks, (2) or folding of the Yakima basalt independently of the basement rocks. As neither one of these modes of genesis can be demonstrated, it is necessary to compare the folds studied with other folds illustrative of these modes of genesis. In the Pryor Mountains of southwestern Montana Blacksone (1940) has described folding of a thick sedimentary succession because of faulting in the crystalline basement (Figure 10).

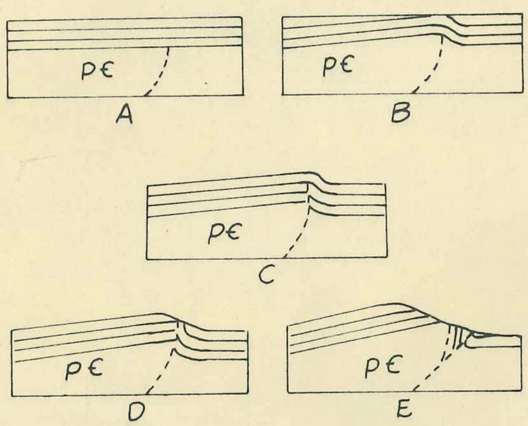
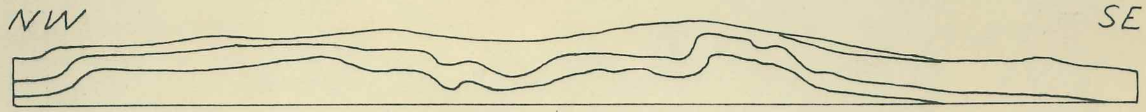


Fig. 10. (Diagrammatic). Cross-sections demonstrating relation of subsurface fracturing to surface folding (Blackstone 1940, p. 609).

Folding independent of the basement is best known in the Jura Mountains of Switzerland. Many of the less extreme Jura folds resemble the folds studied, especially Toppenish Ridge and Snipes Mountain (Figure 11).



Scale approx. 1:200,000

Figure 11, A: Jura Mountains folding (Heim, 1919, Querprofile No. 12, Tafel XXIV)

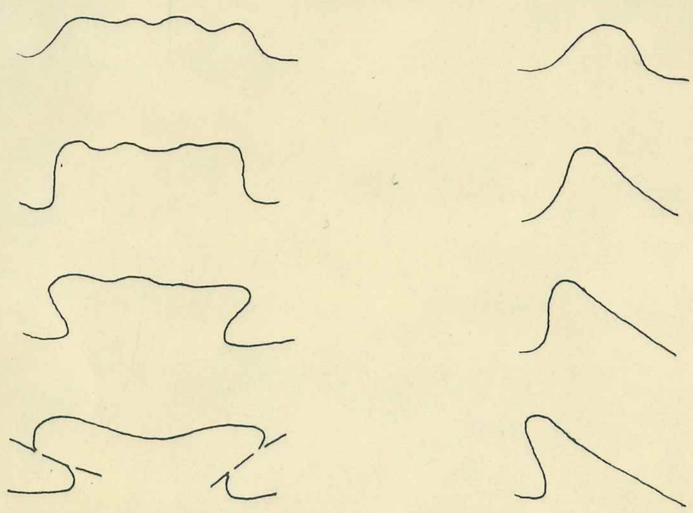


Figure 11, B: Jura fold types (Heim, 1919, Figures 91, 92, p. 582)

The Columbia Basin folds studied may have originated in either of these two modes or some combination of the two. The abrupt flexure of Snipes Mountain and the complexities of the Toppenish Ridge anticline suggest Jura type folding. On the other hand, both Jura and Pryor mountain types of structure are suggested in the thrust faulting of Saddle Mountains and the

Horse Heaven Hills and also in the thrusting of Umtanum Ridge described by Hammer (1934) and mapped by Mackin (1946, 1955 A).

STRUCTURAL HISTORY

The structural history of the portions of the Columbia Basin studied begins with general downwarping during accumulation of the Yakima basalt. More localized differential warping is suggested in late Yakima basalt time. Localized warping appears to have increased in intensity until in late Ellensburg formation time, probably early to perhaps middle Pliocene, anticlinal ridges were formed. After the folding, differential warping resumed as indicated by the deposition of the Ringold formation in much the manner postulated by Waters (1955) and the subsequent slight differential rising of that formation to the north (see p. 90). Normal faults relatively lowered the structural relief of at least some of the anticlinal ridges, probably in late Pleistocene time. The observed normal fault zones are highly inclined, suggesting origin by isostatic adjustment, presumably regional. The effects of the Walla Walla Basin earthquake of 1936 described by Brown (1937) suggest that warping or isostatic adjustment still continues.

S U M M A R Y

A sequence of Upper Cenozoic lavas and sediments is exposed in the southwestern part of the Columbia Basin. The rocks of structural significance are the Mio-Pliocene sequence of Yakima basalt, Selah formation, Wenas basalt formation, and Ellensburg formation, together with the Pleistocene Ringold formation. The Mio-Pliocene sequence forms a sedimentary lithosome which is mutually interfingered with a flood lava lithosome.

The lower part of the Yakima basalt is exposed only at Saddle Mountains. The upper part of the formation is exposed throughout the area studied and hence is much better known. The lower part consists of several lava flows and the sedimentary Vantage member. The upper part consists of several members that are single lava flows, sequences of flows, single sedimentary units, and sequences of flows and sediments. In the areas examined these are from base upward: the Frenchman Springs basalt member, the sedimentary Squaw Creek member (including diatomites beyond the immediate thesis areas), the Roza porphrytic basalt member, and the Priest Rapids basalt member. The characteristic lithologies of these members, two of which (Roza porphyritic and Frenchman Springs basalt) are porphyritic, make possible the tracing of the lavas and sediments over hundreds of square miles and permit detailed mapping of structures. The Yakima basalt records regional downwarping of the Columbia Basin area and, at least in the Priest Rapids basalt member, mild, localized differential warping contemporaneous with accumulation.

The Selah formation consists essentially of fluviatile and aeolian hornblende andesite clastics locally interbedded with quartzitic conglomerates and basalt flows. It records andesitic volcanism to the west and probably to the north of the present Columbia Basin. It also records the beginning of northern Columbia River basin drainage in somewhat its present form. The

Wenas basalt formation consists of one or two lava flows that are arbitrarily assigned locally to the Selah and Ellensburg formations. The Selah and Wenas together afford evidence of localized warping during their accumulation.

The basal part of the Ellensburg formation has essentially the same lithology as the Selah formation and records the same processes of volcanism, erosion of older rocks, and sedimentation in basins that tended to become more and more localized. The upper part of the Ellensburg consists of hornblende andesite clastics mixed with angular basaltic debris. At Saddle Mountains and somewhat less clearly at the north front of the Horse Heaven Hills this material lies unconformably on the older rocks. It records the erosion of the Mio-Pliocene rocks concurrent with the rise of anticlinal ridges.

The Ringold formation, not definitely exposed in the immediate areas examined, is thought to have been deposited largely because of differential warping after the episode of folding.

Petrographically the lavas are tholeiitic and range in composition from basalts to basic andesites. The better crystallized portions of the flows are composed essentially of plagioclase, pigeonite, magnetite, and an andesitic glassy residium. Olivine comprises a few per cent of the Wenas flows and is a very minor or trace constituent of other flows. Augite and hypersthene were identified as minor constituents in a few thin sections. Sideromelane is interstitial in most of the well crystallized portions of the flows and is abundant in flow tops and pillow lava. Tachylyte is a major constituent of the thinner parts of the Wenas flows and commonly occurs in the more rapidly chilled portions of other flows. There are three generations of crystals. The first consists of corroded intratelluric labradorite, olivine, and pigeonite. These crystals, especially the more abundant labradorite, commonly form megaphenocrysts consisting of single crystals and clots. The principal second and third generation crystals are plagioclase, pigeonite, and magnetite. The second generation plagioclase is sodic labradorite or calcic andesine and the third generation is calcic or sodic andesine.

Petrographically the sediments have three principal lithologies; hornblende andesite, quartzose, and mixed. The hornblende andesite clastics form most of the Selah and Ellensburg formations and part of the sediments interbedded with the Yakima basalt flows. The fluviatile clastics consist of pebbles of stony and glassy andesite and sands of the constituent minerals and glass. The aeolian clastics of this type are pumicites of andesitic glass shards and very fine-grained tuffs. The quartzose lithology is represented in the fluviatile sediments that form much of the Selah, Ellensburg, and Ringold formations as well as the Vantage member, and other Yakima basalt interbeds. The coarse clastics are pebbles of quartzite, plutonics, metamorphics, basalt, and other volcanics. The sands are composed of quartz and other non-volcanic minerals commonly admixed with andesitic material.

The petrologic characteristics of the lavas and sediments suggest the possibility of correlations with volcanic sequences of similar lithology in areas adjacent to the Columbia Basin.

The structures mapped are part of a group of folds in a structural depression, the Columbia Basin, typified elsewhere by gentle structural slopes. Three types of anticlinal structures were mapped: (1) simple anticlines consisting of a single convex upward flexure; (2) composite anticlines formed of broad arches with subsidiary flexures; and (3) monocline-like structures bounded on one or both sides by subsidiary flexures and locally thrust northward.

Snipes Mountain exemplifies the first type of anticline. Toppenish Ridge is a composite structure. Saddle Mountains is a monocline-like structure overturned and thrust a few hundred feet to the north. The Horse Heaven Plateau is a very broad monocline-like structure with subsidiary flexures on both sides. A change in the trend of the northern anticlines from east-northeast to west-northwest divides the structure into two segments. The north limb of the western segment is overturned and thrust to the north near the change in trend. East of the deflection Rattlesnake Hills structures merge with the Horse Heaven structure. Sillusi Butte on the south flank of the eastern Horse Heaven segment is part of a north-south chain of small anticlines. The synclines that can be examined are generally smoothly concave or nearly flat-floored.

Tear faults accompany the thrusts and minor transverse faults accompany changes in the plunge of anticlinal axes. Normal faults include those incidental to the formation of the anticlines and younger antithetic faults best exposed on the north flank of the eastern Rattlesnake Hills structures.

Two modes of strucural genesis are suggested: folding free of the basement, or folding directly related to deformation of the basement. The first is suggested in the similarity of Snipes Mountain and Toppenish ridge to some of the simpler of Jura Mountains folds, and the second is suggested in the similarity of Saddle Mountains and the Horse Heaven Plateau to the Pryor Mountains of Montana. Neither type of folding can be proved because the base of the Yakima basalt is not exposed in the areas mapped.

The indicated sequence of events begins with the accumulation of the Yakima basalt flood lavas accompanied by general downwarping and some fluviatile, aeolian, and lacustrine sedimentation. In latest Yakima basalt time more localized differential warping is indicated. This continued into Selah-Wenas-basal Ellensburg time when great volumes of hornblende andesite clastics were washed into the Columbia Basin area from the west and probably from the north. At this time detrital, non-volcanic sediments were deposited by a stream or streams, presumably part of the ancestral Columbia River system.

In later Ellensburg time, probably early to middle Pliocene, anticlinal ridges were raised and detritus washed from their flanks and deposited unconformably on the older rocks. The Columbia River seems to have had essentially its present course at that time and probably had established a nearly graded condition before renewed or continued differential warping caused the deposition of the Ringold formation in the Pasco Basin. Probably in post-Ringold time antithetic faulting slightly lowered the structural relief of some of the ridges. Perhaps this faulting was nearly contemporaneous with differential warping that raised the Ringold formation to the north. Deformation of the anticlinal structures may have continued to the present time.

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APPENDIX A

MEASURED SECTIONS

Locality 1

East side of Sentinel Gap (Beverly quadrangle, 15 minute series, Grant County) where the Columbia River passes through the Saddle Mountains anticline. The Yakima basalt section was measured in the river bluffs and in gullies and is modified from Galster (1955) and Gray (1955). The remainder of the section was measured near the pumicite quarry in the SW 1/4, NW 1/4, sec. 23, T.15 N., R.23 E., and is modified in part from Carithers (1946) and Mason (1953).

Unit	Description	Feet
RINGOLD FORMATION (?)		
	Pebble conglomerate--basalt, quartzite, metamorphics, volcanics, well rounded; sand fraction medium-grained, rather poorly sorted--feldspar, quartz, 2 or 3% heavies; moderately cemented by carbonate, some sand lenses; unconformable on Wenas basalt and Ellensburg formations.	50
ELLENSBURG FORMATION (tectonic phase)		
(4)	Gravel--basaltic, fresh, 4 inch maximum diameter, locally cemented, poor outcrop.	25
(3)	Sand and silt--tuffaceous, slightly consolidated; contains feldspar, glass, magnetite, hornblende, biotite; one pebbly bed.	50
(2)	Gravel and sand--basaltic, 4 inch maximum diameter, few andesite and quartzite pebbles; sand similar to unit above.	50
(1)	Silt--pale gray, laminated, caliche cemented.	5
	Total Ellensburg approx.	130

Unit	Description	Feet	Smp. #
WENAS BASALT FORMATION			
(3)	Basalt--dark gray, vesicular, aphanitic, close blocky jointing, upper 10 feet locally softened.	20	
(2)	-----dark blue-gray, aphanitic, slightly porphyritic (2 mm plagioclase), blocky jointing, slightly vesicular.	55-60	#202-7
(1)	-----dark gray, aphanitic, blocky, vesicular.	5-10	
	Total Wenas approx.	90	
SELAH FORMATION			
(17)	Pumicite--light tan, very fine-grained, massive, fritted at top, moderately consolidated.	5	
(16)	Sandstone--pale gray, cross-laminated, soft, tuffaceous.	2	
(15)	Pumicite--light blue-gray, fine-grained, massive, firm.	9	
(14)	Siltstone--green-gray, massive, soft.	3.5	
(13)	Conglomerate--pebble and cobble, quartzitic type, 50% andesitic sand by volume, slight cementation. Pebble count--20% basalt, 6% quartzite, 33% plutonic, 15% metamorphic, 12% andesite, 14% miscellaneous volcanics.	6	
(12)	Sandstone--gray, coarse-grained, andesitic.	3	
(11)	Conglomerate--similar to Unit 13.	11	
(10)	Silt--light yellow-gray, sandy, moderately cemented.	0.5	
(9)	Sand--gray, medium-grained, massive slightly cemented.	2.5	
(8)	Conglomerate--cobble and pebble, quartzitic lithology, about one-third andesitic sand; slightly to well cemented.	6.5	

Unit	Description	Feet
(7)	Pumicite--gray, fine to very fine-grained, nearly 100% angular shards of glass, consolidated; consists of four beds with differences in grain size and degree of cross-lamination. East of here on the south flank of Saddle Mountain, this unit is replaced by a tongue of Wenas lithology basalt, which pinches out in the pumicite very abruptly in the first gully east of the quarry. ← #204-1	40.5
(6)	Sandstone--gray, medium to fine-grained, tuffaceous, andesitic, moderately cemented, massive.	9.1
(5)	Sandstone--white, very fine-grained, tuffaceous, laminated, firm.	6
(4)	Tuff--yellow-gray, very fine-grained, "chalky".	2
(3)	Sandstone--light gray, medium-grained, massive, moderately cemented.	11
(2)	Sandstone--light gray, feldspathic, cemented, flaggy.	1
(1)	Conglomerate--cobble and pebble, quartzitic lithology; sand matrix of andesitic and quartzose lithology; some sand lenses; slightly cemented.	90
	Total Selah approx.	209

YAKIMA BASALT

Priest Rapids basalt member

Flow No. 2 (Sillusi?)

Unit	Description	Feet
(4)	Basalt--dark green, very vesicular, columnar tendency, altered to stiff clay-like consistency.	5
(3)	-----dark gray, vesicular, weathered to red-brown, columnar tendency, fine-grained, fairly well-crystallized.	15 #234-4

Unit	Description	Feet	
(2)	-----dark gray, finely vesicular, red-brown weathering, massive columns 4 to 5 feet in diameter, slabby basal jointing on 1 to 2 foot spacing, medium-grained, well crystallized, few small phenocrysts.	20	261-B
(1)	-----blue-gray, scoriaceous, aphanitic.	1	
	Total flow No. 2	41	
Interbed			
	Tuff--gray, fine-grained.	0.3	
Flow No. 1 (Umatilla?)			
(5)	Basalt--dark gray, aphanitic, finely porphyritic, vesicular, red-brown weathering, slabby.	36.5	
(4)	-----dark gray, red weathering, finely vesicular, massively columnar, slabby, fine-grained, minutely porphyritic.	31	
(3)	-----dark blue-gray, fine-grained, finely porphyritic, massive columns 8 to 10 feet in diameter, red weathering.	33-38	261-3
(2)	-----similar unit above, but jointing very irregular; massive columns are split into arcuate high angle slabs, fine-grained, well crystallized, finely porphyritic, basal few feet locally very closely fractured.	47.5-52	261-5
(1)	-----dark gray, vesicular, some palagonitic alteration.	5-10	
	Total flow No. 1 approx.	160	
	Total Priest Rapids approx.	201	
Petrified wood	--local accumulations of logs and limbs. (Stratigraphic equivalent of Burke diatomite).	0-5	
Roza porphyritic basalt member			
(4)	Basalt--dark gray, slightly porphyritic (locally very porphyritic) vesicular, columnar tendency.	15	

Unit	Description	Feet	
(3)	-----dark gray, very porphyritic (one or two feldspars up to one centimeter long per square inch of outcrop), columnar (two to three feet in diameter), slabby, slightly vesicular in part, red-brown weathering.	65	267-2
(2)	-----slabby, porphyritic as above, non-vesicular, red-brown weathering.	25	
(1)	-----dark gray, vesicular, porphyritic.	5	
	Total Roza flow	110	

Note: At Saddle Mountain crest, just east of the Columbia River, the flow is formed of two units. 226-1A upper, 226-2 lower unit

	Petrified wood--local accumulations of logs and limbs with opaline matrix. (Stratigraphic equivalent of Squaw Creek member).	0-2	205-1
	Frenchman Springs basalt member		
	Sentinel Gap flow (flow No. 4)		
(3)	Basalt--dark gray, very vesicular to vesicular, aphanitic, blocky and somewhat slabby, red weathering tendency.	40	
(2)	-----dark gray, vesicular to slightly vesicular, aphanitic, sparsely porphyritic (3/4 inch maximum feldspar clots), jointing irregular with columnar and slabby tendency.	50	267-3, 261-7
(1)	-----dark gray, very fine-grained, sparsely porphyritic, columnar, slightly vesicular at base.	40	260-1A
	Total Sentinel Gap flow	130	
	Flow No. 3		
(3)	Basalt--dark gray, very vesicular to scoriaceous, sparsely porphyritic, aphanitic.	21	
(2)	-----dark gray, vesicular, sheeted, sparsely porphyritic, aphanitic.	30	

Unit	Description	Feet
(1)	-----dark gray, red weathering, columnar, (3 or 4 feet in diameter), cross-jointed on order of 3 to 6 feet, sparsely porphyritic, aphanitic, thin platy zones midway and 2 to 3 feet of vesicular and sheeted basalt at base. 229-1 262-1B	75
	Total flow No. 3	126
Flow No. 2		
(3)	Basalt--dark gray, red weathering, columnar, very vesicular to scoriaceous, sparsely porphyritic, aphanitic.	24
(2)	-----dark gray, red-brown weathering, vesicular (large elongate, up to 10% of rock volume), columnar (2 to 3 feet in diameter), sparsely porphyritic, very fine-grained. 264-2 264-1	102
(1)	-----dark gray, red weathering, columnar (3 to 4 feet in diameter), fine-grained, well crystallized, moderately porphyritic (feldspar clots up to 1 inch diameter average about 6 per square foot).	15
	Total flow No. 2	131
Flow No. 1		
(3)	Basalt--dark blue-gray, red weathering tendency, close blocky jointing, vesicular, sparsely porphyritic, nodular opal at top.	50
(2)	-----similar to above, but columnar (2 feet diameter), lower part poorly exposed. 264-4 258-1A	60
(1)	-----columnar and blocky basalt locally exposed, probably pillow-palagonite in part, bench topography.	20
	Total flow No. 1 approx.	130
	Total Frenchman Springs approx.	517

Unit	Description	Feet	
Vantage member			
(2)	Tuff--very light gray, very fine-grained, soft, bentonitic, poorly exposed.	5	
(1)	Sandstone--light gray, coarse-grained, cemented by silica locally, slightly cross-bedded, quartzose, tuffaceous.	15-20	201-2
	Total Vantage	20-25	
Museum flow			
(5)	Basalt--dark gray, scoriaceous to very vesicular (20 to 25% vesicles), closely fractured, some columnar tendency, some sheeting.	13	
(4)	-----dark gray, red weathering, columnar (2 feet diameter), slightly vesicular, aphanitic, abundant small feldspar phenocrysts and some up to 5 mm long.	11	
(3)	-----similar to above, but more massively columnar, very slightly vesicular.	30	263-7C
(2)	-----similar to above, massively columnar, basal sheeting on order of 2 to 3 inches spacing, porphyritic (feldspars up to 5 mm diameter on order of 1 per sq. ft. of outcrop).	17	263-7A
(1)	-----similar to above, but moderately vesicular.	20	
	Total Museum flow approx.	91	
Flow F			
(6)	Basalt--dark gray, aphanitic, very scoriaceous to clinkery (angular, welded fragments), 2 feet of relief at upper surface.	7	
(5)	-----dark gray, aphanitic, vesicular (5%), columnar tendency (1 foot dia.).	55	263-6
(4)	-----dark gray, red weathering, blocky columnar jointing one foot in diameter, very sparsely porphyritic (2 mm dia. feldspars on order of one per square		

Unit	Description	Feet	
	foot of outcrop), aphanitic, becomes vesicular midway increasing to 25 to 35% at top.	45	263-5
(3)	-----dark gray, red weathering, thinly columnar and blocky, aphanitic, very sparsely porphyritic (2 mm feldspars), basal 6 inches vesicular.	50	
(2)	-----dark blue-gray, aphanitic, blocky.	18	
(1)	-----dark blue-gray, red weathering, massively columnar (4 feet dia.), jointed parallel to base, very fine-grained, porphyritic (feldspars up to 2 mm in dia. and rarely to 5 mm about one per square foot of outcrop), very sparsely vesicular.	27	263-3
	Total flow F approx.	202	
Flow E			
(2)	Basalt--dark gray, red weathering tendency, aphanitic, 10 to 25% vesicularity, closely jointed and somewhat sheeted; in part consists of welded fragments; upper surface has several feet of undulating relief.	19	263-2B
(1)	-----blue-black, red weathering, columnar (4 feet in dia.), slabby, very fine-grained, well crystallized, finely porphyritic, upper part intergrades with closer jointing above.	16	263-2A
	Total flow E approx.	35	
Flow D			
(11)	Basalt--dark gray, red weathering tendency, very vesicular to scoriaceous, clinkery, consists of about 50% angular fragments welded together, aphanitic, very closely jointed.	38.5	
(10)	-----similar to above, but 5% vesicularity (vesicles 1/4 inch to 2 inches in diameter and few up to 6 inches elongated horizontally), some columnar tendency.	6	

Unit	Description	Feet
(9)	-----blue-black, red weathering, very fine-grained, columnar jointing 2 feet spacing and cross-jointing, slightly vesicular throughout, few scoriaceous pockets.	12
(8)	-----dark gray, aphanitic, closely jointed.	15
(7)	-----dark gray, aphanitic, closely jointed, columnar toward base. Units 7 and 8 are largely talus covered.	40
(6)	-----dark blue-gray, red weathering, jointed into columns 2 feet in diameter and cross-jointed on 2 inch to 1 foot spacing, slightly vesicular, fine-grained, porphyritic (feldspars 1 to 2 mm dia. and few to 4 mm).	6
(5)	-----similar to unit above, but sheeted and slightly better crystallized.	3
(4)	-----similar to above, but jointed into columns 4 feet in diameter and horizontally jointed on 2 to 3 feet spacing, slightly vesicular, tends to form a ledge.	15
(3)	-----similar to unit 2, but jointed into columns 8 inches in diameter.	30
(2)	-----similar to unit 1, but jointed into columns 1 foot in diameter, upper 10 feet vesicular and largely talus covered.	18
(1)	-----dark blue-gray, red weathering, jointed into massive, arcuate columns, medium-grained, well crystallized, basal few inches sheeted.	15
	Total flow D approx.	198

265-3

265-1C

265-1A

Flow C

Unit	Description	Feet
(11)	Basalt--gray, aphanitic, more or less columnar, massive jointing, moderately vesicular, vesicles up to 2 inches in diameter, typically forms a bench.	6

Unit	Description	Feet
(10)	-----gray, aphanitic, vesicular to scoriaceous, locally clinkery, closely fractured.	9
(9)	-----gray, aphanitic, slightly vesicular, blocky.	5
(8)	-----gray, vesicular, sheeted.	1/2-1
(7)	-----gray, very vesicular to scoriaceous.	2
(6)	-----clinker of gray and dark red, angular fragments welded together, 3 to 4 feet of relief at contacts.	12.5
(5)	-----dark gray, some red weathering, blocky, rather close jointing, somewhat clinkery, aphanitic, a few feldspar phenocrysts up to 3 mm long. Consists of several units of varying degrees of vesicularity and closeness of jointing.	27.5
(4)	-----similar to above, but with elongate vesicles up to 2 inches long in part filled with yellow-tan impure opal.	3
(3)	-----gray, aphanitic, vesicular, several thin units of varying vesicularity.	38 266-6
(2)	-----dark gray, aphanitic, columnar (1 foot dia.), slightly vesicular.	11
(1)	-----dark gray, aphanitic, finely porphyritic, jointed into columns 3 feet wide and jointed horizontally on 1/2 to 3 feet spacings, slightly vesicular, red weathering.	90
	Total flow C approx.	205

Flow B

Unit	Description	Feet
(5)	Basalt--dark gray, red weathering, roughly columnar, massive jointing, vesicular, aphanitic.	46.5
(4)	-----dark gray, red weathering, aphanitic, blocky jointing.	25

Unit	Description	Feet
(3)	-----blue-black, red weathering, jointed into 1 foot blocks, some fan jointing near base, jointing varies considerably throughout, aphanitic, finely porphyritic.	71.5 [266-5]
(2)	-----dark gray, red weathering, close blocky jointing, aphanitic.	20
(1)	-----blue-black, some red weathering, jointed into well formed columns 3 feet in diameter (thinner and tilted in the upper 10 to 15 feet), aphanitic, finely porphyritic. Basal contact not seen.	60 [266-3]
	Total flow B approx.	223
Flow A		
	Basalt--dark blue-gray, aphanitic, massive, irregular jointing and close, blocky, secondary jointing, upper contact not seen, base is river beach.	51 [266-1]
	Total exposed flow A approx.	51
	Total Yakima basalt approx.	1854
Total "Columbia River basalt" (Wenas, Selah, Yakima)	approx.	2158

Locality 2

Near boundary section 31, T.9 N., R.19 E. and section 6, T.9 N., R. 19 E., on north side of Logy Creek valley about one mile northwest of Satus Creek, Zillah quadrangle.

Unit	Description	Feet
WENAS BASALT FORMATION		
	Basalt--blue-black, glassy base, finely porphyritic, largely disintegrated into 6 inch blocks.	20
SELAH FORMATION		
	Soil--light gray, tuffaceous, no real outcrop.	100

Unit	Description	Feet
YAKIMA BASALT-Priest Rapids member		
Flow or flow unit No. 2 (Sillusi flow?)		
(2)	Basalt--dark gray, brown speckled, medium-fine-grained, porphyritic, (yellow weathered, tabular feldspars up to 5 or 6 mm in dia.), massively columnar, platy, top not exposed.	60
(1)	-----similar to above, less massive, not platy.	20
	Total exposed flow No. 2	80
Flow or flow unit No. 1 (Umatilla flow?)		
(4)	Basalt--dark gray, vesicular to scoriaceous.	20
(3)	-----dark gray, fine-grained, porphyritic (feldspar laths up to 5 mm long sparsely distributed), blocky jointing.	60 54-29-2
(2)	-----vesicular.	20
(1)	-----dark gray, medium-grained, porphyritic (feldspar laths up to 5 mm long as above), columnar, vuggy, intermittent exposures to creek bottom.	70
	Total flow No. 2	170
	Total exposed Priest Rapids	250

Note: about 1/2 mile northwest, tuffaceous sediments outcrop at approximately the stratigraphic level of the base of the above section.

Locality 3

Section measured in gullies in sections 2, 3, 4, 5, 7, 8, T.9 N., R.19 E., north and south sides of Toppenish Ridge, Zillah quadrengle.

Unit	Description	Feet
ELLENSBURG FORMATION		
	Tuffaceous sediments and quartzitic conglomerates intermittently exposed in gullies on lower slopes.	?

Unit	Description	Feet	
WENAS BASALT			
	Basalt--black, aphanitic, blocky; upper 5 to 10 feet vesicular and lower 20 to 30 feet more massively jointed and better crystallized.		54-19.2
	Approximately	50	
SELAH FORMATION			
	Tuffaceous sediments poorly exposed in a topographic saddle.		
	Approximately	250	
YAKIMA BASALT			
Priest Rapids member			
	Umatilla (?) flow (north side of ridge)		
	(5) Basalt--dark gray and red-brown, vesicular and clinkery with tongues of dense basalt. This is an unusually thick vesicular zone.	112	
	(4) -----dark gray, red-brown weathering, fine-grained, massively columnar and slabby, a few large feldspar phenocrysts.	180	54-20-3B 176 178
	(3) -----similar to above, but platy, closely cross-jointed.	22	
	(2) -----brown, well weathered, slightly vesicular, closely fractured.	14	
	(1) Opal--dark brown, tinged with blue and red, massive, amygdaloidal, replaced basalt.	1.5	
	Total Umatilla (?) flow approx.	329	
	Mabton (?) interbed		238-opal 177-pet. wood
	Sandstone--blue-gray, very fine-grained, tuffaceous, baked.	2	
	Basal Priest Rapids flow		
	(2) Basalt--black, coarsely vesicular, aphanitic, closely jointed, joint surfaces red.	10	

Unit	Description	Feet	Smp.#
(1)	-----dark blue-gray, very fine-grained, columnar and platy, locally shattered due flexure.	100	188 182 179 54-18-1B
	Total basal Priest Rapids	110?	
Roza porphyritic basalt member			
(2)	Basalt--dark gray, limonite speckled, fine-grained, porphyritic (abundant feldspar laths and clots up 1 cm. long, but averaging 3 to 4 mm.), vesicular, irregularly jointed.	10-15	180 242
(1)	-----similar to above, but columnar, finely vesicular, and toward base of flow non-vesicular, columnar, sheeted and closely cross-jointed.	85-90?	
	Total Roza porphyritic approx.	100	

Note: this flow is not well exposed at any one locality. The section is an approximation drawn from several localities on both sides of the ridge in this vicinity.

Unit	Description	Feet
Squaw Creek member (?)		
	Tuff--light gray, very fine-grained, "chalky", (found only on south flank of ridge).	10
Frenchman Springs basalt member		
	Basalt--vesicular over columnar, porphyritic, not well exposed.	?
	Total exposed Yakima basalt approx.	550

Locality 4

Center of NE 1/4, sec. 6, T.9 N., R.20 E., Toppenish Ridge, Zillah quadrangle near Toppenish garbage dump north of U.S. Highway 97.

Unit	Description	Feet
ELLENSBURG FORMATION		
(3)	Sandstone--few small exposures of medium and coarse-grained, tuffaceous sandstone.	50?

Unit	Description	Feet
(2)	Basalt--Wenas lithology; probably fills a channel in the Ellensburg beds.	50? #149
(1)	Sediments--tuffaceous and conglomeratic, (hornblende andesite and quartzite lithologies), almost no outcrop.	175?
	Total Ellensburg "exposed" approx.	275

WENAS BASALT FORMATION

	Basalt--black, glassy base, finely porphyritic, some feldspars up to 2 mm long, jointed into 2 to 8 inch blocks with conchoidal surfaces; vesicular at top, but exact top and base not seen; forms hogbacks. 7-30	40?

SELAH FORMATION

(16)	Tuffaceous soil--light gray, rather loose.	46
(15)	Sandstone--pale gray, medium-grained, tuffaceous.	23.5
(14)	"Claystone"--olive-brown, greasy luster, brittle, massive, conchoidal fracture.	26
(13)	"Claystone"--similar to unit above, but sandy.	6
(12)	Pumicite--pale yellow-tan, slightly iron-stained, medium to fine-grained, nearly pure glass.	17.8
(11)	Pumicite--blue-gray, medium-coarse-grained, thin-bedded, firm, pure.	5.5
(10)	Pumicite--similar to unit 12.	4.5
(9)	Sandstone--yellow-tan, iron-stained, medium-grained, tuffaceous, slightly micaceous, firm.	6.4
(8)	"Claystone"--olive-brown, silty, greasy luster, bentonitic, conchoidal fracture.	34.5
(7)	similar to unit 8, but sandy.	13.2

Unit	Description	Feet
(6)	Sandstone--yellow-tan, iron-stained, medium-grained, tuffaceous, moderately firm.	9.5
(5)	Tuff--yellow-tan, stained, clayey, silty, firm, brittle, bentonitic.	12
(4)	Sand--yellow stained, medium-grained, feldspathic, micaceous, partly cross-bedded.	3.7
(3)	Clay--pale tan, silty, brittle, blocky, bentonitic.	9.5
(2)	Siltstone--pale gray, tuffaceous, friable, blocky.	13.5
(1)	"Claystone"--light gray, slightly iron-stained, silty, brittle, blocky, bentonitic, bedded 3 to 5 feet thick.	44.4
	Total Selah approximately	273

YAKIMA BASALT-Priest Rapids member

Unit	Description	Feet
(3)	"Claystone"--olive-brown, greasy, gritty, stiff, has traces of vesicular structure	10
(2)	Basalt--dark gray, brown weathering, vesicular, very fine-grained, well crystallized, sparsely and finely porphyritic. Approx.	20
(1)	-----similar to above, but massively columnar, base not exposed.	

54-42 (202)

Locality 5

South slope of 1821 summit (Hembre triangulation station) of Toppenish Ridge in the center of the NW 1/4, sec. 3, T.9 N., R.20 E., Zillah quadrangle. Section is modified greatly from Mason's (1953) locality No. 7.

Unit	Description	Feet
	WENAS BASALT FORMATION	
(2)	Basalt--dark blue-gray, aphanitic, finely porphyritic, close irregular fracturing, in part weathered yellow and red-brown, vesicular for one or two feet at top. Rounded quartzite pebbles and tuffaceous soil at summit are remnants of Ellensburg formation.	9

208

Unit	Description	Feet
(1)	-----similar to above, but jointed into irregularly curving columns a few inches thick, vesicular for a few inches at base.	9.5
	Total Wenas	18.5

SELAH FORMATION

(36)	Sandstone--pale gray, coarse-grained, andesitic, tuffaceous, baked, thickness varies.	0.3
(35)	Tuff-blue-gray, brittle, baked, columnar structure.	1.3
(34)	Siltstone--olive-brown, tuffaceous, brittle, conchoidal fracture, greasy luster, gritty.	1.5
(33)	Sandstone--cream, medium-grained, tuffaceous, feldspathic, firm.	9.0
(32)	Siltstone--similar to unit 34.	5.5
(31)	Tuff--pale gray, stained yellow-brown, altered, soft, clayey, contains altered pumice lapilli.	2.1
(30)	Sandstone--similar to unit 33.	0.8
(29)	Sandstone--buff, medium-grained, tuffaceous, micaceous, feldspathic, firm, partly thin-bedded.	7.1
(28)	Sandstone--similar to unit above, but loose, cross-laminated.	10
(27)	Sandstone--buff, fine-grained, tuffaceous, firm, has thin clayey partings.	4.7
(26)	Sandstone--similar to unit 28.	4.1
(25)	Sandstone--similar to unit 27.	3.7
(24)	Siltstone--olive-brown, gritty, brittle, firm.	0.6
(23)	Siltstone--light tan, tuffaceous, thin-bedded, firm.	4.0
(22)	Siltstone--similar to unit 34.	7.9

Unit	Description	Feet
(21)	Sandstone--light tan, very fine-grained, massive, tuffaceous, firm.	2.9
(20)	Tuff--white, silty, massive, sandy at base, moderately hard.	4.9
(19)	Pumicite--light tan-gray, medium-grained, nearly pure glass, laminated.	1.6
(18)	Siltstone--very light gray, tuffaceous, "chalky".	1.5
(17)	Siltstone--similar to unit 34.	2.9
(16)	Siltstone--similar to unit 18.	1.7
(15)	Sandstone--light tan, medium-grained, tuffaceous, micaceous, feldspathic, firm, toward base finer and more tuffaceous.	26.3
(14)	Sandstone--light gray, medium-grained, feldspathic, micaceous, loose.	1.1
(13)	Sandstone--similar to unit 14, but slightly coarser grained, tuffaceous, firm.	1.0
(12)	Siltstone--light gray, tan stained, very fine-grained, firm--	5.1
	grades to--	
(11)	Siltstone--olive-brown, similar to unit 24.	8.2
(10)	Siltstone--light gray, very fine-grained, firm.	2.1
(9)	Sand--tan, very fine-grained, feldspathic, loose.	1.5
(8)	Siltstone--light gray, tuffaceous, firm.	0.7
(7)	Sandstone--tan, medium-grained, tuffaceous.	1.7
	grades to--	
(6)	Sandstone--tan, very fine-grained, silty.	1.9
(5)	Siltstone--light gray, tuffaceous, laminated, firm.	12.8
(4)	Sand--light gray, fine-grained, feldspathic, micaceous.	0.7
(3)	Siltstone--light gray, tuffaceous, firm.	6.1

Unit	Description	Feet
(2)	Siltstone--light gray, tuffaceous, bedded 2 to 3 feet thick and laminated.	11.1
(1)	Sandstone--light gray, very fine-grained, silty, tuffaceous, cross-laminated.	0.5
	Total Selah approx.	165
YAKIMA BASALT--Priest Rapids member		
(2)	"Claystone"--dark green, greasy luster, gritty, "stiff", altered basalt.	6.9
(1)	Basalt--dark gray, aphanitic, brown weathering, slightly porphyritic (1 to 2 mm feldspars), vesicular, rotten, palagonite and opal in cracks and vesicles, columnar tendency, few tuffaceous partings. Grades to solid columnar basalt below.	54-52-17 54-129

Locality 5A

Gully southwest of 1821 summit of Toppenish Ridge in the center of sec. 3, T.9 N., R.20 E., Zillah quadrangle.

Unit	Description	Feet
WENAS BASALT FORMATION		
	See section 5 measured on south slope of the 1821 summit.	18.5
SELAH FORMATION		
	See section 5, units 24 to 36.	
	Basalt--Wenas lithology, blue-black, aphanitic, slightly vesicular, jointed into columns 2 to 3 feet thick; top has evidently been weathered away to some extent; approximate stratigraphic equivalent of units 22 to 25 of section 5; caps the ridge at 5A.	15
	See section 5, units 1 to 21. Most of the beds with good outcrop are continuous, but lensing introduces some variation.	100
	Total Selah approximately	167

Unit	Description	Feet
YAKIMA BASALT--Priest Rapids member		
	Sillusi flow (flow units and sedimentary interbeds)	
(12)	"Claystone"--dark green, greasy luster, gritty, "stiff", residual from basalt below.	6
(11)	Basalt--dark gray, brown stained and weathered, aphanitic, vesicular and clinkery.	27
(10)	Tuff-cream, medium-grained, brittle, cemented by opal.	4
(9)	Pumicite--tan, medium-grained, weathered, soft.	3
(8)	"Claystone"--dark green, greasy luster, gritty, brittle, residual from basalt below.	2.5
(7)	Basalt--dark gray, brown stained and weathered, rotten, palagonitic, partly columnar.	12
(6)	No outcrop--probably tuffaceous sediments.	15
(5)	Tuffaceous sediments--poorly exposed.	3
(4)	Pumicite--light gray, medium-grained, nearly pure glass, firm.	3
(3)	Basalt--dark gray, brown weathered, vesicular, columnar.	10
(2)	Tuffaceous sediments--andesitic siltstones and sandstones, poorly exposed.	33
(1)	Siltstone--tan, tuffaceous, massive, firm.	7
	Total Sillusi flow units and interbedded sediments approx.	125

Umatilla flow

Basalt--dark blue-gray, brown weathered, very fine-grained, sparsely porphyritic (feldspars up to 6 mm long), vesicular and clinkery at top grading downward to non-vesicular, massively columnar and sheeted, well crystallized; base not exposed.

Locality 6

South side of Snipes Mountain on both limbs of the anticline in sections 32 and 33, T.10 N., R.22 E., Zillah quadrangle. The Selah section was not measured in all detail, but is a composite from Carithers (1946, p. 67) and Mason (1953, p. 73) with a few modifications observed in the field.

Unit	Description	Feet
ELLENSBURG FORMATION		
(5)	Tuffaceous sediments interbedded with quartzitic conglomerates; no real exposure, overlain by silty alluvium.	300 +
(4)	Pumicite--blue-gray, fine-grained, massive, firm, locally very fine-grained, laminated at top.	10
(3)	Quartzitic conglomerate--6 inch maximum, rounded cobbles and pebbles in matrix of medium to coarse-grained sand; locally iron-stained and cemented. Typical constitution: 85% coarse clastics by weight consisting of (pebble count) 22% tan quartzite, 2% purple-brown quartzite, 34% basalt, 24% miscellaneous volcanics including hornblende andesite, 8% granitic, 8% metamorphic, 2% conglomerate; 15% sand and silt size hornblende andesite and quartz clastics.	75-100
(2)	Sandstone--blue-gray, coarse and very coarse-grained, cross-bedded and cross-laminated, feldspathic, tuffaceous, present at eastern end of Snipes mountain only; locally thick.	3-10 +
(1)	Conglomerate--similar to unit 3, locally underlain by sandstone similar to unit 2 and locally interfingered with the upper few feet of Wenas basalt.	8
	Total Ellensburg measurable	400-420
WENAS BASALT FORMATION		
(3)	Basalt--black, aphanitic, vesicular; locally clinkery.	10 ±

Unit	Description	Feet
(2)	-----dark gray, weathered brown to various degrees, fine-grained, well crystallized, somewhat porphyritic (feldspars to 2 mm or so long), massively columnar locally.	50±
(1)	-----black, aphanitic to fine-grained, blocky, locally vesicular at base. Locally this phase constitutes the bulk of the flow.	50±
	Total Wenas approximately	110
SELAH FORMATION		
(12)	Sandstone--blue-gray, fine-grained, very tuffaceous, brittle due baking at top, some columnar structure developed below immediate top.	8
(11)	Pumicite--blue-gray, fine-grained, pure, firm.	8
(10)	"Claystone"--green and gray, brittle, silty, massive.	13
(9)	Sandstone--pale red, very fine-grained, tuffaceous.	5
(8)	Pumicite--white, very fine-grained, massive.	3
(7)	Pumicite--blue-gray, fine-grained, firm.	2
(6)	Pumicite--similar to unit above, but laminated, rather loose.	5
(5)	Sandstone--light gray, yellow-tan stained, medium to fine-grained, thin bedded and laminated, tuffaceous.	35
(4)	Pumicite--light tan, very fine-grained, massive, firm, resistant.	10
(3)	Silt--white, laminated, tuffaceous, rather soft.	10
(2)	Pumicite--light gray, very fine-grained, soft.	3
(1)	Pumicite--light gray, fine-grained, massive, rather soft.	10
	Total Selah approximately	112

Unit	Description	Feet
YAKIMA BASALT-Priest Rapids member		
(2)	Basalt--dark gray, speckled by limonite and brown weathered, very fine-grained, very vesicular, massively and irregularly columnar, sparsely porphyritic (feldspar laths up to 5 mm long and very rare clots up to 2 cm in diamter).	40
(1)	-----similar to above, but finely vesicular to non-vesicular and massively to very massively columnar.	30
	Total Priest Rapids exposed	70

152-2
152-1

Locality 7

Horse Heaven Hills south of Mabton, Yakima county, Zillah quadrangle along and near Mabton-Roosevelt road in sections 34, 35, 36, T.8 N., R.22 E.

Unit	Description	Feet
ELLENSBURG FORMATION		
Tectonic phase		
	Tuffaceous sediments and angular basalt gravel and boulders accumulated as fans and slope wash and now being dissected. Overlain by Quaternary silts and aeolian silts and sands.	100?
Original or volcanic phase		
(6)	Tuffaceous sediments and interbedded quartzitic conglomerates (hogback forming), not exposed sufficiently for direct measurement.	500?
(5)	Quartzitic conglomerate--topographic expression and scattered pebbles indicate about--	50
(4)	Sandstone--light gray, fine-grained, tuffaceous, micaceous, massive.	4
(3)	-----light gray, fine-grained, tuffaceous, micaceous, cross-laminated, slightly consolidated.	6
(2)	Conglomerate--quartzitic, contains pebbles of basalt, quartzite, plutonics, metamorphics,	

Unit	Description	Feet
	felsite; coarse-grained sand matrix and interbeddings.	17
(1)	-----similar to unit 2, but cobble size, rather loose; about 20 feet of Wenas type basalt is intercalated near the base at the lower quarry west of the road.	81
	Total Ellensburg measurable about	160
	Total Ellensburg "exposed" about	750?
WENAS BASALT FORMATION		
(2)	Basalt--dark blue-gray, vesicular	20
(1)	-----dark blue-gray, slightly vesicular, aphanitic, jointed into irregular blocks about 8 inches in diameter.	65
	Total Wenas	85
SELAH FORMATION		
(4)	Pumicite--pale blue-gray, fine-grained, about 10% crystalline grains, massive to laminated and fissile, compact, very slightly baked at top.	50 ±
(3)	Tuff--cream to white, massive, fine-grained, slightly bentonitic, contains about 5% altered pumice lapilli.	30 ±
(2)	Sand--pale gray, stained yellow, medium-grained, slightly tuffaceous, slightly pebbly (pink and gray andesite).	70 ±
(1)	Sandstone--blue-gray, coarse-grained, tuffaceous, firm.	15 ±
	Total Selah approximately	165
YAKIMA BASALT		
Priest Rapids member		
Sillusi flow		
(2)	Basalt--dark gray, rust-brown weathering, vesicular, slabby.	45 ±

Unit	Description	Feet
(1)	-----dark gray, red-brown and greenish weathering, aphanitic, well crystallized, jointed into columns about 5 feet thick and rather closely jointed.	55±
	Total Sillusi approx.	100

Umatilla flow

(2)	Basalt--dark gray, rust-brown weathering, aphanitic, vesicular, slabby.	50±
(1)	-----similar to above, better crystallized, non-vesicular, jointed into columns 4 or 5 feet in diameter and closely cross-jointed (due flexure).	235±
	Total Umatilla approx.	285

270-1

Mabton interbed (type locality)

(6)	Siltstone--dark green, very fine-grained, brittle, opaline, very closely fractured.	3.5
(5)	Sandstone--pink gray, medium-fine-grained, tuffaceous, thin-bedded, brittle, red stained.	4.5
(4)	Siltstone--similar to unit 6, rather clayey.	6
(3)	Tuff--pale gray, very fine-grained, firm, massive.	20
(2)	Sand--white, very coarse-grained, poorly sorted, composed of pumice grains.	20
(1)	Tuff--similar to unit 3, poorly exposed.	21
	Total Mabton approx.	75

Note: Mabton varies in lithology from place to place in regard to amounts of sub-aerial and fluvial materials and varies greatly in thickness.

Basal flows

Flow No. 3

(2)	Basalt--dark gray, red weathering, fine-grained, slabby, vesicular, forms red soil.	45

Unit	Description	Feet	
(1)	-----dark gray, red weathering, finely vesicular to non-vesicular, coarsely columnar and slabby, porphyritic (abundant feldspars 1 to 2 mm long and few up to 5 mm.	76	270-4
	Total flow No. 3	121	
	Flow No. 2		
(2)	Basalt--dark gray, vesicular, slabby.	5	
(1)	-----dark blue-gray, red weathering tendency, massively columnar, cross-jointed, may be flow unit of No. 3.	30	271-1
	Total flow No. 2	35	
	Opal--various colors, petrified tree limbs, opaline void fillings.	2-5	
	Flow No. 1		
(2)	Basalt--dark gray, very vesicular, slabby tendency.	15	271-2 ↓
(1)	-----dark gray, rust stained, finely vesicular, aphanitic, jointing varies, but massive columns are typical.	45	
	Total flow No. 1	60	
	Total Priest Rapids approx.	580	
Roza porphyritic basalt member			
(3)	Basalt--dark gray, rust spotted, finely vesicular, very porphyritic (feldspars up to 1 cm.), glassy to aphanitic.	15	275-1
(2)	-----dark gray, red weathering, massively columnar, very porphyritic, very finely vesicular.	40	273-1
(1)	-----similar to above, but more vesicular.	5	
	Total Roza	60	
Frenchman Springs basalt member			
(2)	Basalt--dark gray, locally brick-red, vesicular,		

Unit	Description	Feet	
	moderately porphyritic (feldspar clots up to 3/4 inch diameter).	5	275-2
(1)	dark gray, porphyritic (about 5% by volume), aphanitic, massively columnar, base not exposed.	10	273-2
	Total Frenchman Springs exposed	15	
	Total Yakima basalt exposed approx.	655	
	Total Yakima-Selah-Wenas approx.	900	

Locality 8

Sections 17, 18, 19, 20, 29, 30, T.8 N., R.23 E., along and near Byron Hill road, Yakima County, Prosser quadrangle.

Unit	Description	Feet	
ELLENSBURG FORMATION			
	Tuffaceous sands and silts interbedded near base at least with quartzitic conglomerates.	?	
WENAS BASALT FORMATION			
	Basalt--dark gray to black, aphanitic, blocky close jointing; not well exposed.	100?	
SELAH FORMATION			
	Tuffaceous sediments--very poorly exposed.	100?	
YAKIMA BASALT			
Priest Rapids member			
Upper flows			
(3)	Basalt--vesicular over massive, columnar and slabby, intermittently exposed, details not available, structural relations indicate about---	600	325-2 325-1 320-C-2 320-C-1
(2)	-----red, clinkery.	5	
(1)	-----dark gray, rusty, well fractured, aphanitic.	30	
	Total Priest Rapids above Mabton	635±	

Unit	Description	Feet
Mabton interbed		
(4)	Tuff--gray-blue, very fine-grained, brittle.	7
(3)	-----brick red, fine-grained, sandy, brittle, friable.	3
(2)	-----tan-gray, similar to above.	6
(1)	-----slumped and gullied. Approx.	27
	Total Mabton approx.	43
Basal flow		
	Basalt--dark gray, finely vesicular, jointed into columns 4 feet in diameter, very fine-grained, sparsely porphyritic (feldspar clots up to 5 mm in diameter).	8
	Total Priest Rapids approx.	680
Unassigned interbed		
	Tuff--gray-blue, brittle, porcellaneous.	1-1.5
Roza porphyritic basalt member		
(2)	Basalt--gray, rusty, vesicular, columnar, porphyritic, (several feldspars per square foot of outcrop, average 3 to 4 mm long, but up to 1 cm.).	5
(1)	-----dark gray, very porphyritic, finely vesicular, jointed into columns 3 to 4 feet in diameter.	9
	Total Roza	14
Frenchman Springs basalt member		
Flow No. 2		
(3)	Basalt--red and purple, very vesicular, slightly clinkery, ropy surfaces, very porphyritic (feldspar clots on order of 1 per square inch), slabby pahoehoe structure.	20
(2)	-----dark gray, aphanitic, very sparsely porphyritic, jointed into small blocky columns.	50
	Total flow No. 2	120

Unit	Description	Feet
Flow No. 1		
(2)	Basalt--red and gray, clinkery slab pahoehoe.	50
(1)	-----gray, red weathering, sparsely porphyritic, jointed into columns 18 inches in diameter, well fractured due to flexure, base not exposed.	50
	Total flow No. 1 exposed	100
	Total Frenchman Springs exposed	220
	Total Yakima basalt exposed approx.	915

Locality 9

NE 1/4, NW 1/4, sec. 33, T.8 N., R.24 E. at gravel quarry south of Richards Road, and in sections 14 and 23, T.8 N., R.24 E., along and near Ward Gap Road, Benton County, Prosser quadrangle.

Unit	Description	Feet
ELLENSBURG FORMATION		
	Tectonic phase--debris of basalt gravel and tuffaceous material.	50-100
	Original phase--sandstones and siltstones--tuffaceous, cross-bedded, interbedded with quartzitic conglomerates.	300 +
	Total Ellensburg approx.	350
WENAS BASALT FORMATION		
Upper flow		
	Basalt--dark gray to black, aphanitic, vesicular, blocky at top and massively jointed at base, not completely exposed.	60 ±
Lower flow		
(3)	Basalt--dark gray to black, aphanitic, vesicular, irregular jointing.	10
(2)	-----dark gray, aphanitic, jointed into irregular blocks about 8 inches in diameter.	10

326-1

Unit	Description	Feet
(1)	-----dark gray, very fine-grained, rather massive, roughly columnar jointing, vesicular at bottom and glassy at base.	10
	Total flow No. 1	30
	Total Wenas approx.	90

SELAH FORMATION

Unit	Description	Feet
(6)	Tuff--gray-blue, fine-grained, massive, brittle.	2
(5)	Sandstone--light tan-gray, medium-grained, micaceous, tuffaceous, massive, friable.	6
(4)	Sandstone--similar to that above, but thin-bedded and cross-bedded, contains pumice fragments and thin beds of pumicite.	7
(3)	Pumicite--pale blue-gray, medium-grained, micaceous and feldspathic, interbedded with very gine-grained pumicite.	7
(2)	Tuff--pale-gray-tan, very fine-grained, massive, bentonitic.	3.5
(1)	No exposures--slump and wash indicate tuff similar to that above.	22
	Total Selah approx.	47

YAKIMA BASALT

Priest Rapids member

Sillusi flow--unit 2

Unit	Description	Feet
(3)	Basalt--blue-gray and purple, clinkery; has inclusions of tuffaceous material.	11
(2)	-----blue-gray, finely vesicular, very soft, altered, has inclusions of tan tuff, sheeted at bottom.	12
(1)	-----gray, gradational from above, platy jointing, very fine-grained, sparsely porphyritic (feldspar clots up to 4 or 5 mm in diameter).	4
	Total unit 2	27

326-3

Unit	Description	Feet
Sillusi flow--unit 1		
	(2) Basalt--red above gray, vesicular.	20
	(1) -----gray, green and brown weathering, jointed into blocks about 1 foot in diameter, very fine-grained, sparsely porphyritic (small clots).	50
	Total unit 1	70
	Total Sillusi flow	97
Interbed		
	Tuff-gray, very fine-grained, brittle.	2
Umatilla flow		
	Basalt--not well exposed; vesicular at top and massively columnar in main body. Structural relations indicate about---	400
Mabton interbed		
	Tuff--blue-gray over red, very fine-grained, brittle.	5
Basal flow		
	Basalt--rather massively columnar, very poorly exposed.	50
	Total Priest Rapids approx.	575
Roza porphyritic basalt member		
	Basalt--dark gray, very porphyritic, jointed into columns about 3 feet in diameter, top not observed.	20?
Frenchman Springs basalt member		
	No real outcrop	
	Total Yakima basalt approx.	600

Locality 10

Section measured at the north crest of the Horse Heaven Hills along and near U.S. Highway 30, south of Prosser, in section 4, T.8 N., R.25 E., Benton County, Prosser quadrangle. Section is modified in part from Mason's (1953) locality 14.

Unit	Description	Feet
WENAS BASALT FORMATION		
Upper flow		
	Basalt--black, aphanitic, blocky, vesicular at bottom, top eroded.	25
Prosser interbed (type locality)		
(7)	Tuff--blue-gray, very fine-grained, vesicular, brittle, massive.	3
(6)	Pumicite--light tan, massive, micaceous.	2
(5)	-----blue-gray, medium-grained, thin-bedded and laminated, friable, impure.	14
(4)	-----light blue-gray, very fine-grained, massive.	4
(3)	Tuff--blue-gray, very fine-grained, brittle, bentonitic, massive.	10
(2)	Sandstone--blue-gray, medium-grained, thin-bedded, contains pumicite grains, friable.	6.5
(1)	Sandstone--gray-tan, medium-grained, tuffaceous, thin-bedded, very friable.	4.5
	Total Prosser interbed	44
Lower flow		
(2)	Basalt--black, aphanitic, coarsely vesicular, rather massively jointed.	20
(1)	-----black, aphanitic, vesicular, jointed into blocky columns 1 to 1 1/2 feet thick, slabby at bottom.	15
	Total lower flow	35
	Total exposed Wenas	104
YAKIMA BASALT-Priest Rapids member		
	Basalt--dark gray, red weathering, vesicular (coarsely at top), massively jointed. Exposed approx.	20

Locality 11

Section measured in cutting on U.S. Highway 410, about 3 miles east of Prosser in NW 1/4, SW 1/4, section 33, T.9 N., R.25 E., Benton County, Prosser quadrangle. Rocks are overturned here.

Unit	Description	Feet
WENAS BASALT FORMATION		
Upper flow		
	Basalt--dark gray, aphanitic, massively jointed and very closely fractured; top not exposed.	20
Prosser interbed		
(2)	Tuff--light gray, very fine-grained, brittle, massive, bentonitic.	10
(1)	Sandstone--light tan, fine-grained, tuffaceous.	15
	Total Prosser interbed	25
Lower flow		
	Basalt--dark gray, aphanitic, vesicular, at top and near base, close irregular, blocky jointing.	80
	Total Wenas exposed	125
SELAH FORMATION		
(2)	Pumicite--blue-gray, medium-grained, interbedded with very fine-grained tuff.	6
(1)	Sandstone--light tan, fine-grained, red spotted, basal contact not exposed. Exposed	26
	Total Selah exposed	32
YAKIMA BASALT-Priest Rapids member		
	No outcrop, only float of shattered fragments.	

Locality 12

Composite section from several localities on the north flank of the Horse Heaven Hills and in highway and railroad cuts from about 3 miles east of Prosser to about 2 miles east of Chandler in the Prosser quadrangle, Benton County.

Unit	Description	Feet
ELLENSBURG FORMATION		
	Light gray, soft, tuffaceous soil and scattering small outcrops of tuffaceous sandstones and pumicite; scattered pebbles of quartzite, basalt and other types may indicate interbedded conglomerates or may be of more recent origin.	?
WENAS BASALT FORMATION		
Upper flow		
	Basalt--black, jointed into small, irregular shaped blocks in upper part and massively jointed in lower 15 to 20 feet typically; top not observed. Estimated thickness	50
Prosser interbed		
	Fine-grained tuffs, fine and medium-grained sandstones, pumicite, and east of Chandler, a few feet of diatomite associated with pumicite and opal. Thickness varies from 0 to 100 feet and seems to depend largely on development of clinker at the top of the underlying flow.	
	Thickness at "mine" shaft 3 miles east of Prosser--	21
	"Thickness" in N.P.R.R. cut near Glen	0
	Thickness 2 miles east of Chandler	100
Lower flow		
(4)	Clinker--red and dark gray, pebble to cobble size scoria clotted together, open textured where weathering has removed matrix of smaller fragments and tan silica gel; development varies considerably, topographically prominent.	0-60
(3)	Basalt--dark gray to blue-gray, vesicular, locally clinkery, not well developed where clinker is thick.	10±
(2)	-----dark gray to black, aphanitic, jointed into small irregular blocks with conchoidal surfaces.	50±

Unit	Description	Feet
(1)	-----dark gray, red weathering tendency, rather massive columnar jointing, aphanitic to very fine-grained, commonly sheeted and "shaly" especially midway.	15
	Total lower flow	75-125
	Total Wenas	125-275

SELAH FORMATION

	Fine-grained tuffs, tuffaceous sandstones, pumicite, possibly some conglomerate as indicated by float pebbles. Typically about 50 feet thick, but locally very thin or absent.	0-50

YAKIMA BASALT-Priest Rapids member

Umatilla flow (?)

(3)	Clinker--red and gray scoria, pebble to cobble size clotted together; voids filled with smaller fragments and silica gel.	0-75
(2)	Basalt--dark gray, red-brown weathering, vesicular, massively columnar, locally very vesicular and forms top of flow, at other places merges with clinker. Very approx.	20-30
(1)	-----dark gray to dark blue-gray or dark blue-green, red weathering, fine-grained, jointed into plates with curved surfaces.	170-180?
	Total Umatilla flow (?) approx.	275

Note: the above may be two flows, but the outcrops do not afford evidence of this.

Mabton interbed

(2)	Tuff--gray, very fine-grained, bentonitic, massive, firm, sandy in lower part, commonly brick red color in upper few feet possibly due to ancient weathering or to optalic metamorphism.	35
(1)	Sandstone--light gray, yellow stained, medium-grained, cross-laminated, tuffaceous, micaceous.	65
	Total Mabton approx.	100

Unit	Description	Feet
	Note: the above was observed south of Chandler where good exposures exist, elsewhere the thickness and lithology probably vary.	
Basal Priest Rapids		
	Basalt--vesicular, very scanty exposures.	?
	Total Yakima (Priest Rapids) exposed approx.	375

Locality 13

Composite section measured in sections 3 and 4, T.9 N., R.27 E. and in section 32, T.10 N., R.27 E. on the southwest and northwest slopes of Red Mountain, Benton County, Pasco quadrangle (30' series) and Richland quadrangle (15' series). In part this is a modification of Mason's (1953) locality 22.

Unit	Description	Feet
WENAS BASALT FORMATION		
Upper flow		
(2)	Basalt--black, aphanitic, vesicular.	4
(1)	-----black, aphanitic, jointed into irregular columns about 1 foot thick.	16
	Total upper flow exposed	20
Lower flow		
(3)	Basalt--black, brown weathered, vesicular, slabby.	10
(2)	-----dark gray, aphanitic, finely porphyritic, jointed into columns about 1 foot thick with rosette structures.	90 312-1
(1)	-----dark gray, fine-grained, brown weathered, jointed into massive columns and blocks.	20-30
	Total lower flow approximately	120
	Total Wenas exposed approximately	140
SELAH FORMATION		
(2)	Tuff or tuffaceous sandstone--gray-blue, locally baked and altered to brick red, soft, very poor outcrop.	5

Unit	Description	Feet	
(1)	Pumicite--light blue-gray, nearly pure glass shards, poor outcrop.	10	
	Total Selah approximately	15	
	YAKIMA BASALT		
	Priest Rapids member		
	Sillusi flow		
(2)	Basalt--dark gray, red weathering tendency, aphanitic, finely porphyritic, coarsely vesicular, slabby.	20	
(1)	-----similar to above, but columnar.	30	312-2
	Total Sillusi approx.	50	
	Umatilla flow		
(2)	Basalt--dark gray, brown weathered, vesicular.	20	314-1
(1)	-----dark gray, brown weathered, aphanitic, finely porphyritic, columnar, not well exposed.	80	
	Total Umatilla approx.	100	
	Mabton interbed?--Mason (1953, locality 22) reports 14 feet of tuffaceous sediments apparently at this stratigraphic position, but they were not observed.		
	Basal flow(s)		
(2)	Basalt--dark gray, vesicular, limonite speckled, led, aphanitic base, abundant tiny crystals and some feldspars up to 5 mm long.	10	314-2
(1)	-----similar to above, but columnar, not well exposed. Exposed approx.	10	
	Exposed basal Priest Rapids approx.	20	
	Total exposed Priest Rapids	170	

Locality 14

Section measured at the west end of The Butte in the SW 1/4, section 3, T.7 N., R.30 E., Benton County, Pasco quadrangle.

Unit	Description	Feet

WENAS BASALT FORMATION

Upper flow

(2) Basalt--dark gray, brown weathered, aphanitic to fine-grained, jointed into columns 2 to 8 feet in diameter, coarsely vesicular and vuggy. — 20±

(1) -----similar to above, but jointed into columns about 1 foot thick, slightly vesicular, not well exposed. — 50± 307-1

Total upper flow approx. — 70

Prosser interbed

Pumicite--light blue-gray, cross-laminated, observed only at one place in quarry at west end of The Butte and at last examination had been removed completely, may represent a local accumulation. — 2-3?

Lower flow

(2) Basalt--black, jointed into irregular columns 6 to 8 inches in diameter and cross-jointed into small blocks, slightly vesicular. — 105 307-2

(1) -----dark blue-gray, jointed into columns 2 to 3 feet in diameter, aphanitic, finely porphyritic, base not exposed. — 20 306-1 306-2

Exposed lower flow — 125

Total Wenas exposed approx. — 195

Locality 15

Section measured in the SE 1/4, NW 1/4, section 16, R.30 E., T.7 N., east side of Nine Canyon, Horse Heaven Hills, Benton County, Pasco quadrangle. Section is in part a modification of Mason's (1953) locality 17.

Unit	Description	Feet

WENAS BASALT

Upper flow

(3) Basalt--black, aphanitic, minutely porphyritic,

Unit	Description	Feet
	jointed into irregular columns 2 to 3 feet in diameter, moderately vesicular, spheroidally weathered, evidently a flow unit.	5
(2)	Sandstone--green-gray, medium-grained, tuffaceous, contains scattered granules of basalt, massive structure.	3
(1)	Basalt--dark gray and blue-gray, dense and vesicular, aphanitic, minutely porphyritic, black glass selvage in lower 1 inch, lower contact has several feet of relief and pumicite has been caught up into basalt locally, evidently a flow unit.	7
	Total upper flow	15
Prosser interbed		
	Pumicite--light blue-gray, medium-grained, cross-laminated and cross-bedded, friable, nearly 100% glass shards, some pumice lapilli.	9-10
Lower flow		
(2)	Basalt--brown weathered, friable, sand-like, vesicular.	20
(1)	-----dark gray, brown weathered, vesicular, close blocky jointing and irregular columnar structure, base not exposed in gully at bottom. Exposed	50
	Total exposed lower flow	70
	Total exposed Wenas approx.	95

53-3
53-1A

Locality 16

Section measured on bluff, northwest side of Columbia River gorge (Wallula Gap) in southeastern 1/4, section 13, T.6 N., R.31 E., Benton County, Umatilla, Wallula and Pendleton quadrangles.

Unit	Description	Feet
WENAS BASALT FORMATION		
(5)	Basalt--black, aphanitic, red-brown weathering, slightly vesicular, jointed into sinuous	

Unit	Description	Feet	
	columns 6 to 8 inches in diameter, top of flow eroded.	55	304-14
(4)	-----black, massively columnar, thinly platy transverse to columns.	23	304-13
(3)	-----dark blue-gray, very fine-grained, jointed into columns 2 to 3 feet in diameter and into secondary vertical slabs.	37	
(2)	-----no outcrop.	10	304-12
(1)	-----dark gray, very closely fractured, sparsely vesicular at base.	30	
	Total Wenas measurable	155	

YAKIMA BASALT

Priest Rapids member

Sillusi flow

Unit	Description	Feet	
(3)	Basalt--dark gray, moderately vesicular, irregularly jointed.	7	
(2)	-----dark gray, red-brown weathering, limonitic speckled, moderately vesicular, jointed into columns 2 feet in diameter.	55	304-11
(1)	-----dark blue-gray, red-brown weathering, jointed into columns 8 feet in diameter, very fine-grained, moderately to sparsely vesicular.	63	
	Total Sillusi flow	125	

Umatilla flow

Unit	Description	Feet	
(5)	Clinker--red and gray, cobble size, ropy-surfaced, irregularly rounded basalt fragments partly welded together, silica gel matrix.	10	
(4)	Basalt--dark blue-gray, very fine-grained, jointed into columns 8 feet in diameter, sparsely vesicular.	40	304-10
(3)	-----similar to above, but jointed into columns 5 feet thick.	10	

Unit	Description	Feet	
(2)	-----similar to above, but 20 to 50% vesicularity; vesicle pipes and small spiracles issue upward from less vesicular basalt below.	4	
(1)	-----similar to above, but moderately vesicular and rather closely cross-jointed into blocks.	16	304-9
	Total Umatilla flow	80	
	Total Priest Rapids	205	
Frenchman Springs basalt member			
	Flow or flow unit No. 7		
(4)	Basalt--dark gray, vesicular (up to 25%), closely fractured, aphanitic.	15	
(3)	-----dark blue-gray, red weathered, jointed into columns 5 feet thick, very fine-grained, sparsely porphyritic (1/2 inch max. clots and 1/4 inch laths), slightly vesicular.	24	304-8
(2)	-----dark gray, moderately vesicular, smaller columns than above and below, undulating basal partings.	20	304-7A,B
(1)	-----blue-black, red weathered, jointed into columns 5 feet thick and broken into blocks by cross-jointing, fine-grained, sparsely porphyritic (clots up to 3/4 inch).	40	
	Total flow No. 7	99	
	Flow unit No. 6		
	Basalt--dark blue-gray, red-weathering, jointed into columns 2 to 3 feet thick, slightly vesicular to very vesicular and crumbly upward, aphanitic, sparsely porphyritic (clots up to 1/2 inch).	22	304-6
	Flow unit No. 5		
	Basalt--dark blue-gray, aphanitic, red weathering, jointed into columns 2 to 3 feet thick, slight vesicularity increasing to 50% at top where columns are very tiny, sparsely porphyritic (clots up to 1 inch).	36	304-5A,B

Unit	Description	Feet
Flow unit No. 4		
	Basalt--dark blue-gray, red weathering, jointed into columns 2 feet thick, irregularly shaped, upper 11 feet vesicular and columns smaller, aphanitic, very sparsely porphyritic (clots up to 1/4 inch). 304-4	44
Flow or flow unit No. 3		
(3)	Basalt--dark blue-gray, red weathering tendency, jointed into columns 6 inches to 1 foot thick, moderately vesicular.	17
(2)	-----similar to above, slightly vesicular, sparsely porphyritic (1/2 inch max. clots), well defined parting between base and non-vesicular basalt below. 304-3	50
(1)	-----dark blue-gray, red weathering, jointed into well formed columns 2 to 3 feet in diameter, aphanitic, sparsely porphyritic (1/2 inch max. clots).	38
	Total flow No. 3	105
Flow or flow unit No. 2		
(3)	Basalt--dark blue-gray, red weathering, 25% vesicularity, locally vuggy, sheeted, crumbly.	20
(2)	-----similar to below, but slightly vesicular increasing upward. 304-2	24
(1)	-----blue-green-gray (fresh surface), red weathering, jointed into columns 3 to 6 feet in diameter, aphanitic, porphyritic especially near bottom where clots up to 3/4 inch in diameter constitute about 1% of volume, smaller laths of feldspar numerous, considerable cross-jointing and basal slabby jointing.	44
	Total flow No. 2	88
Flow or flow unit No. 1		
	Basalt--blue-black, aphanitic, porphyritic, (clots up to 1 inch long average 4 or 5 per square foot of outcrop and single	

Unit	Description	Feet
	feldspar crystals up to 1/4 inch long are fairly common, moderate vesicularity at base increasing upward; base of exposure is McNary Dam reservoir surface at approximately elevation 340 feet. 304-1A,B	25
	Total Frenchman Springs exposed	419
	Total Yakima basalt	624
	Total Yakima and Wenas exposed	779

Locality 17

Section measured in southeast corner NE 1/4, section 6, T.5 N., R.30 E., Benton County, Umatilla quadrangle, at mouth of Spukshowki Canyon and in railroad cuts upstream on north side of the Columbia River.

Unit	Description	Feet
WENAS BASALT FORMATION		
(2)	Basalt--black, partly red-brown weathered, jointed into thin sinuous columns and closely cross-jointed into blocks, aphanitic, slightly to moderately vesicular. 53-16	25
(1)	-----similar to above, but non-vesicular, and near base more massively jointed.	85
	Total exposed Wenas	110
YAKIMA BASALT		
Priest Rapids member		
Sillusi flow		
(2)	Basalt--dark blue-gray, red weathered, aphanitic, vesicular.	10
(1)	-----dark blue-gray, red weathered, very fine-grained, massively columnar, locally platy. 53-18B	85
	Total Sillusi	95
Umatilla flow		
(3)	Basalt--dark gray, red-brown weathered, vesicular, jointed into columns about 2 feet in diameter, upper part not well exposed. 53-19B	44

Unit	Description	Feet	
(2)	-----similar, columns 3 feet in diameter.	11	
(1)	-----dark blue-gray, similar to above, but very massively columnar, and has high angle, platy jointing.	25	
	Total Umatilla	80	
Basal flows			
Flow or flow unit No. 3			
(3)	Clinker--red and gray, vesicular and dense, irregularly rounded fragments of basalt, largely of cobble size with void fillings of impure silica gel.	25	
(2)	Basalt--dark blue-gray, red-weathered, closely jointed, aphanitic.	22	53-68A
(1)	-----dark blue-gray, red-brown weathered, massively columnar, very fine-grained, some close fracturing.	24	53-10
	Total flow No. 3	71	
Flow or flow unit No. 2			
(3)	Clinker--similar to that at top of flow No. 3	5-10	53-8B
(2)	Basalt--dark gray, aphanitic, massively columnar, slightly vesicular, very rare large feldspar phenocrysts, a few auto-injective dikes rise from basalt into clinker above.	15	53-7B
(1)	-----dark gray and red, vesicular and clinkery, development varies locally.	4	
	Total flow No. 2 approx.	25	
Flow or flow unit No. 1			
(4)	Clinker--red, rugosely rounded fragments.	3-4	53-76A
(3)	Basalt--dark gray, vesicular, slabby.	6	53-5C
(2)	-----dark gray, red weathered, very fine-grained, slightly vesicular, jointed into short columns about 2 feet in diameter, moderately cross-jointed.	18	

Unit	Description	Feet
(1)	-----dark gray, massively columnar, very fine-grained.	4
	Total flow No. 1	32
	Total Priest Rapids	303

Frenchman Springs basalt member

Basalt--red and gray, coarsely vesicular, sparsely porphyritic (feldspar clots up to 1/2 inch in diameter). Little exposure in immediate vicinity. 53-32

Locality 18

Section measured at south face of Sillusi Butte and in vicinity of McNary Dam in bluffs on north side of the Columbia River and at McNary Dam inexcavations and from drill core records. Area includes sections 2, 3, 4, 10, T.5 N., R.28 E., Benton County, Umatilla quadrangle.

Unit	Description	Feet
WENAS BASALT FORMATION		
(3)	Basalt--dark gray to black, commonly weathered red-brown, very vesicular, jointed into well-formed columns about 2 feet in diamter, aphanitic.	10
(2)	-----dark gray to black, commonly weathered red-brown, jointed into sinuous columns on order of 6 to 8 inches in diameter with extensive, undulating basal partings on order of 2 to 8 feet apart; slightly vesicular in part, aphanitic, finely porphyritic.	155
(1)	-----similar to above, but more massive and better formed columns; development varies locally, slightly vesicular.	10
	Total Wenas	175

117 125B 127 128 131

Note- A thin upper flow or flow unit may exist at Sillusi Butte on top of the above section.

YAKIMA BASALT-Priest Rapids member

Sillusi flow (type locality)

(3) Basalt--dark gray, brown weathered, vesicular,

Unit	Description	Feet	
	columnar or sheeted, locally clinkery, aphanitic.	5-20	
(2)	-----dark gray, brown weathered, jointed into columns 2 to 5 feet in diameter and locally into roughly cubical blocks about 8 feet in diameter, locally platy, aphanitic, moderately porphyritic on fine scale. Approx.	100	112 B 113 A 113 B
(1)	-----similar to above, but with vesicular, sheeted zones, development varies locally.	50	
	Total (average) Sillusi	150	
	Note; Sillusi thickness varies in this vicinity from about 130 to about 170 feet depending upon development of clinker at top of Umatilla flow.		
Umatilla flow (type locality)			
(3)	Clinker--red and gray fragments of vesicular and dense basalt, surfaces irregularly rounded and ropy to angular, cobbly texture common, voids filled with small fragments of basalt in various stages of alteration and with tan, impure silica gel; dikes from massive part of flow below are common; thickness varies due to irregularities in top and bottom surfaces from 25 to 70 feet and averages about....	50	122 C
(2)	Basalt--dark gray to black, aphanitic, finely porphyritic, vesicular and locally vuggy at top, jointed into columns 3 to 8 feet in diameter with roughly rectangular cross-sections, locally much platy cross-jointing.	100-120	114A, B 122 A 122 B MCN-1, 2
(1)	-----similar to above, but less massive, much cross-jointing and sheeting, locally vesicular. (Known only from drill cores).	0-20	
	Total (average) Umatilla	170	
Mabton interbed (known only from drill cores here)			
(3)	Clay--green-gray, brittle, tuffaceous, silty, massive, gradational to:		
(2)	Sandy clay, silt, fine to medium-grained sand--interbedded and laminated, poorly consolidated, tuffaceous, gradational to:		

Unit	Description	Feet
(1)	Sandstone--medium to coarse-grained, pebbly (small, rounded, quartz pebbles), locally well cemented, locally coarse-grained non-pebbly at base.	
	Total Mabton	28.5-64

Thickness of Mabton interbed varies due to erosion of underlying basalt flow, presumably by agent of Mabton deposition and due to erosion of interbed itself by same agent; interbed thins upstream and has no outcrop here.

"Basal flow"

Basalt--incompletely known from drill records, presumably of Priest Rapids lithology.

<u>Locality 19</u>

Section measured on slopes of Alder Ridge and Golgotha Butte in sections 3, 4, 9, 10, T.4 N., R.23 E., Klickitat County, Blalock Island quadrangle.

Unit	Description	Feet
WENAS BASALT FORMATION		
	No outcrop here, but about three miles west of Alder Creek, 77 feet of typical blocky Wenas outcrops in bluffs along south side of Alder Ridge crest, and the topographic expression indicates that about 50 feet more may be covered by talus at the base of the flow.	77+
SELAH FORMATION		
	Not well exposed at above locality, but the topographic expression indicates possibly 15 or 20 feet of Selah.	15?
YAKIMA BASALT-Priest Rapids member		
Sillusi flow		
(2)	Basalt--dark gray, red weathering, vesicular, jointed into slender columns, very fine-grained, finely porphyritic. Approx.	20
(1)	-----similar to above, vesicular at top, jointed into columns 4 to 8 feet thick.	60

296-1

Unit	Description	Feet
	Total measurable Sillusi	80
	Total probable Sillusi	100 ±
Umatilla flow		
(4)	Basalt--dark gray, red weathering, vesicular, rather massively jointed.	4
(3)	-----red, clinkery.	6-8
(2)	-----red weathered, slightly vesicular, jointed into slender columns.	15 296-2
(1)	-----dark blue-gray, red weathered, fine-grained, finely porphritic, sparsely vesicular, jointed into columns 4 to 8 feet in diameter, vesicular at base. Approx.	120
	Total Umatilla approx.	145
Mabton interbed		
	Sandstone--cream to tan, tuffaceous, cross-laminated in part, coarse to fine-grained, andesitic lithology, massive to thin-bedded, details not well exposed.	45-50
Basal flow(s)		
(2)	Basalt--dark gray, vesicular and red, clinkery; locally altered in top 15 feet to a green, stiff, clay-like material retaining vesicular structure.	25
(1)	-----dark gray, aphanitic, massively columnar, sheeted and cross fractured, base not exposed. Approx.	100 298-1
	Exposed basal flow(s) approx.	125
	Total exposed Priest Rapids approx.	400

Locality 20

Section measured in Glade Creek valley walls in northwest 1/4, section 20, T.7 N., R.23 E., Yakima County, Prosser quadrangle.

Unit	Description	Feet
WENAS BASALT FORMATION		
	Basalt--black, aphanitic, jointed into irregular blocks 6 to 8 inches in diameter, top eroded.	22
SELAH FORMATION		
	Sandstone--light gray, fine-grained tuffaceous; indicated by tuffaceous soil here and by outcrops farther down valley.	22
YAKIMA BASALT--Priest Rapids member		
Sillusi flow		
	(3) Basalt--dark gray, red weathering, vesicular, columnar.	20
	(2) -----similar to above, but more massively columnar and less vesicular.	50 292-1
	(1) -----dark gray, red weathering, jointed into columns 4 to 5 feet in diameter, aphanitic.	25
	Total Sillusi	95
Umatilla flow		
	(3) Basalt--dark gray, red weathering, vesicular at top, jointed into columns 8 to 10 feet in diameter and into slabs, aphanitic.	25
	(2) -----dark gray, red weathering, aphanitic, finely porphyritic, jointed into rather massive columns cut by arcuate, high angle platy jointing.	95
	(1) -----dark blue-gray, similar to above, but arcuate, platy jointing conceals columnar jointing almost entirely.	60
	Total Umatilla	180
Mabton interbed		
	Tuffaceous sediments--light gray, fine-grained, details poorly exposed, spring horizon below, baked at top. Approx.	25

Unit	Description	Feet
Basal flows		
	Basalt--dark blue-gray, vesicular, massively jointed, porphyritic (feldspars up to 1/4 inch long and some small clots), aphanitic, base not exposed. Exposed...	15
	Total exposed Priest Rapids	315

APPENDIX B

MAPS AND SECTIONS

(In pocket)

no pocket
May 15 1971
Coculo

VITA

William Norris Laval, the son of Mr. and Mrs. Carl F. Laval was born on January 27, 1922, at Seattle, Washington. He attended Roosevelt High School in Seattle and graduated in 1939. He received the degrees of Bachelor of Science in 1943 and Master of Science in 1948, from the University of Washington. His professional experience includes employment as a geologist with the United States Geological Survey, the United States Army Corps of Engineers, and Ebasco Services Incorporated.