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GEOLOGY OF THE SADDLE BUTTE QUADRANGLE
SOUTHEASTERN WASHINGTON

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
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MASTER OF SCIENCE

IN GEOSCIENCES-GEOLOGY

JUNE 1968

By

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ABSTRACT

The Saddle Butte Quadrangle lies in the southeastern corner of Washington, between $40^{\circ} 00'$ and $40^{\circ} 15'$ north latitude, and $117^{\circ} 15'$ and $117^{\circ} 30'$ west longitude. The area is slightly more than 172 square miles.

The quadrangle lies in the northernmost segment of the Blue Mountains physiographic sub-province. The Blue Mountains anticline crosses it about 6 miles north of the Washington-Oregon border. The crest of the anticline follows a broad arc, open to the south. Dips are steepest on the southern limb.

Four igneous rock units are recognized: 1. the Yakima basalt, 2. dikes, 3. the Grouse Creek diabase, and 4. Pliocene-Pleistocene volcanic rocks. In addition to the igneous rocks two sedimentary units are recognized: 1. lake beds of Eocene to early Pleistocene age, and 2. Pleistocene loess. The Yakima basalt covers most of the area, it was erupted from fissures which may be traced by the dikes which congealed in them. Extrusion of the Yakima basalt began in the early Miocene and continued into the late Pliocene. Shortly before the end of the volcanic activity the Grouse Creek diabase was emplaced. It is either a thick sill or a ponded flow. In the late Pliocene or early Pleistocene volcanism was renewed. Olivine basalts were erupted onto the surface of the Yakima basalt. Activity was confined to two centers around which low shield volcanoes were built.

At the time the olivine basalts were being extruded the Grande Ronde River was meandering across a broad flood plain. Sand and silts

of the lake beds were deposited on the plain, probably at the time when the olivine basalts dammed the canyon of the Snake River near Asotin.

Shortly after the formation of the lake beds the area was compressed along a north-south axis. This caused east-west-trending folds and minor faults to form. The deformation caused the rejuvenation of the Grande Ronde River. Subsequent rapid erosion trapped the river in its meanders.

During pre-Wisconsin time, loess was deposited over much of the area. It has since been removed from all but parts of the northern limb of the Blue Mountains anticline, Grouse Flats and parts of Mallory Ridge. The stratigraphic position of the loess indicates that it is part of the Palouse formation.

Two terraces in the Grande Ronde River Canyon indicate periods of aggradation. These probably coincided with the Clarkston stage of the Snake River. During this period 400 feet of sediment was deposited in the Snake River near Lewiston, Idaho, this was probably sufficient to cause aggradation in the Grande Ronde River Canyon.

INTRODUCTION

Purpose and Scope

The Saddle Butte Quadrangle was selected for study primarily because it contains volcanic rocks ideal for careful, detailed study, which had previously been mapped on a regional basis only. In addition, work in this area is needed to add to the general knowledge of the southeastern part of the state of Washington, that heretofore has largely been ignored. The purpose of the study is to determine the nature, extent and relationships of the rock units in the area. The study includes detailed mapping and some petrographic work on all the units exposed in the quadrangle.

Location

The study area is located in the extreme southeast corner of the state of Washington (fig. 1). The area extends from $40^{\circ} 00'$ north latitude, the Washington-Oregon border, to $40^{\circ} 15'$ and from $117^{\circ} 15'$ to $117^{\circ} 30'$ west longitude, encompassing slightly more than 172 square miles. It lies about 10 miles southwest of Clarkston, Washington and 12 miles west of the Washington-Idaho border. The area can be reached by several gravel roads from the north, east and northeast. Washington State Highway 3 enters the area in the southeast corner, where it crosses the Grande Ronde River $1/8$ of a mile before the river leaves the quadrangle. A network of roads within the area is maintained by the U. S. National Forest Service and the counties of Garfield and Asotin. These roads provide access to the area for fire protection, logging and ranching.

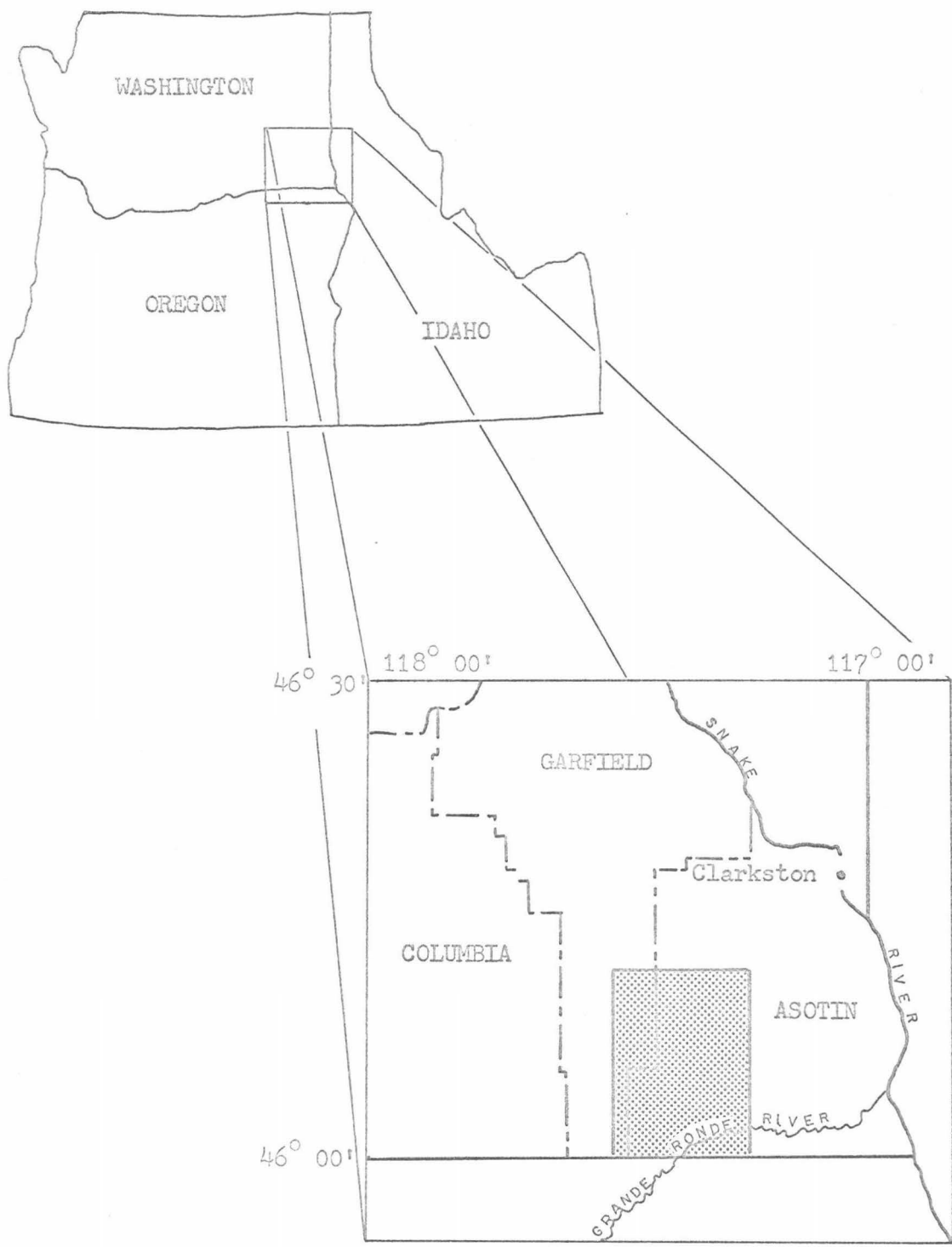


Figure 1. Index map showing the location of the Saddle Butte 15' Quadrangle, southeastern Washington.

Field Work

Field work was conducted during June, July and August of 1966 and June and July of 1967. Geologic units were mapped on an enlarged copy, scale equal to 1:31,250 of the U. S. Geological Survey quadrangle map of the area. Air photographs, on a scale of 1:54,000 aided in the interpretation and location of the various geologic features. Information was later transferred to a 1:1 copy of the quadrangle map, scale equal to 1:62,500, for inclusion in the thesis. Three stratigraphic sections were measured with Brunton compass and cloth tape. The thickness, lithology and distinctive features of each flow were recorded.

Previous Investigations

Russell (1897 and 1901) made the first studies of southeastern Washington and southwestern Idaho which included the area of this thesis. He presented some ideas on the regional structure and geology, which have been substantiated by later workers. His interpretations of the folds and faults of the area are accepted by recent workers.

Lindgren (1901) gives the general area a brief mention but adds no new data to that given by Russell. The 1901 report of Lindgren contains a map showing that rocks exposed in the area are mainly the Columbia River basalt and associated rocks.

Since Russell's and Lindgren's work there has been no direct reference to the Saddle Butte Quadrangle in the literature. The areas immediately to the east and northeast have been studied by many workers, including Fuller (1928), Lupper (1944), Lupper and Warren (1945), C. R. Hubbard (1956) and Waters (1961). Unpublished theses concerned with these same areas have been presented by Graham (1949), Strand (1949),

Laval (1956), and Hollenbaugh (1959). A study of the dikes in the lower Grande Ronde River canyon (Gibson, 1966) undoubtedly includes some from the Saddle Butte Quadrangle. Waters (1961) mentions a stratigraphic section measured in the canyon of the Grande Ronde River, but a precise location is not given.

Climate

The climate of southeastern Washington is semi-arid. The average annual rainfall in the area of Saddle Butte is about 16 inches, and 65 to 75 percent of this falls during the winter months. Upland areas of the Blue Mountains receive slightly more, almost all as snow, which accumulates to depths of several feet. Winter is characterized by cloudy weather with temperatures below freezing. Temperatures below 25° F are rarely recorded in the lower parts of the area; the higher elevations are typically cooler. The average annual temperature is 52° F, but temperatures above 100° are common in July and August. Rarely the temperature is as high as 111°, as it was during July of 1967.

Acknowledgments

The author wishes to express his gratitude to the following persons for their aid in his work: Dr. J. Stewart Lowther, for help in identification of fossils; Mr. A. S. Post, for providing ground transportation; Mr. A. B. Hubbard, for his assistance in the field, and Mr. Bogan, for his insights into the history and developments of the area. Mr. Bogan also advised on locations of camp sights and provided help in contacting local farmers.

STRATIGRAPHY

Introduction

More than ninety-five percent of the rocks exposed in the Saddle Butte Quadrangle are flows of the Yakima basalt and associated dikes. A thick diabase unit within the Yakima basalt crops out in the middle reaches of Grouse Creek. Sedimentary rocks are confined to small areas of lake beds of Tertiary age, exposed in the southwestern part of the quadrangle. Younger rocks include Pleistocene basalts in the central part of the map area. Much of the northern limb of the Blue Mountains anticline is mantled with a thin layer of Pleistocene loess.

Yakima Basalt

Russell (1901) gave the name Columbia River basalt to the lavas of the Pacific Northwest. Still earlier in 1893 he described these basalts under the name of Columbia River lavas. In 1901 Merriam and Smith, working independently in different parts of the region underlain by the basalts, reached the conclusion that the term Columbia River basalt included rocks of such diverse age and petrography that in detailed mapping lavas of different ages must necessarily be separated. Smith (1901) introduced the term Yakima basalt for lavas of Miocene age. Since that time the names Columbia River basalt and Yakima basalt have been used interchangeably for Miocene basalts of the Pacific Northwest.

Because of the diverse petrographic nature and ages of basalts exposed in the John Day Basin Waters (1961) suggested that the name Picture Gorge basalt be used for older flows directly overlain by the Mascall formation, a sequence of fluvial and lacustrine beds of Middle to Upper Miocene age. He also suggested that the term Yakima basalt be

reserved for younger flows of Miocene age, which unconformably overlie the Mascall formation and the Picture Gorge basalts in the John Day Basin. At the same time he suggested that the name Columbia River basalt be changed to group status in the form of "Columbia River Group". This two-fold division of Russell's Columbia River basalt has been recognized by Bond (1963) in the Clearwater Embayment in Idaho and by Ptacek (1965) in the Seven Devils region of Idaho. The U. S. Geological Survey has since formally recognized the term Columbia River Group to include the Picture Gorge basalt and the Yakima basalt as suggested by Waters in 1961 (Thayer and Brown, 1966).

Because the petrologic and field characteristics of the basalts exposed in the Saddle Butte Quadrangle are strikingly similar to those of the Yakima basalt as defined by Waters (1961), the name Yakima basalt will be used in this report for basalts of Miocene to early Pliocene age. These basalts are also very much like the "Upper" basalt of Bond (1963), who tentatively correlated them with the Yakima basalt. These similarities and the proximity of the area to the Clearwater Embayment support this usage.

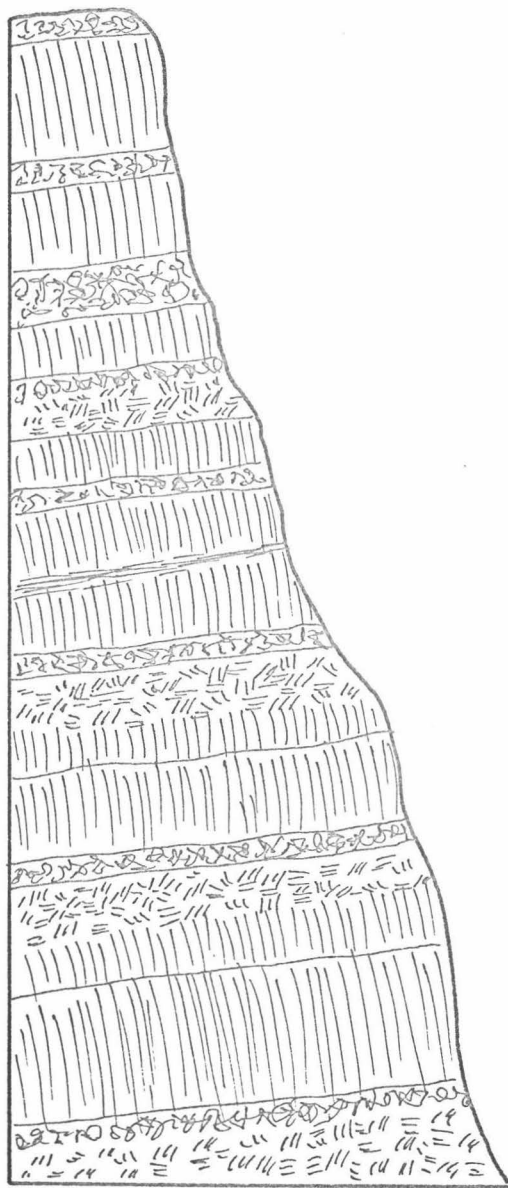
The age of the Yakima basalt has been established as late Miocene to early Pliocene. This age is based on fossil evidence primarily compiled by Knowlton (1926) and Berry (1927). Potassium argon dates obtained by Gray and Kittleman (1967) show that extrusion may have extended over a period of eight million years, the upper flows being as young as the late Pliocene.

Saddle Butte lies immediately south of the Columbia River Plateau, and several miles west of the Clearwater Embayment; hence it is assumed

that, although there is no basement exposed in the quadrangle, the pre-basalt surface shared in the high relief demonstrated in these areas (Russell, 1897; and Anderson, 1930). Later flows have completely buried the pre-basalt surface under at least 2,000 feet of lava. The nearest outcrops of basement rock are Steptoe Butte and the Ringold Hills to the north (Strand, 1949) and in the Snake River Canyon twelve miles east of Little Butte (Russell, 1897).

The Yakima basalt is the largest mappable unit. It underlies the entire quadrangle. Locally it is overlain by basalts of Pliocene-Pleistocene age and alluvium. A section 2,000 feet thick was measured in the walls of the North Fork of Asotin Creek, east of Pinkham Butte (pages 8,9 and 10). A continuous section at least 2,100 feet thick is exposed in a small tributary of the West Fork of Wenatchee Creek (spelled Menatchee Creek on the U. S. Geological Survey quadrangle map).

Recognition of the Yakima basalt in the field is facilitated by the characteristic columnar jointing and the tendency for the denser parts of each flow to form prominent cliffs. The average thickness of the flows is seventy-eight feet, somewhat thinner than is found toward the center of the Columbia River Plateau. In the average flow exposed in the North Fork of Asotin Creek from 12 to 20 percent of the lava is scoriaceous, a much higher percentage than is common elsewhere in the Yakima basalt. The deviations in thickness and scoria percent may be due to the proximity of the Grande Ronde dike swarm, which Waters (1961) considers to be one of the major sources of the Yakima basalt. Such an



Flow # 18. 70' thick; top 25' scoriaceous; 45' of massive, dark gray, crudely columnar basalt.

Flow # 17. 56' thick; top 22' red scoria; 34' of fine grained, dark gray, columnar basalt.

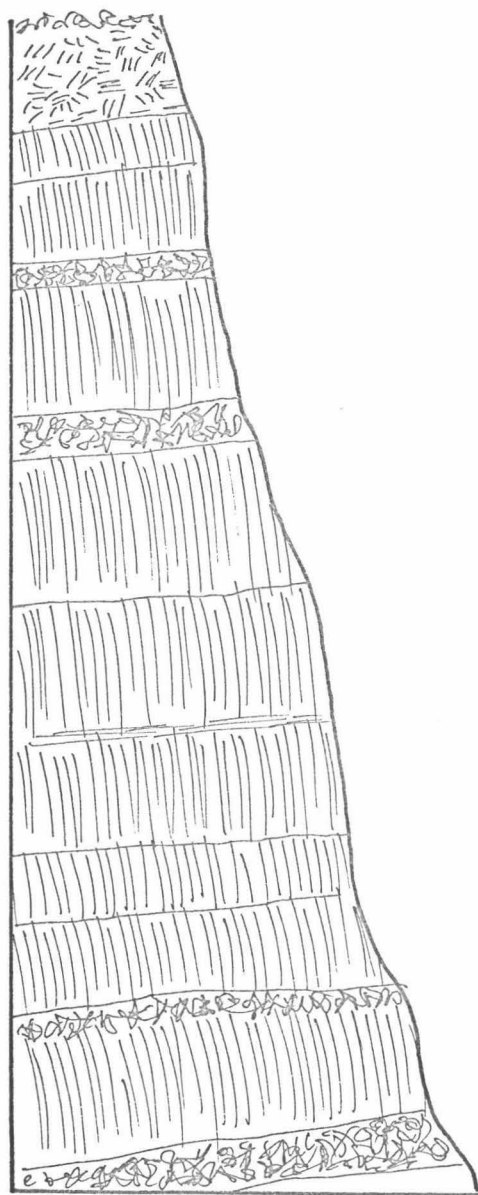
Flow # 16. 60' thick; top 34' reddish gray scoria; 26' of massive, fine grained, dark gray basalt.

Flow # 15. 64' thick; 40' of scoriaceous to irregularly jointed basalt; 24' of massive dark gray basalt.

Flow # 14. 83' thick; 9' of red scoria; two tiers of crudely columnar dark gray to black basalt, top tier 22' thick, bottom tier 52' thick.

Flow # 13. 131' thick; 14' of reddish gray scoria, 50' of irregularly jointed gray basalt, 67' of fine grained, crudely columnar basalt.

Flow # 12. 102' thick; 60' of dark gray, irregularly jointed basalt, scoriaceous near top, 42' of fine grained columnar basalt.



Flow # 11. 89' thick; 64' of irregularly jointed basalt scoriaceous near top; 25' of crudely columnar, fine grained basalt.

Flow # 10. 57' thick; a single tier of crudely columnar basalt.

Flow # 9. 85' thick; a single tier of crudely columnar dark gray, fine grained basalt, highly vesicular to scoriaceous near the top.

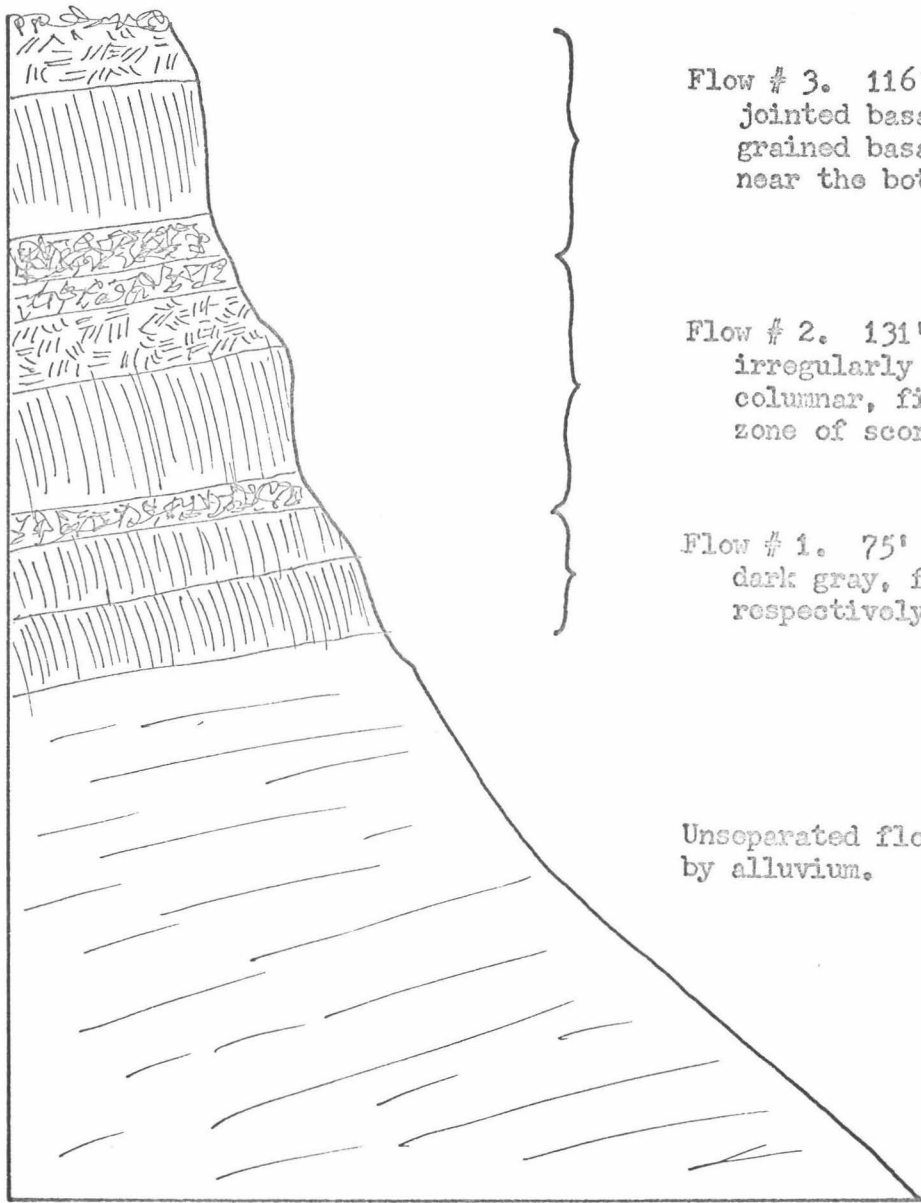
Flow # 8. 73' thick; a single tier of crudely columnar, fine grained, dark gray basalt.

Flow # 7. 131' thick; two tiers, 71' and 60' thick, of dark gray, fine grained basalt, massive to crudely columnar.

Flow # 6. 35' thick; a single crudely columnar tier.

Flow # 5. 40' thick; a single crudely columnar tier of fine grained, gray to black basalt.

Flow # 4. 115' thick; upper parts of the flow are scoriaceous, mostly dark gray, fine grained, crudely columnar basalt.



Flow # 3. 116' thick; 33' of scoriaceous to irregularly jointed basalt, 63' of columnar dark gray, fine grained basalt. 10' of scoriaceous, light red basalt near the bottom.

Flow # 2. 131' thick; 22' of red scoria, 30' of irregularly jointed basalt and 64' of crudely columnar, fine grained, dark gray basalt; lower zone of scoria 15' thick.

Flow # 1. 75' thick; two tiers of crudely columnar dark gray, fine grained basalt, 32' and 43' thick respectively.

Unseparated flows of Yakima basalt, mostly covered by alluvium.

assumption may be valid, as the last lava to issue from a vent has been partially degassed. Such lavas are more viscous and have a greater tendency to form scoriaceous aa surfaces.

Generally the lower portion of each flow is made up of one or two tiers of crudely formed columns, separated by a narrow zone of irregular jointing. Columns are usually from one to five feet across. An exceptional column twelve feet across is exposed in Warner Gulch, where the gulch joins the South Fork of Asotin Creek. The upper tier of columns is generally smaller than the lower, grading upward to irregularly jointed to massive basalt. Normally this zone is followed by a reddish-gray to bright red scoriaceous layer which continues to the base of the overlying flow.

In hand specimen the rock is seen to be a gray to nearly black, very fine grained basalt. In more than 90 percent of the flows, minute laths of feldspar set in a glassy mesostasis are visible to the naked eye. The lower portion of each flow is generally dense, grading upward into more vesicular rock. Near the top the flows are frequently bright red where groundwater and exposure to the atmosphere have oxidized some of the magnetite.

The most common response to weathering is the formation of a buff to reddish brown oxidized layer not more than a few millimeters thick. In general, as the top of the flow is approached the layer becomes thicker and redder until the scoriaceous zone is reached and the entire mass of the flow is affected.

Campbell (1950) reviewed the petrographic observations of several workers. He found that these studies showed the Columbia River basalt

to consist mostly of plagioclase, pyroxene, and glass. The plagioclase is calcic labradorite and accounts for 45 to 75 percent of the rock. Pyroxenes are commonly reported as pale brown augite and pigeonite. The glass is of two types, pale sideromelane and darker tachylite. Where present, olivine often shows a reaction relationship to the augite.

Accessory minerals most often reported are olivine, apatite, and magnetite. Alteration products frequently reported are iddingsite, palagonite, nontronite, chlorophaeite, and kaolinite.

Waters (1961), in a preliminary report on his study of the Picture Gorge and Yakima basalts, reported that his results agreed in general with those of previous workers as described by Campbell (1950). Bond (1961), working in the Clearwater Embayment also found that petrographically the basalts belonged to the Columbia River Group. Specifically, the "Upper" basalt of Bond is tentatively correlated with the Yakima basalt of Waters.

For the present study detailed petrographic examinations were made of four samples thought to be representative of the Yakima basalt in the map area. The results of modal analysis are presented in Table I. Photomicrographs of typical textures are shown in figures 2 and 3. Included in these are samples taken from the centers of two thick flows exposed in Warner Gulch (Ty-1) and Alder Gulch (Ty-2), in the northern part of the quadrangle. A third specimen comes from a thin flow exposed in George Creek, north of Little Butte (Ty-3). The fourth sample is from the flow directly overlying the Grouse Creek diabase where it is exposed in the cliffs above the Lake beds in Grouse Creek (Ty-4).

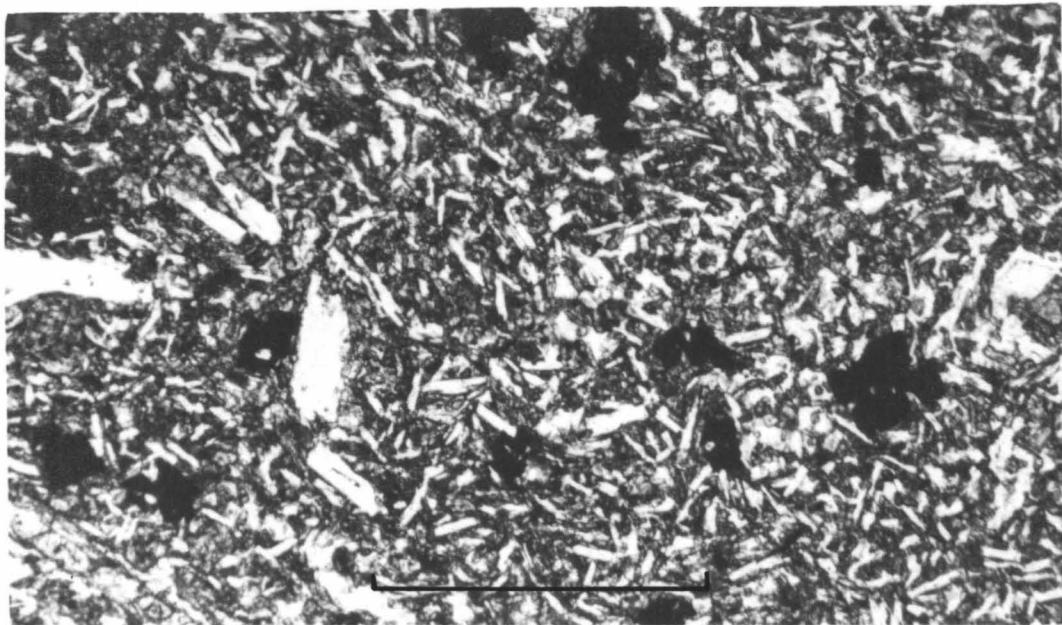


Figure 2. Photomicrograph of the Yakima basalt, sample no. Ty-1. Plagioclase phenocrysts in a groundmass of augite, glass and serpentine. Augite ophitically surrounds some of the plagioclase.

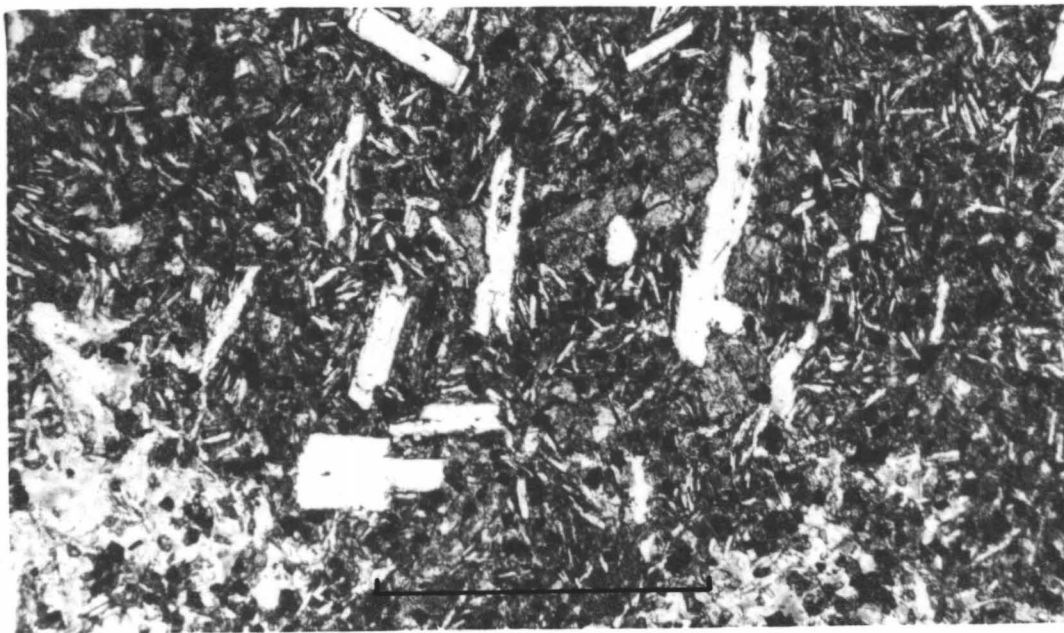


Figure 3. Photomicrograph of the Yakima basalt, sample no. Ty-2. Plagioclase phenocrysts in a groundmass of plagioclase, augite, and glass.

TABLE I. MODES OF THE YAKIMA BASALT

Sample Number	% Plagioclase	% Monoclinic pyroxene	% Glass	% Magnetite	% Olivine	% Other	Ab-An ratio
Ty-1	56	24	6	11	2	1	37:63
Ty-2	57	34	3	5	0	1	32:68
Ty-3	48	30	9	8	3	2	34:66
Ty-4	48	37	5	5	3	2	39:61

The specimens selected for detailed study were chosen after examination of 60 thin sections. All of the sections appear to be similar in mineralogy and texture to those given close examination.

The petrographic study shows that the basalts of the Saddle Butte Quadrangle are part of the monotonously uniform tholeiites of the Columbia River Group described by Waters (1955). The mineralogy and textures of the basalt flows are generally in agreement with the observations compiled by Campbell (1950) and Waters (1961). Grain size is variable, ranging from very fine to medium, the average centers around 1 millimeter.

Plagioclase of the Yakima basalt is calcic labradorite. The albite:anorthite ratio varies between $Ab_{39}:An_{61}$ and $Ab_{32}:An_{68}$. Well formed laths displaying distinct albite twinning are the predominant form.

In thin section the pyroxenes are honey colored to pale brown. Larger crystals are optically positive and have a 2V of 40° to 45° . Many of the smaller crystals have a positive 2V less than 15° . Those pyroxenes with a 2V larger than 15° are considered to be augite. The smaller crystals with the lower 2V have been identified as pigeonite. For the purpose of determining the percentage of each mineral present, the augite and pigeonite have been grouped together. The ratio of plagioclase to monoclinic pyroxene is about 2:1. Plagioclase nearly always forms about 50 percent of the rock and the augite 25 to 30 percent.

Volcanic glasses, both sideromelane and tachylite, are abundant. Glass is the most variable constituent: it forms more than half the rock near the flow contacts. The glass content decreases toward the center of each flow but it is never entirely absent.

Only minor amounts of olivine were found in the Yakima basalt. Its normal occurrence is as rounded relict grains commonly completely surrounded by thick reaction rims of augite. Reddish-brown and green to orange alteration products, identified as iddingsite and chlorophaeite, are common. In most flows the olivine if ever present has reacted completely to form augite.

Magnetite is invariably an important component. It is often present in amounts of about 10 percent. It is common as euhedral crystals and as finely divided dust-like particles. The mineral often forms rims and stringers of small grains around the borders and along fractures in the ferromagnesian minerals. Frequently the minute dust-like grains are so numerous in the glass as to render it almost opaque.

Other minerals observed include apatite, primarily as inclusions in the plagioclase, and rims of palagonite (?) surrounding a few grains of glass. A single case of calcite filling a vesicle was observed.

Microscopic examination of the flows indicates that they are probably equivalent to the Yakima basalt of Waters (1961) and the "Upper" basalt of Bond (1963). Positive correlation cannot be made without further study, including chemical analysis, because of the similarity of the Yakima and Picture Gorge basalts.

Textures range from hyaloophitic to hypocrystalline. Laths of plagioclase surrounded by slightly smaller crystals of augite are

frequently observed (fig. 2 and 3). Both minerals are set in a mesostasis of olivine, magnetite, glass, pigeonite and small crystals of plagioclase and augite.

Dikes

Dikes which presumably fed flows of the Yakima basalt were first reported in southeastern Washington by Russell (1897). Since that time it has been shown that a large number of dikes occurs in northeastern Oregon and adjacent parts of Washington (Russell, 1901; Lindgren, 1901; Fuller, 1927; Waters, 1950, 1961; and Gibson, 1966). Most dikes in this region are grouped within an area 45 miles long and 10 to 20 miles wide. This cluster of dikes has been named the Grande Ronde dike swarm (Waters, 1961). The dikes are 10 to 70 feet wide and strike approximately 30° east of north. Connections of the dikes to the flows they fed are rare. Fuller (1928) and Waters (1961) have reported examples of connection of the dikes to the flows in the Grande Ronde dike swarm. No connection of dikes to the flows were seen in the study area.

At least 18 dikes of the Grande Ronde swarm are exposed in the mapped area. With one exception the dikes crop out in the canyon walls and do not appear to penetrate the entire thickness of the Yakima basalt. The dikes generally strike 18 to 20° west of north, in contrast to the northeast strike of the dikes in the Oregon part of the swarm. The dikes exposed in the canyons cutting the Blue Mountains anticline range from 10 to 60 feet in width, and in several instances they can be traced for more than a mile. They are concentrated in the eastern part of the map area, forming a diagonal zone of high concentration beginning in the southeastern corner and extending beyond the northern border of

the quadrangle. A single dike occurs along the western edge of the area, in the East Fork of First Creek, but its location, high olivine content, and penetration of the entire sequence of the Yakima basalt suggest that it belongs to a later period of volcanism.

Dike rock is typically dense, dark gray to black. Near joints it is slightly altered, being lighter in color and softer. Vesicles are rare in most dikes. Where they are present they are small, about 0.5 mm in diameter, and nearly spherical. Most vesicles are empty, but a few are filled with limonitic material or chlorophaeite. Grain size is usually slightly larger than in the associated flows, probably as a result of slower cooling.

Two distinct patterns of jointing are exhibited by the dikes. The predominant form is parallel stacks of columns perpendicular to the contacts of the dike (fig. 4). Much less commonly, the columns are perpendicular to the contacts near the margins of the dike, but curve upward within the body of the dike until they are nearly parallel to the contacts at the center (fig. 5). The two sets of joints from the opposite sides of the dike join along a plane marked by thin plates of basalt parallel to the contacts. This type of jointing is commonly called chevron jointing when it occurs in flows (Baily, 1922; Spry, 1962).

The first type of jointing is easily explained by formation of the columns perpendicular to the cooling surfaces of the dike (James, 1920; Jaeger, 1961; Spry, 1962). Under normal conditions a dike would cool inward from both margins producing columns perpendicular to the contacts.

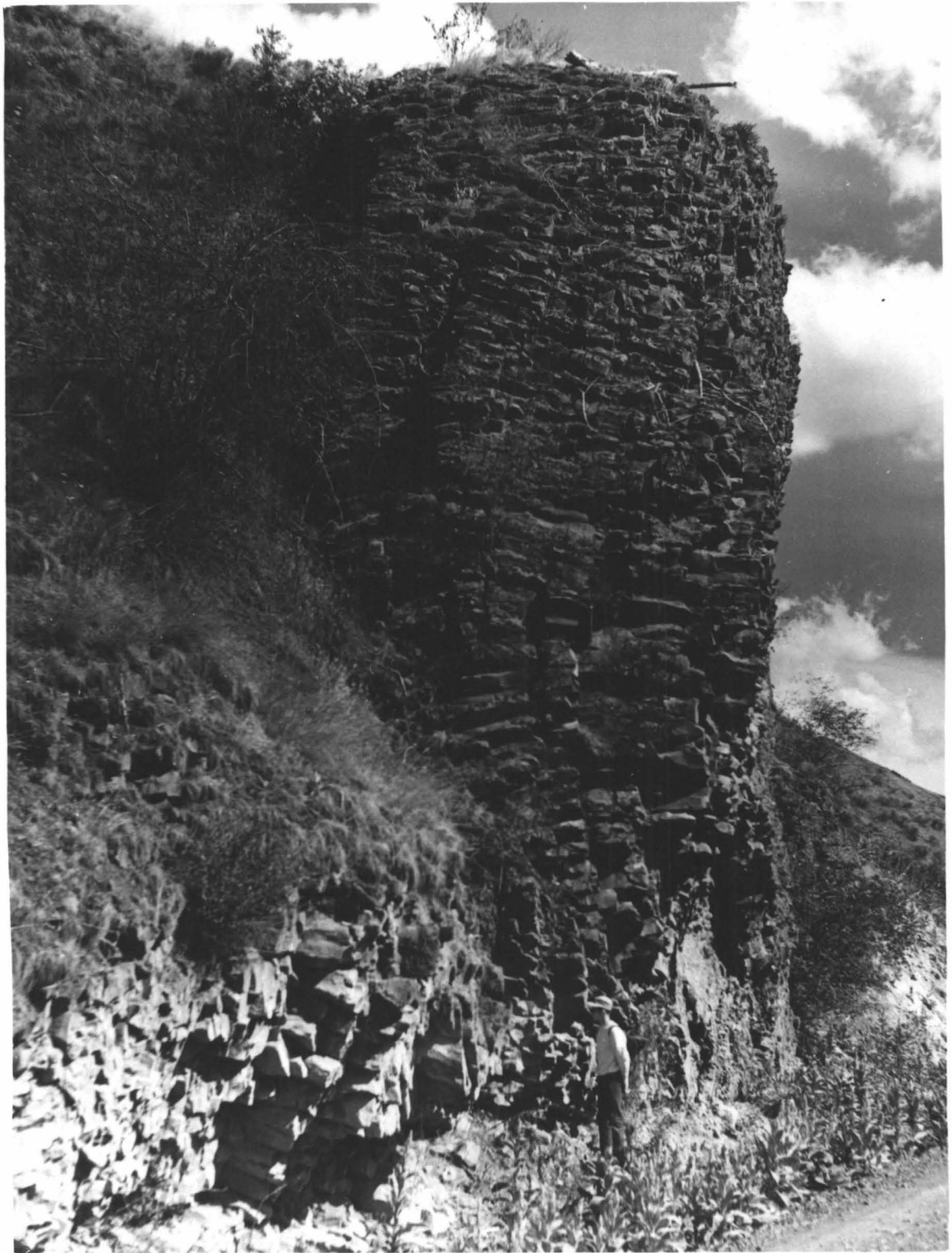


Figure 4. Dike in the South Fork of Asotin Creek showing stacks of columns perpendicular to the contacts with the surrounding flows.



Figure 5. Dike exposed in Cooper Canyon showing curved columns.

The second type of jointing poses a more difficult problem. If, as is commonly assumed, the columns are formed perpendicular to the cooling surfaces, it is necessary that these surfaces be at angles to the contacts. Construction of the isotherms perpendicular to the columns of the dike shown in figure 5 results in the configuration shown in figure 6. Such a configuration obviously requires the dike to become cooler with depth.

J. C. Jaeger (1961) derived isotherm configurations for a number of irregularly shaped igneous bodies. His results for an extrusive sheet with a feeder of equal thickness (fig. 7) shows a hot spot at the junction of the flow with the feeder. This hot spot extends downward to a depth approximately equal to the width of the feeder. If such a hot spot were to extend downward into the feeder considerably farther than the analyses suggest, then the chevron jointing in the Saddle Butte dikes could represent the top hundred or so feet of the dikes.

If the chevron jointing does indicate the proximity of the dike to the flow it fed, then the first type of jointing should be exhibited in the lower portions of the dike. A single case of change from type one to chevron jointing was observed in a dike exposed in the North Fork of Asotin Creek, 1/8 mile east of the U. S. National Forest boundary. This dike is as much as 50 feet wide. The chevron jointing extends to depths of several times the average width.

An increase in the depth of chevron jointing in the dikes may result from drain back of lava into the feeder after a hot spot has

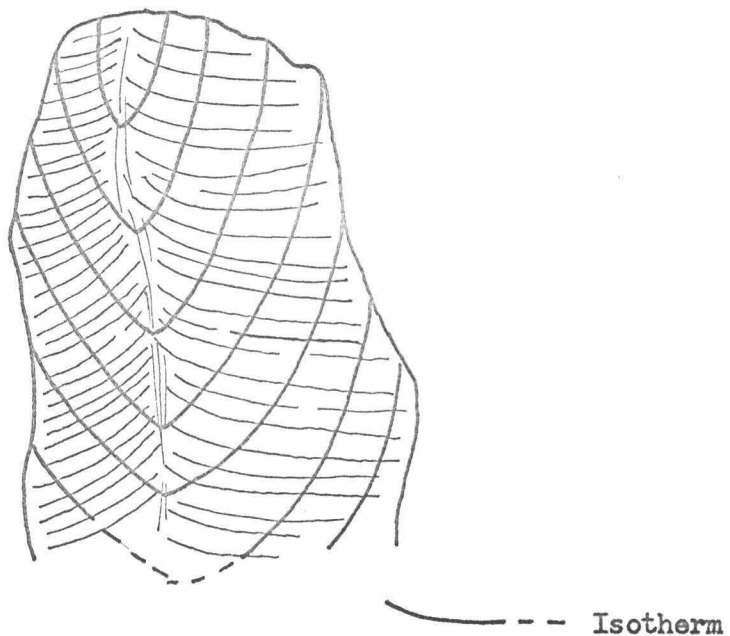


Figure 6. Hypothetical isotherms drawn perpendicular to the columns of the dike shown in figure 5.

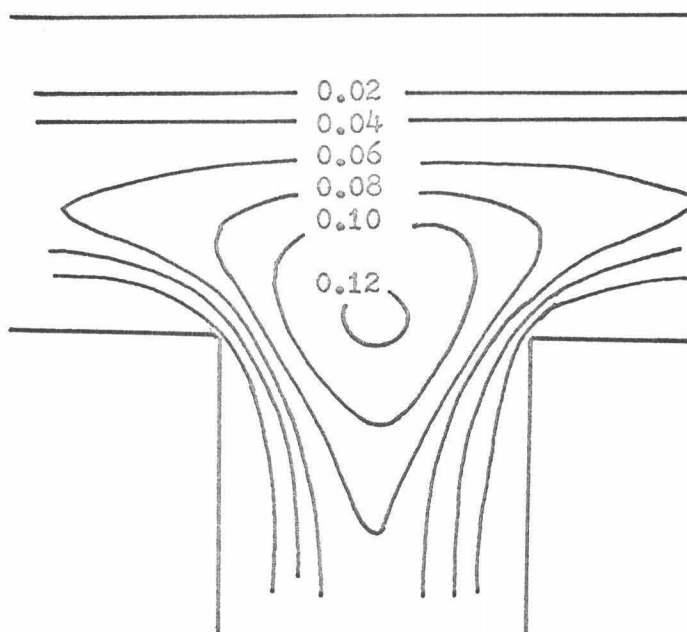


Figure 7. Numerically derived isotherms for an extrusive sheet with a feeder of the same thickness, after J. C. Jaeger (1962).

formed. This may help to account for the discrepancies between the numerical analysis of Spry and the observations made in the Saddle Butte Quadrangle.

Chevron jointing might also form if a small amount of upward movement occurred in the central portions of the dike after jointing had begun near the margins. In this case columns that had begun to form at right angles to the cooling surfaces would form perpendicular to planes of equal stress developed in the interior of the dike. A similar mechanism is cited by (Spry, 1962) to account for tilted columns in lava flows. If this is the mechanism by which the curved columns are formed, then chevron jointing should extend downward into the dikes indefinitely.

The dike rocks are petrographically similar to the Yakima basalt. The same minerals are found in the dikes as are found in the flows. Size of the mineral grains in the dikes is only slightly larger than those in the average flow.

At least one thin section from each dike exposed in the map area was given a casual examination. From these sections, four representative examples were selected for detailed study. Samples were taken from the central portions of each dike and, where possible, from near the contacts with the enclosing flows. Of the samples selected for careful study, the first is from the center of a dike exposed in Asotin Creek (D-1), the second from a dike in Charley Knight Gulch (D-2), the third sample comes from a dike exposed in the canyon of the Grande Ronde

River, about 1/8 mile west of the highway bridge (D-3), and the fourth (D-4) is taken from an unusually olivine-rich dike exposed in the East Fork of First Creek.

Mineralogically, the majority of the dikes are indistinguishable from flows of the Yakima basalt. The dike in the East Fork of First Creek contains unusual amounts of olivine. It is mineralogically similar to the volcanic rocks of Pleistocene age. Grain size in the dikes ranges from fine to medium, the average diameter is about 1.2 millimeters.

Plagioclase in all dikes is labradorite with a range in composition slightly less than that of the flows. The albite:anorthite ratio ranges from $Ab_{34}:An_{66}$ to $Ab_{32}:An_{68}$. Commonly laths several times the average grain size are accompanied by numerous much smaller laths. The albite:anorthite ratio is the same for both size groups.

Pyroxene crystals of the dikes exhibit much the same characteristics as those of the flows. Pale brown colors predominate: honey-colored pyroxenes are less common. The 2V of the larger crystals ranges from about 40° to slightly less than 50° . Smaller crystals commonly have a 2V less than 15° . The 2V is positive in both size groups. The pyroxenes have been identified as augite and pigeonite respectively.

As in the flows, volcanic glass is the most variable component. Samples taken from near the margins of the dikes generally contain more glass than samples from near the center. Both sideromelane and tachylite are present, tachylite predominating.

With the exception of the dike in First Creek, olivine is rare. It seldom accounts for more than 2 percent of the rock. Crystals are often

rounded and embayed. They are uniformly small. Thick reaction rims of augite frequently surround the olivine. Alteration is similar to that found in the Yakima basalt. Iddingsite, magnetite, and chlorophaeite are the most common alteration products.

Magnetite is present as euhedral grains and finely distributed dust. As in the flows, magnetite is often present in sufficient quantities to render much of the glass nearly opaque. Other minerals observed include apatite, as inclusions in plagioclase, and waxy alteration products of chlorophaeite.

Textures of the dike rocks range from hyaloophitic to subophitic. In many sections the rock is seen to be microporphyritic. Phenocrysts of plagioclase are often observed set in a mesostasis of finer plagioclase, augite, magnetite, and glass. Figures 8 and 9 show typical textures of the dike rocks.

The petrographic similarity of most dikes to the flows of the Yakima basalt is strong evidence that the dikes are feeders of the flows. The fact that none of them penetrate the entire sequence of flows supports this conclusion. Minor differences in grain size and texture can be accounted for by the slower cooling expected in the dikes. The exceptional dike in the East Fork of First Creek is thought, because of its high olivine content and penetration of every flow of the Yakima basalt, to belong to a later period of volcanism.

Grouse Creek Diabase

The Grouse Creek diabase, Tys, is a tabular body contained between flows of the Yakima basalt. The main area of exposure lies in the southwestern corner of the quadrangle. Here, the diabase is exposed

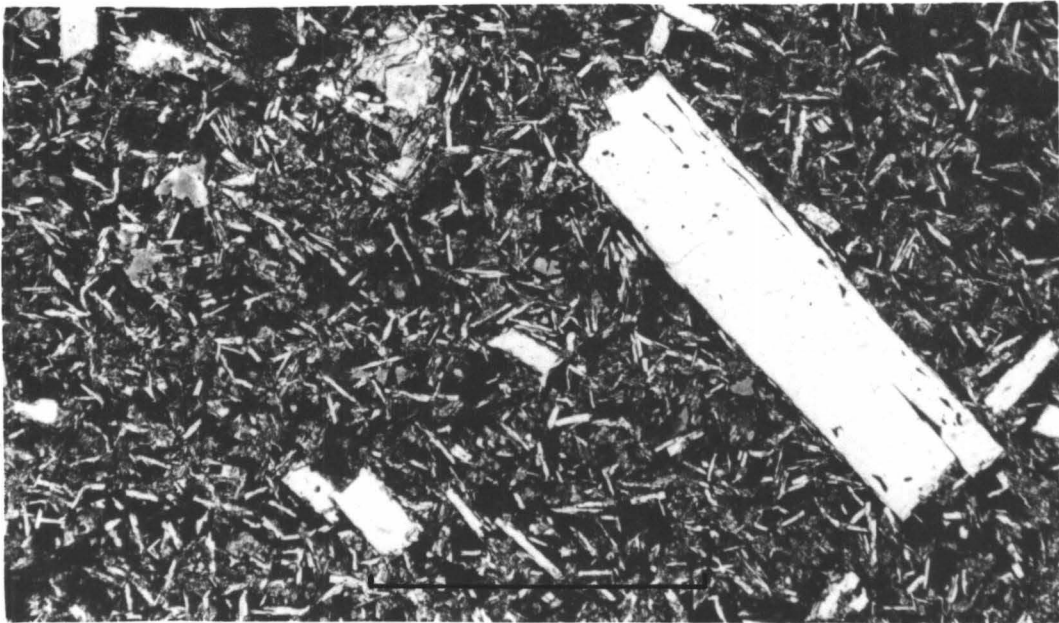


Figure 8. Photomicrograph of a dike, sample no D-2. Large phenocryst of plagioclase in a groundmass of augite, magnetite and glass. Groundmass is intersertal to subophitic.



Figure 9. Photomicrograph of the olivine-rich dike in First Creek, D-4. The texture is hyalophitic.

TABLE II. MODES OF THE DIKES EXPOSED IN THE SADDLE BUTTE QUADRANGLE

Sample Number	% Plagioclase	% Monoclinic pyroxene	% Glass	% Magnetite	% Olivine	% Other	Ab-An ratio
D-1	43	31	1	23	1	0	34:66
D-2	49	35	7	7	2	0	32:68
D-3	30	18	7	42	2	1	32:68
D-4	62	13	1	10	12	1	34:66

in cliffs rising as much as 300 feet above the surface of the Tertiary lake beds. Total thickness of the unit, including outcrops above and below the Tertiary lake beds, is about 500 feet.

Lower portions of the unit exhibit well-formed columns up to 2 feet across. The average diameter of the columns is about one foot. Most of the columns are nearly vertical. Exposures of the diabase in Medicine Creek near Mountain View School exhibit columns up to 25 feet long. Columns in the outcrops nearest the bottom of the unit depart from the vertical by as much as 10 to 15 degrees.

Jointing in the upper half of the diabase, about 250 feet above the lower contact, is much more complex. It closely resembles the jointing in the entablatures of many thick lava flows. Nearly all of the forms of jointing described by Spry (1962) are exposed in the cliffs above the lake beds. The major difference between the jointing of the diabase and the flows is the scale. The forms in the diabase are much larger than is common in flows. Figure 10, shows the jointing of the Grouse Creek diabase in the cliffs along Grouse Creek.

The most frequent form of jointing is dike-like stringers of horizontal columns cutting across the entire thickness of the exposure. The cross-cutting character of these joint units suggests an origin similar to that of dikes. They may have formed as the result of auto-intrusion of liquid magma from lower portions of the unit into the solidified upper portions.

The origin of the more complex forms of jointing is obscure. Tomkeieff (1940) related the formation of similar forms in the



Figure 10. The Grouse Creek diabase. Unusual joint patterns of the upper 200-300 feet exposed in cliffs above the Lake beds along the middle reaches of Grouse Creek.

entablatures of flows to regions of rapidly moving isotherms. Spry (1962) accounted for the complex jointing of the entablatures to tensile stresses produced in the flows when the core solidified.

The position of the complex jointing in the diabase is at the top, whereas the entablature of a flow is a considerable distance below the top. This contrast of position casts considerable doubt on the validity of the comparisons made in the last paragraph. It may be that the joints are the result of complex auto-intrusion and currents within the upper portions of the unit.

In order to determine the exact nature of the diabase several thin sections were examined. Of a total of 14 sections, three were selected for detailed study. The slides selected for further study are representative in mineralogy and textures of the unit as a whole. Results of modal analyses are shown in Table III.

Microscopic study of the Grouse Creek diabase shows it to be mineralogically similar to the Yakima basalt. All the minerals found in flows of the Yakima basalt are present in the diabase. In addition, small amounts of alkali feldspar are present. The grain size is highly variable. Some parts of the upper portions are exceedingly fine with average grain size less than 0.2 mm. In other samples the grains reach 4 mm in diameter. Often the average diameter lies between 2 and 3 mm.

Plagioclase, with an albite:anorthite ratio of $Ab_{37}:An_{63}$ to $Ab_{32}:An_{68}$, forms the bulk of the rock. The most common form is laths of variable size surrounded by pyroxenes of the same average size. Laths

of plagioclase are sometimes clustered in masses several times the diameter of the average grains. The clusters are surrounded by grains of pyroxene and magnetite.

Alkali feldspar occurs as interstitial crystals. It is clear and unaltered. Extinction often occurs as a dark band moving across the crystal as the stage is rotated.

Pyroxenes are pale honey-colored to light brown, much the same as those found in the Yakima basalt. The $2V$ varies between 40° and 50° in the larger crystals. In many of the smaller crystals the $2V$ is less than 15° . The pyroxene grains have been identified as augite and pigeonite, based on measurement of the $2V$. Many of the pyroxene crystals are subhedral and exhibit good cleavage in contrast to the poor cleavage displayed by pyroxenes of the Yakima basalt. Plagioclase:pyroxene ratios are seldom as high as 2:1. Pyroxene commonly forms about 30 percent of the rock and the plagioclase about 45 percent.

Occurrence of the olivine in the diabase is much the same as in the flows. The mineral seldom exceeds 3 percent of the rock. Crystals are nearly always rounded and rimmed with augite. Crystal boundaries are often marked by lines of dust-like grains of magnetite.

Magnetite always forms a significant percentage of the rock. Its prevalent form is as inclusions in plagioclase and the pyroxenes. Minute grains are commonly scattered throughout the entire rock.

Other minerals observed are chlorophaeite and iddingsite surrounding some olivine grains. Chlorophaeite is also present as intersertal grains. Traces of apatite are present as inclusions in many of the plagioclase crystals.

Sideromelane, largely altered to palagonite, is present in amounts up to a few percent. Numerous inclusions of magnetite made determination of the refractive index impractical.

The striking resemblance of the mineralogy of the Grouse Creek diabase to the flows of the Yakima basalt strongly suggests a common parent magma for both rocks.

Texture and fabric of the diabase are widely variable. Examples of the most common are shown in figures 11 and 12. In the lower portions of the unit the grain size is consistently coarse: crystals up to 4 mm across are not uncommon. In the upper portions of the unit the grain size is highly variable. Some of the specimens require examination with a hand lens to discern the individual grains, in others the average grain size is as large as that found in lower portions of the unit. Fine grain size is commonly associated with the dike-like joint units cutting the upper parts of the diabase (fig. 10). Textures range from intersertal to subophitic. Locally glomeroporphyritic textures were observed.

The exact origin of the Grouse Creek diabase is not known. The position of the unit within the Yakima basalt and its petrographic similarity suggest a common parentage. The unit may be either a sill intruded between flows of the Yakima basalt or an unusually thick flow. The limited extent of the unit requires that any flow be dammed in some manner to attain the unusual thickness displayed by the diabase.

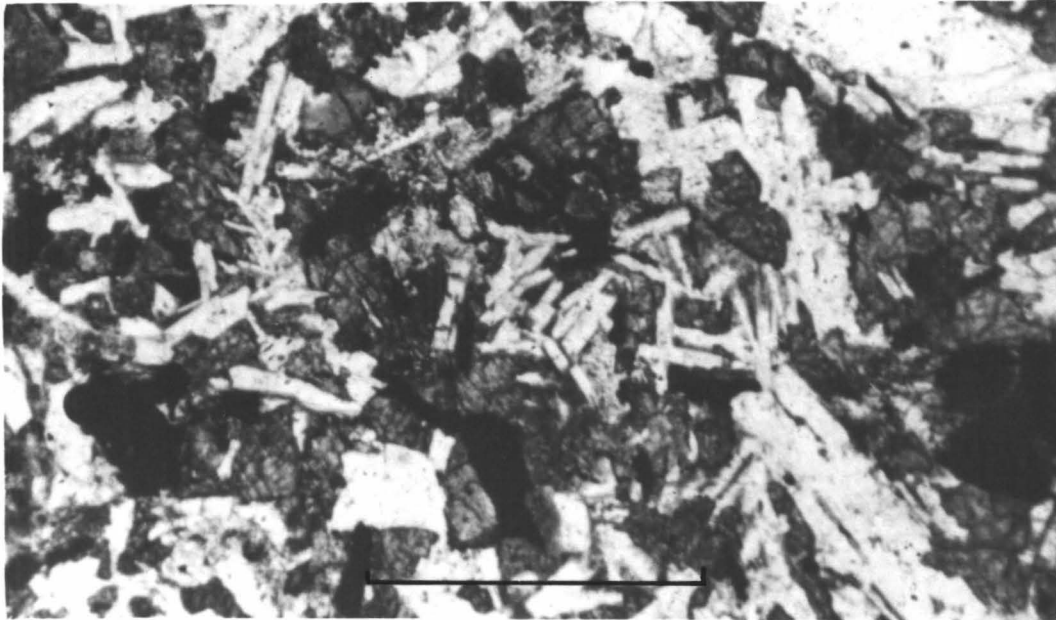


Figure 11. Photomicrograph of the Grouse Creek diabase, sample no. Gc-3. Subophitic to intersertal texture, sometimes poikilitic.



Figure 12. Glomeroporphyritic texture in the Grouse Creek diabase, sample no. Gs-1. Clumps of plagioclase in a mesostasis of augite.

An intrusive origin for the unit is favored because of its limited extent and great thickness. The case for intrusion is favored by the lack of vesicles near either of the contacts. Unfortunately, neither the upper contact nor the lower contact is exposed.

The similarity of the jointing in the upper half of the diabase to that in some flows favors an extrusive origin for the unit. If the diabase was originally much thicker, the jointing would be directly analogous to that described by Spry (1962). This would, however, require extensive erosion to remove the top of the flow. The unusual thickness would require damming of the flow. Since the diabase lies near the top of the Yakima basalt, it would have been extruded on a fairly flat surface formed by previous flows, therefore such a dam is highly unlikely. The lack of previous erosion demonstrated by the flat contacts with the flows above and below the diabase make an extensive valley fill improbable. Further, the parallelism of flows above and below the unit indicates no major deformation that could account for damming of the flow.

Although it is impossible to determine which of these two hypotheses accounts for the Grouse Creek diabase, the writer believes its probably a sill for the reasons outlined above.

Lake Beds

The lake beds are composed of poorly consolidated sandstone, siltstone and claystone which overlies parts of the Grouse Creek diabase. They are confined to a bench from a few feet to slightly over a mile wide, cut in the diabase by the ancestral Grande Ronde River prior to uplift of the Blue Mountains. The upper surface of the Grouse Creek

TABLE III. MODES OF THE GROUSE CREEK DIABASE

Sample Number	% Plagioclase	% Monoclinic pyroxene	% Glass	% Magnetite	% Olivine	% Other	Ab-An ratio
Gc-1	39	30	15	12	3	1	32:68
Gc-2	52	37	1	5	3	2	34:66
Gc-3	55	31	4	6	2	2	37:63

diabase, which underlies the sediments, appears to rise to the north at about the same rate as the present surface. The lake beds never exceed about a hundred feet in thickness. Remnants of the sediments are found plastered against the diabase up to four hundred feet above the contact with the Grouse Creek diabase, but erosion since the time of deposition has reduced the average thickness to less than 50 feet.

The sediments consist of alternating layers of medium to coarse quartz sandstone containing some olivine, and interbeds of siltstone and thinly laminated claystone. There appears to be no regular sequence to the beds. In the lower parts of the unit sandstones tend to predominate, followed by ever increasing proportions of well bedded siltstones. Typically the beds are only a few feet thick, and they are never more than 10 feet.

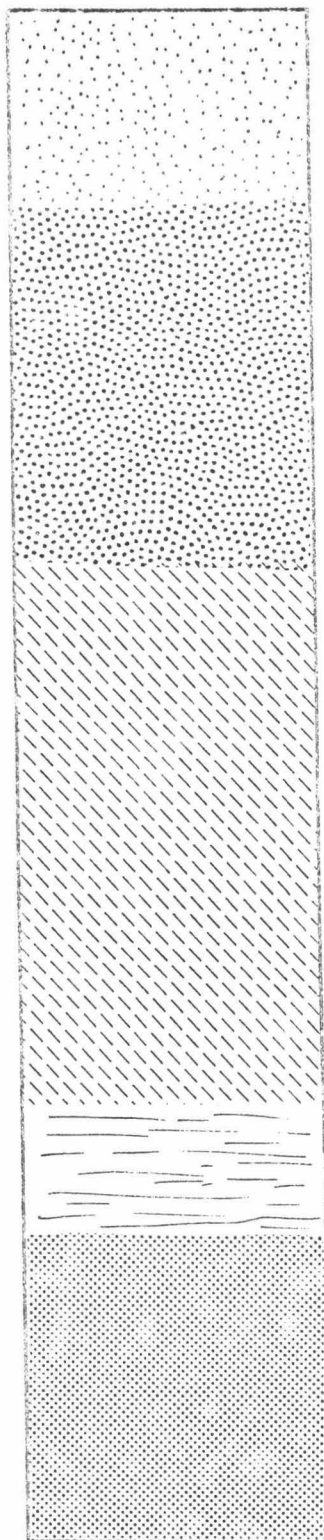
The middle beds of the sequence are generally more ashy than the lower ones. Beds of structureless ash up to 15 feet thick are exposed in road cuts in the upper part of Cougar Creek. The coarser beds of the central part of the sequence show poorer sorting than do the sandstones of the basal beds.

Beds forming the upper portions of the section are predominantly sandstone. The average grain size of the upper sandstones is smaller than that of the lower sediments. Unlike the basal sandstones these rocks show strong cross-bedding. This indicates a change in the depositional environment from quiet water to running water.

A generalized columnar section compiled from scattered outcrops is given in (fig. 13). The thickness of each member is estimated from the elevations of the various outcrops. Actual thicknesses were not determined because of the lack of continuous outcrops.

Locally, siltstones and claystones of the central part of the section contain fossil angiosperm leaves and stems, possibly of Miocene to early Pleistocene age. These fossils (fig. 13) have been tentatively correlated with floras described from the Latah formation (Berry, 1929; Knowlton, 1926; Chaney and Axelrod, 1959). The fossils were taken from white ashy siltstones and claystones. The fossiliferous beds are exposed in road cuts along the western margin of the lake beds below Grouse Flats. The weathered condition of the surface results in numerous fractures perpendicular to the bedding. As a result, many of the fossils are fragmentary and difficult to identify.

The age indicated by the fossil leaves in the lake beds is necessarily inconclusive. The fragmentary nature of the fossils, and the state of the knowledge of Tertiary angiosperms in general, do not permit accurate age assignments. The age span indicated by the plants has been shown by Gray and Kittleman, 1967, to be as much as eight million years. The youngest age the fossils can represent is early Pleistocene, the oldest, middle Miocene. The position of the lake beds on the Grouse Creek diabase indicates that a late Pliocene to early Pleistocene age is probably more nearly correct.



70 to 80 feet of fine to medium grained poorly consolidated quartz sandstone, strongly cross-bedded in the upper parts.

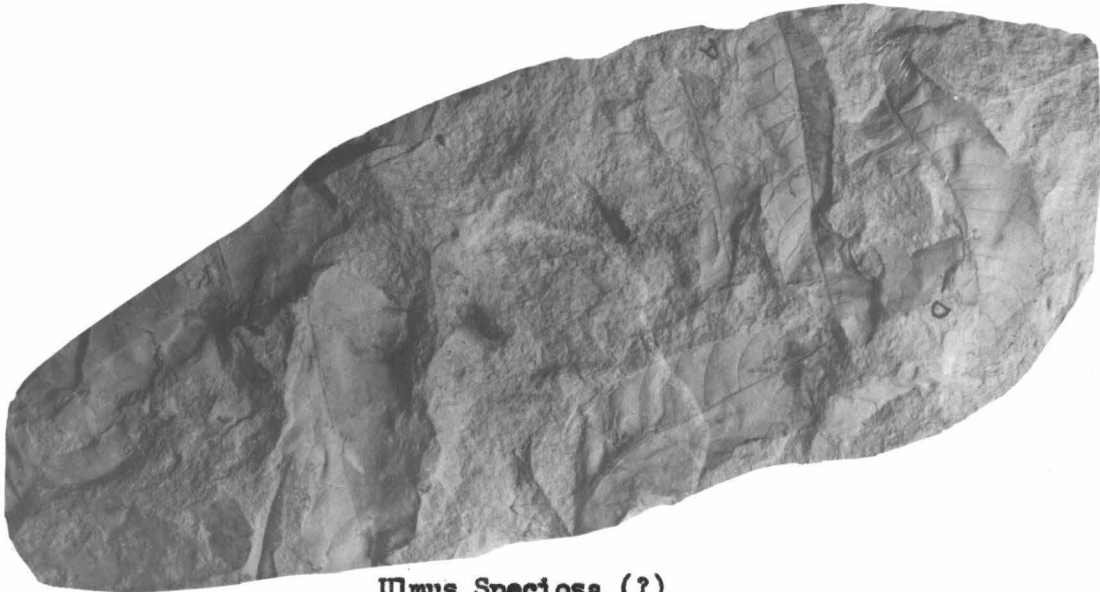
75 to 100 feet of medium grained quartz sandstone with ashy matrix. Interbeds of structureless ash

130 to 150 feet of massive ash, with occasional beds of siltstone and claystone. Some beds with quartz grains scattered throughout the ash.

25 to 30 feet of alternating finely laminated claystone and sandstone, some plant fossils.

60 to 75 feet of poorly consolidated medium to coarse grained, light brown quartz sandstone with minor amounts of olivine, some cross-bedding.

Figure 13. Generalized section of the Lake beds, compiled from scattered outcrops. All thicknesses shown are approximate.



Ulmus Speciosa (?)



Ulmus Speciosa (?)



Silix Hesperia (?) (Knowlton)

Figure 14. Fossil angiosperm leaves found in the Lake beds west of Grouse Creek. The leaves are late Miocene to early Pleistocene in age.

The sediments were probably deposited when the Snake River was dammed by Pliocene to Pleistocene lava flows down stream of the junction with the Grande Ronde. These lavas completely filled the canyon of the Snake and formed lake extending many miles up stream.

Pliocene-Pleistocene Volcanic Rocks (Younger Basalts)

Late Pliocene to early middle Pleistocene basalts were first described in southeastern Washington in 1928 by Richard Fuller. These are intravalley basalts exposed in the canyon of the Snake River between the towns of Asotin and Clarkston, Washington. Fuller considered the basalts to be the products of explosive eruptions from vents outlined by the present exposures. Later workers (Lupher and Warren, 1945; Graham, 1949; Hollenbaugh, 1959) have failed to confirm his conclusions. The basalts are now considered to be valley-filling basalts which flooded an old canyon of the Snake River in early Pleistocene time. To date no source for the intravalley basalts has been mentioned in the literature.

Basalts of similar occurrence to the intravalley basalts crop out along the eastern margin and across the central parts of the Saddle Butte Quadrangle. These basalts issued from two centers, Little Butte and Big Butte, around which they built low domical mounds (fig. 15). Farther from the centers of eruption the flows spread over the surface of the Yakima basalts as broad thin sheets. Immediately north of Little Butte the flows filled a 500-foot-deep canyon cut in the Yakima basalt.

The most important of the two centers of eruption is Little Butte. Although the shield volcano marking this vent is smaller than that of Big Butte, lavas of Little Butte spread farther over the surrounding countryside than did those of its larger neighbor. At least six flows



Figure 20. Blue Mountains anticline, view west from Sawtooth Ridge. The crest of the anticline is just south of Saddle Butte.

are known to have issued from Little Butte. The exact sequence of eruption of the flows cannot be definitely determined because of the heavy forest growing on most of the shield.

The most voluminous flows from Little Butte are dense, dark gray to black basalts. The summit of the shield is occupied by a red breccia surrounded on the west, north and east by a black glassy basalt. A thin flow of reddish-purple basalt issued from the southern flank of the shield, about 100 feet below the present summit.

As nearly as can be determined the first flow to issue from the Little Butte volcano is a light-gray to black medium-grained basalt. This flow is exposed along a narrow strip on the northeast slope of the shield. The surface of the flow is covered by a thick forest soil. No good samples could be obtained for microscopic study. Examination of pieces of float with a handlens shows the rock to be a medium to fine grained olivine basalt. Crystals of plagioclase and augite are also identifiable.

The eruption of the light gray basalt was followed by a much more voluminous flow of olivine basalt, the Coombs Canyon basalt. This flow, named for the canyon above which it is best exposed, forms most of the lower northeast slopes of Little Butte. Outcrops of the Coombs Canyon basalt extend in a low cliff around the southern flank of the shield. It is found directly underlying the Alder Gulch basalt, a later flow, on Smiley and Tripple ridges, several miles west of the vent. The rock is greenish-gray and weathers to a greenish-tan color which serves to distinguish it in the field from other flows of Little Butte and from the Yakima basalt.

Immediately overlying the Coombs Canyon basalt on the southern slopes of Little Butte is a small flow of reddish-purple basalt, known as the Red basalt, Rbf. The time interval between eruption of the Coombs Canyon and the Red basalt was probably short. The contact is exposed on the southern slopes of the volcano and shows no soil zone developed between the flows. Outcrops of the Red basalt extend in a low cliff westward along the southern slopes of Little Butte for about one and a half miles.

Directly overlying the Red basalt on the western slopes of Little Butte is the Alder Gulch basalt, Tag. This is the largest flow known to have been erupted from the volcano. The Alder Gulch basalt flowed northward for at least three miles, filling a canyon cut 500 feet into the Yakima basalt. Outcrops of the basalt are found as far as six miles west of the vent.

V-shaped valley fills of the Alder Gulch basalt are exposed on the walls of George Creek, directly north of Little Butte (fig. 16) and in Coombs Canyon $\frac{1}{2}$ mile south of the confluence of the two streams. These outcrops are characterized by basal zones of irregularly jointed basalt giving way upward into strongly columnar basalts (fig. 17). Above the columnar portion is a zone of hackly jointing.

The eastward extent of the Alder Gulch basalt is not known. The heavy forest cover and inaccessibility of the area immediately east of the map boundary made determination of this information by rapid reconnaissance methods impractical.

The upper 250 feet of the slopes of Little Butte are composed of a black, glassy basalt, here called Little Butte basalt, Tlb. This flow

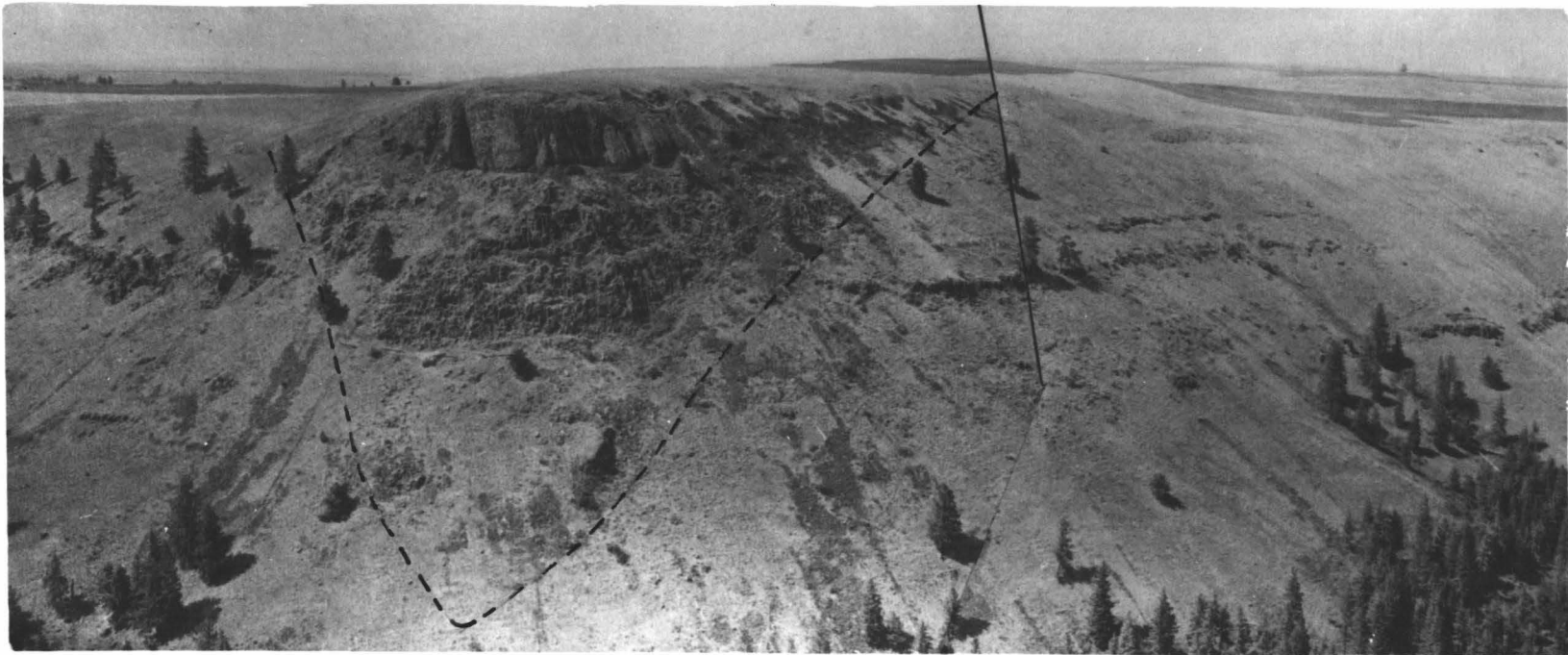


Figure 16. V-shaped outcrop of the Alder Gulch basalt. Outcrop is on the north wall of the canyon of George Creek about $3/4$ mile north of the Little Butte shield.



Figure 17. Well formed columns in the Alder Gulch basalt. Columns are typical of the central portions of the V-shaped outcrops in George Creek and Coombs Canyon.

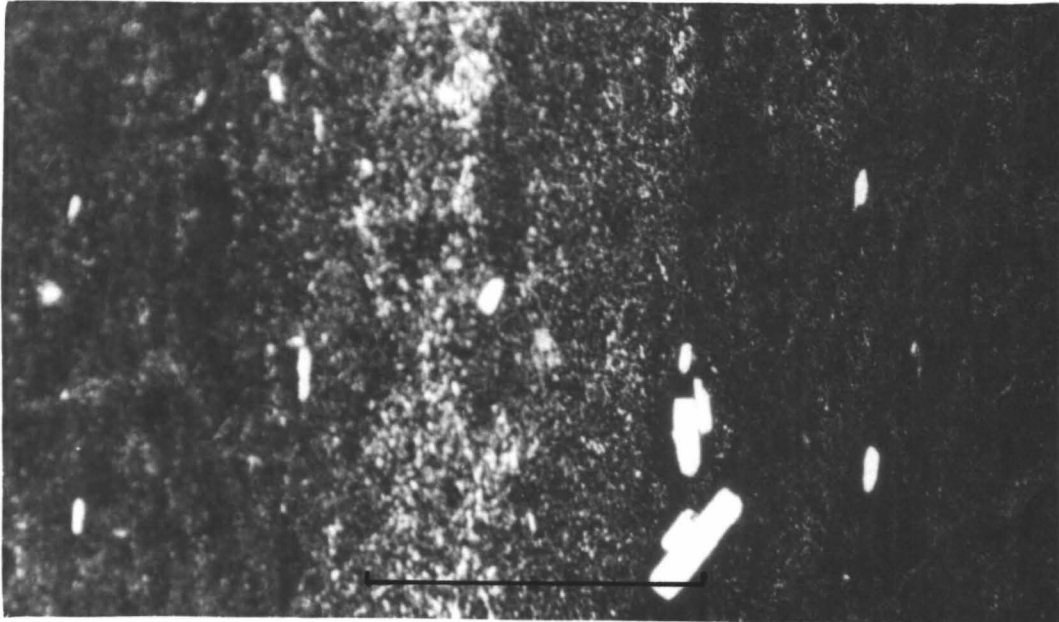


Figure 18. Photomicrograph of the Little Butte basalt, sample no. Lb-7. Light and dark bands are caused by changes in the percentage of tachylite and sub-parallel laths of plagioclase.

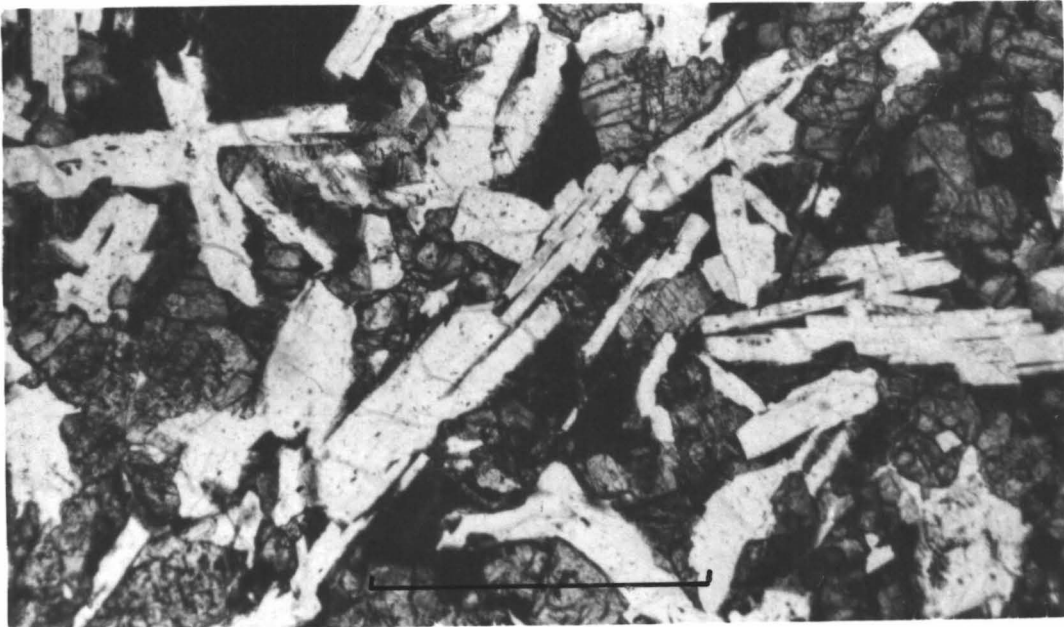


Figure 19. Photomicrograph of a typical coarse grained Pliocene to Pleistocene basalt. Intersertal to intergranular texture.

was probably erupted after the Alder Gulch basalt. An alternate interpretation is that the Alder Gulch basalt was squeezed out from under the Little Butte basalt. It is in direct contact with all previous flows. The Little Butte basalt forms a horseshoe-shaped outcrop around the summit of the shield. The open end of the shoe lies to the south.

Contained within the horseshoe of Little Butte basalt is the last unit to erupt from Little Butte, a dark red volcanic breccia. This unit forms an oval outcrop, $3/4$ mile long and $1/4$ mile wide, at the present summit of the volcano. Contacts with the surrounding rocks are covered except where the breccia is in contact with the Red basalt on the southern slope. Here the exposures are good, the contact is sharp, and there appears to be no weathering of the underlying Red basalt.

The breccia contains dark angular fragments of glassy basalt in a red groundmass. Most of the groundmass can be seen to be composed of small shards of glass. Most of the large angular fragments are completely separated from each other by the groundmass. The distance between fragments is approximately equal to their average diameter. Most of the fragments are equidimensional. Those fragments that are inequidimensional are crudely aligned.

Structurally, Big Butte is much the same as Little Butte. Two flows are known to have erupted from the vent. Other flows may have issued from this volcano but heavy forest on the side east of the map area prevented effective reconnaissance. The lower slopes of the shield are composed of a dense, dark gray to black basalt similar to the Alder Gulch basalt, Tlc. The upper slopes are formed of Big Butte basalt, Tbb, indistinguishable from the Little Butte basalt.

The flow forming the lower slopes spreads westward from the vent for two miles. The northern and southern margins of the flow have been removed by erosion. To the north the flow probably overlapped the flows from Little Butte.

Basalts of Little Butte and Big Butte were poured forth on an apparently flat surface of the Yakima basalt. For the most part this surface was undissected, as shown by the uniform thickness of the younger basalt flows, but locally canyons up to 500 feet deep had been cut in the surface. The canyons are now marked by V-shaped outcrops of Alder Gulch basalt in George Creek and Coombs Canyon. Information presented by Stearns, Crandall and Steward (1938) indicates that the maximum rate of erosion of basalts in semi-arid climates is about 500 feet in 10,000 to 15,000 years. Such high rates are limited to the canyons cut by vigorous streams. This suggests that the interval between the last flow of Yakima basalt and the first flow from Little Butte was at least 10,000 years. Since the eruption of the Yakima basalt ceased in the Pliocene the younger basalts are late Pliocene to early Pleistocene.

The age of the younger basalts is further indicated by outcrops up dip and topographically higher than their vents. In order for the flows to reach their present location they must have been erupted prior to the formation of the Blue Mountains anticline in the Pleistocene. Luper and Warren (1942) suggest that only a small amount of deformation occurred before extrusion of the intracanyon flows near Asotin. They placed the extrusion of the basalts in the early Pleistocene.

The data presented in the preceding two paragraphs indicate a late Pliocene to early Pleistocene age for the younger basalts. The age of

the basalts of Little and Big Buttes is about the same as that determined for the intravalley basalts of Lupper and Warren. It is probable that the basalts are equivalent and that the vents in the Saddle Butte Quadrangle are the source for the intravalley basalts.

After examination of several thin sections of the younger basalts seven specimens from flows of Little Butte and three specimens from flows of Big Butte were selected for careful study. Microscopic examination of thin sections of these rocks revealed that the basalts of Little and Big Buttes are significantly richer in olivine than the Yakima basalt. In all other respects they are so similar that without the olivine they would be difficult to distinguish from the Yakima basalt by mineralogy alone. The younger basalts of Saddle Butte are petrographically similar to basalts reported in the lower gorge of the Columbia River by Waters (1961). Fuller (1928) reported basic augite olivine basalts in the Snake River Canyon near Asotin. The basalts, later interpreted as valley-fills by Lupper and Warren (1942), are petrographically indistinguishable from the younger basalts in the Saddle Butte Quadrangle.

With the exception of the throat breccia at the summit of Little Butte, the flows can be divided into two groups according to their grain size. The majority of the flows are medium to coarse grained. Flows of the upper slopes of the volcanoes are uniformly glassy. Examples of typical flows from Little and Big Buttes are shown in figures 18 and 19. Table IV gives the modes of the 10 sections examined.

Plagioclase in both rocks is calcic labradorite. Albite:anorthite ratios range from $Ab_{31}:An_{69}$ to $Ab_{38}:An_{62}$. This range considerably

TABLE IV. MODES OF THE PLIocene-PLleistocene BASALTS

Sample Number	% Plagioclase	% Monoclinic pyroxene	% Glass	% Magnetite	% Olivine	% Other	Ab-An ratio
Lb-1	48	27	12	9	3	1	37:63
Lb-2	50	8	8	10	24	0	32:68
Lb-3	53	22	6	5	12	2	38:62
Lb-4	44	27	3	14	10	2	32:68
Lb-5	37	26	14	17	5	1	31:69
Lb-6	52	25	3	5	6	9	32:68
Lb-7	12	1	45	41	1	0	-----*
Bb-1	47	31	4	4	13	1	31:69
Bb-2	54	29	1	4	9	3	32:68
Bb-3	8	--	48	43	1	0	-----*

* Glassy basalts of the upper slopes, nearly all grains are opaque and indices could not be measured.

overlaps the composition of plagioclase in the Yakima basalt and the Grouse Creek diabase. Plagioclases in the younger basalts are only slightly more calcic than those of these two formations. The predominant form of the plagioclase is as laths 0.2 mm to 1.5 mm long and displaying distinct albite twinning.

Augite and pigeonite are pale honey-colored to brown in plain light. The 2Vs of the larger crystals range from 40° to 50° . The smaller grains often have a 2V of less than 15° . The average size of the augite crystals is about the same as the plagioclase laths.

In contrast to flows of the Yakima basalt and the Grouse Creek diabase, olivine is nearly always an important component of the rock. It is seldom present in amounts less than 5 percent and commonly exceeds 10 percent. The occurrence of olivine is similar to that in the Yakima basalt. Most of the grains are rounded relicts enclosed in thick reaction rims of augite. In some sections, however, larger grains, 0.5 mm to 1 mm in diameter, are numerous. In these the reaction rim of augite is absent. Where the reaction rim is thin or absent the margins of the olivine crystals are often marked by numerous minute inclusions of magnetite.

Magnetite is always an important component. It is normally present in amounts up to 10 percent. The smallest quantity observed is 5 percent. The predominant form of the magnetite is as euhedral crystals scattered throughout the rock. Abundant dust-like inclusions are common in the ferromagnesian minerals.

The volcanic glass is predominantly sideromelane. Tachylite is common near the flow contacts and in the glassy basalts of the upper

slopes. The glass is nearly always interstitial to the plagioclase and augite. In several of the thin sections examined the glass contains numerous dust-like inclusions of magnetite. In a few instances the magnetite is present in sufficient quantities to make the glass opaque.

Other minerals observed are palagonite, iddingstie, chlorophaeite and apatite. Apatite is present as inclusions in the plagioclase. The other minerals are alteration products of glass and olivine respectively.

Textures of the medium to coarse-grained group range from hypocrystalline to intergranular. The plagioclase is commonly surrounded by grains of approximately the same size. The interstices are filled with glass and small mineral grains. The textures of the second group are glassy. Flow banding (fig. 18) and crude alignment of the plagioclase laths is common.

Fleistocene Loess

Much of the surface of the northern half of the quadrangle and the area of Grouse Flats is covered by a layer of loess. The color of the loess ranges from light brown to gray. Near the surface, where the silts have become contaminated with organic material, the color darkens. The upper portion of the loess is light in weight and friable, the density and coherence increasing with depth. The characteristics of the loess are very similar to those of the Palouse formation described by Calkins (1905). Newcomb (1961) states that several obviously younger loesses have been included in the Palouse formation. Since no direct

correlation can be made between the loess in the Saddle Butte Quadrangle and the Palouse formation farther north, the name will not be used in this report.

Loess in the mapped area is generally thin, ranging from five feet in the higher sections to as much as 15 feet at lower elevations. The basal portions of the loess at high altitudes often contain residual basalt cobbles and boulders.

The age of the Palouse and associated loess has been put at middle Pleistocene (Shotwell, 1955). Most workers consider the loess pre-Wisconsin in age (Culver, 1937; Schied, 1940; Byran, 1927). Loess from the Palouse formation is thought to have been derived from the Ringold formation of south-central Washington (Merriam and Buwalda, 1917). The stratigraphic position and the similarity of the loess in the Saddle Butte Quadrangle to the Palouse formation indicates that the two formations are probably equivalent.

Recent Sediments

Locally along stream valleys, river gravels and alluvial fans have been deposited. In several places where tributaries enter larger streams the toes of the alluvial fans have been removed. Several of these fans contain lenses or layers of volcanic ash. Hollenbaugh (1959) considered nearly identical ash in the Lewiston Basin to be from one of the Cascade volcanoes. Similar origin is postulated for the ash in the Saddle Butte Quadrangle. The ash was probably originally deposited as a thin sheet over the region and later washed into the streams which deposited it in the fans.

Two terraces up to 100 feet above the present river level are exposed in the canyon of the Grande Ronde River. They are composed of

basalt cobbles, pebbles, and sand similar to the material of the present stream bed. The terraces are tentatively correlated with the Clarkston Stage of the Pleistocene in the Northwestern United States. Lupper (1945) concluded that the Snake River was dammed to a level 400 feet above the river bottom in the Lewiston Basin. This is sufficient to account for the higher terrace in the Grande Ronde. The lower terrace may represent a temporary halt in the removal of the alluvium deposited during the period of aggradation.

STRUCTURE

Introduction

Saddle Butte lies in the northernmost extension of the Blue Mountains physiographic sub-province of Freeman, et al. (1945). It is the site of the northern part of a broad arch extending from the Elkhorn-Greenhorn Mountains more than 100 miles to the south in northern Oregon. This anticlinal structure has been variously called 1. The Blue Hills Uplift (Russell, 1897, 1901); 2. The Grande Ronde Arch (Freeman, et al., 1945); and 3. The Blue Mountains anticline (Newcomb, 1961). Since recent interpretation of the regional structure considers the fold as part of the Blue Mountains anticline of northeastern Oregon (Newcomb, 1961) the term will be used in this report. The general east-west trend of the Blue Mountains anticline is paralleled by several minor faults.

Folds

The structure of the northern part of the Blue Mountains anticline was first described by Russell (1901) as a broad domical uplift, thirty to forty miles wide from north to south and fifty to sixty miles long east to west. Later workers have associated this dome with an elongate uplift trending northwestward in northeastern Oregon (Newcomb, 1961).

Folds of the same age as the Blue Mountains anticline are responsible for the Lewiston Basin, 10 miles to the north (Graham, 1949; Hollenbaugh, 1959). Structural relief on the more northerly folds reaches 4,000 feet. The structural relief on the Blue Mountains anticline is of similar magnitude in the vicinity of Saddle Butte.

Flows of the Yakima basalt rise gently southward from the trough of the Lewiston Basin to the crest of the Blue Mountains anticline. Dips

on the northern limb seldom exceed 15 degrees. Much steeper dips are reached on the southern limb of the anticline. The maximum dip of the flows in the map area, 40 degrees, is attained on the southern limb near the western boundary of the quadrangle.

Basalt flows near the crest of the Blue Mountains anticline dip so gently, 2-3 degrees, that true dips are difficult to determine. The crest of the fold lies within a band of gently dipping to flat flows up to $1\frac{1}{2}$ miles wide. Beginning on the west the crest of the fold describes a broad arc, open to the south, across the central part of the quadrangle (plate 1, in pocket). The crest strikes to the northeast in the vicinity of Saddle Butte. The strike gradually changes to east-west in Indian Tom Creek at about the middle of the quadrangle. Further east, on Mallory Ridge, the strike of the crest is to the northwest. The changes in trend of the crest are reflected in the strike of the flows on both limbs.

The southern limb of the anticline, south of Saddle Butte, is faulted $1/4$ to $1/2$ miles south of the crest. The trace of the fault parallels the crest of the fold for about eight miles. The fault dies out near the junction of Indian Tom and Wenatchee Creeks.

Flows, north of the fault, dip to the south at a maximum of 10 degrees. South of the fault, the dips reach 40 degrees in the same direction. About $1\frac{1}{4}$ to $1\frac{1}{2}$ miles south of the fault the dip of the flows abruptly decreases to 2 degrees or less, resulting in Grouse Flats. Shallow dips continue to the rim of the Grande Ronde River. South of the river the flows dip to the north at a maximum of 5° .

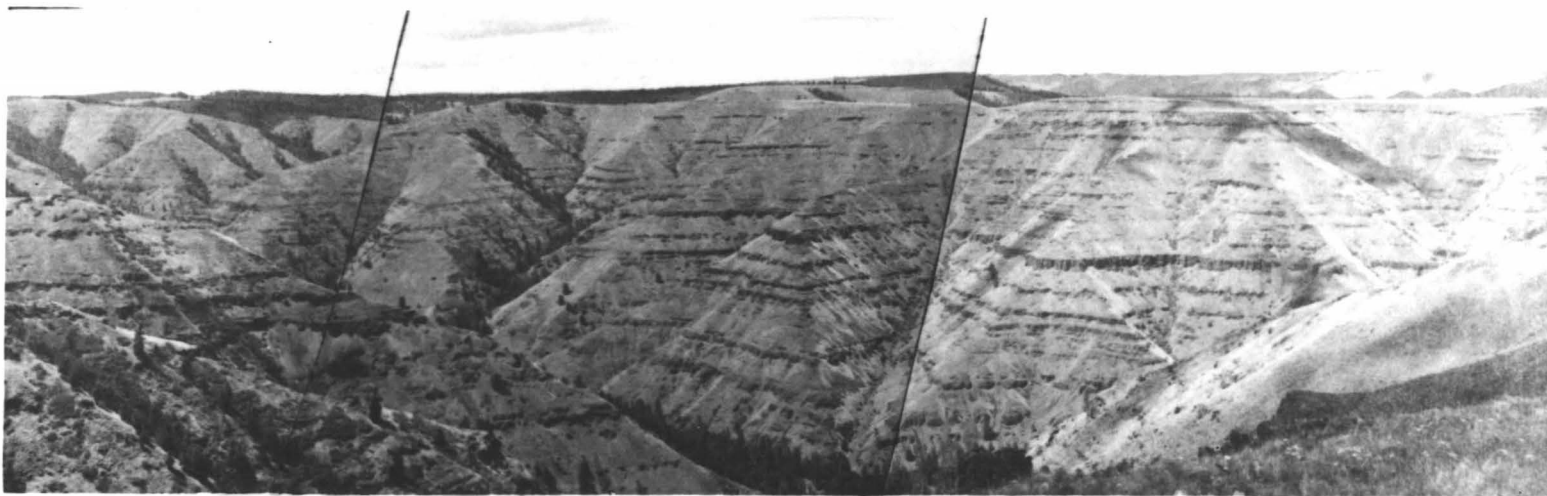


Figure 21. Truncated spurs in the North Fork of Asotin Creek. The valley follows a fault with an approximate displacement of 200 feet. The northern side moved up relative to the southern side. Photograph is taken looking to the northwest.

The low dips which are responsible for Grouse Flats die out to the east and gradually the flats merge with the limb of the anticline. East of Wenatchee Creek the changes of dip are much less abrupt than to the west. Dips of the flows in this area seldom exceed 15 degrees. The maximum dips are near Tamarack Butte. Further to the east, near Cottonwood Creek, the dips are never more than 5 degrees, and there is no area of very low dips.

Faults

The folded flows of Yakima basalt are cut by several minor faults. With the exception of a northward-striking fault in Wenatchee Creek and a northwestward-striking fault in the East Fork of First Creek the faults are nearly parallel to the crest of the Blue Mountains anticline. Uniformity of the basalt flows prevented accurate determination of the displacement. Where approximate determinations are possible the movement is small, from a few hundred feet to $1/4$ mile.

Horizontal displacements of $1/8$ and $1/4$ mile occur on faults cutting a dike exposed in the East Fork of First Creek. The southern fault strikes to the southeast across Saddle Springs and along the valley of the West Fork of Wenatchee Creek. This fault displaces a northwest-striking dike for $1/8$ mile to the west. About $1\frac{1}{2}$ miles farther north the dike is cut by a second fault. This fault strikes to the northeast, displacing the dike $1/4$ mile to the west. A wedge-shaped block of nearly flat flows is contained between the faults. Vertical displacement on the faults was not determined.

In the upper reaches of the North Fork of Asotin Creek vertical displacement of about 200 feet was measured on a fault along the stream

valley. Displacement was determined by relative elevations of two thick lava flows tentatively correlated across the fault. Dikes crossing the fault at nearly right angles do not show significant horizontal displacement.

In the western half of the mapped area, a fault of undetermined displacement parallels the crest of the Blue Mountains anticline. This fault, mentioned previously, is marked by an abrupt increase in the dip of the flows as the fault is crossed from north to south. Between the crest of the fold and the fault the dip never exceeds 10 degrees. Immediately to the south of the fault the dips range from 28 to 40 degrees. The fault can be traced from near the confluence of Indian Tom and Wenatchee Creeks westward for several miles beyond the edge of the quadrangle.

Along the central parts of Wenatchee Creek the strike of the flows shows a marked change. This change in strike is due to a fault marked by the stream valley. West of the fault the strike averages N 45° W, whereas on the opposite side of the fault it is about N 75° W. As nearly as can be determined the western side of the fault has moved down relative to the eastern side.

Age of the Deformation

Many authors (Russell, 1897; Thompson, 1935; Luper and Warren, 1942; Graham, 1949; Strand, 1949; Hollenbaugh, 1959) have concluded that the folding responsible for the Blue Mountains anticline and the Lewiston Basin occurred well after the end of the extrusion of the

Yakima basalt. Lupper and Warren (1942) established that little folding had taken place before eruption of Pleistocene intravalley basalts in the Snake River Canyon.

Thompson (1935), and Tullis (1944), concluded that deformation of the Uniontown Plateau 12 miles north of Saddle Butte occurred during the Pleistocene. Their conclusions are based on uplift and depression of segments of the late valley-filling basalts in the Lewiston Basin. Russell (1897), cited braiding of streams and aggradation of their valleys near Whitman, Washington, west of the study area, as evidence that deformation is still continuing.

The present study revealed no information which requires significant alteration of these findings. Indeed, the relation of the basalts of Little Butte and Big Butte to the Yakima basalt tends to confirm them. If these younger basalts of the Saddle Butte area are considered equivalent to the intracanyon basalts of Lupper and Warren (1942) the validity of the conclusions is further enhanced.

GEOMORPHOLOGY

General Statement

Seven distinct geomorphic units are developed in the Saddle Butte Quadrangle. The largest of these is the relatively undissected inter-canyon surface, preserved on the north limb of the Blue Mountains anticline. This surface was formally named the Clarkston Plateau by Russell in 1901. Incised deeply into this surface are numerous sub-parallel, northeasterly trending youthful canyons. On the southern limb of the anticline, just south of the area of steepest dip, is a preserved structural surface, known locally as Grouse Flats. About 400 feet below Grouse Flats and surrounding it to the east, south, and west is the mature surface of the lake beds. Immediately south of this surface is the entrenched canyon of the Grande Ronde River. In the central portion of the extreme eastern edge of the quadrangle are two low shield volcanoes, and associated valley-filling flows. Crossing the area from east to west is an erosional scarp, closely related to the steep southern limb of the Blue Mountains anticline.

The lowest elevation in the Saddle Butte Quadrangle is 1,250 feet, at the point where the Grande Ronde River leaves the mapped area. The surface of the land rises in steep slopes north and south of the canyon to a bench at the level of the lake beds. Immediately north of this bench the land again rises steeply to an elevation of slightly more than 6,000 feet, north of the crest of the Blue Mountains anticline.

Local geomorphic features are expressions of the structure of the underlying basalt. Streams, except for parts of Asotin Creek and the Grande Ronde River, are consequent. Prominent nearly horizontal

surfaces such as Grouse Flats are underlain by gently dipping to flat flows. The more steeply dipping flows north of Grouse Flats are outlined by hogbacks carved in the basalt by intermittent streams. Along parts of the North Fork of Asotin Creek a series of triangular facets truncating the interstream divides indicate the presence of a fault (fig. 21).

In the eastern part of the quadrangle, $\frac{1}{2}$ mile north of Little Butte, an inversion of topography has occurred. Basalt flows from the Little Butte volcano filled a north-south-trending valley in the Yakima basalt. Erosion later removed the less resistant Yakima basalt, leaving the younger basalt exposed as a broad low ridge.

Inter-canyon Surface

The relatively undissected inter-canyon surface, the Clarkston Plateau of Russell (1901), occupies the northern $\frac{1}{2}$ of the mapped area. It is typically flat, sub-parallel to the dip of the underlying basalt flows. Relief on the surface is measured in a few tens of feet. The surface slopes gently to the northeast, from near Wikiup Spring, descending 2,600 feet in six miles. The inter-canyon surface is mantled with a layer of loess, five to fifteen feet thick.

The surface appears to be the result of the tilting of the flows to the northeast, prior to the deposition of the loess mantle and before the pre-tilting surface had been dissected. Remnants of basalt standing 100 to 200 feet above the present surface and having tops parallel to the inter-canyon surface indicate that erosion has reduced the general elevation by at least this amount. Further evidence for pre-tilting erosion is the unconformable relation of the loess to the basalt, seen

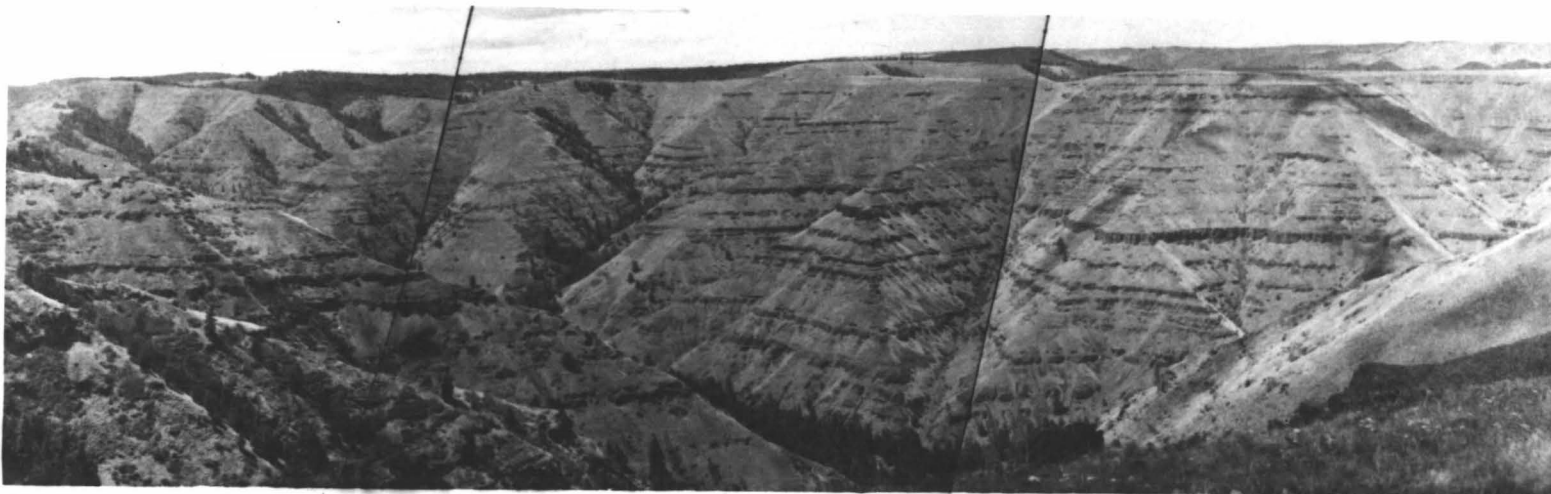


Figure 21. Truncated suprs in the North Fork of Asotin Creek. The valley follows a fault with an approximate displacement of 200 feet. The northern side moved up relative to the southern side. Photograph is taken looking to the northwest.

in the walls of the canyons. The dip of the basalt is slightly less than the slope of the surface, resulting in the truncation of the flows.

The lack of appreciable dissection of the basalt surface prior to the tilting may be due to the original flatness of the surface and the high porosity of the basalt. The effect of the loss of runoff to groundwater would be augmented by the ability of the flow contacts to transmit large quantities of water with ease.

Youthful Canyons

Asotin Creek and the majority of its tributaries flow in north-eastward-trending, sub-parallel canyons, cut as deep as 1,000 feet below the inter-canyon surface. At intervals of about three miles, northward flowing streams cross the general trend of the canyons. The dominant northeast trend of the canyons is in the direction of the dip of the basalt flows in which the canyons are cut. The formation of these canyons is therefore due in part to the northeastward dip of the basalt flows, i.e., the streams are consequent. The extreme youthfulness of the streams and the wide inter-stream divides support this conclusion.

That these canyons are currently undergoing active down cutting is indicated by the presence of numerous slumps and truncation of alluvial fans built into them by tributary streams. Many prominent slumps are associated with over-steepening of the valley walls by sapping of the relatively easily eroded scoriaceous flow contacts. Small slumps are common in all canyons but are particularly evident in the South Fork of the North Fork, and the Middle Branch and North Fork of Asotin Creek. Accumulations of alluvium at the base of the valley walls indicate that they too are being eroded.

The regular spacing of the consequent streams suggests that they bear a relation to structures within the underlying basalt. They may have developed along parallel, regularly spaced lines of weakness trending in the same general direction as the dip of the flows. Such lines of weakness may be joints or minor faults. More likely the regularity is due to the homogeneity of the surface on which the streams developed.

The more widely spaced, northerly to northwesterly-flowing streams appear to be related to some pre-tilting drainage lines. This direction is shown by the filling of an old canyon by the flows from Little Butte. This canyon is in a direct line south of the lower reaches of the South Fork of Asotin Creek, and continues in the same direction for more than a mile. The older drainage system is probably related to structure or original dip of the flows. Discernable remnants of this older drainage system are nearly parallel to the general trend of the dikes, suggesting that the dikes and the streams utilized the same lines of weakness.

The formation of the northeastward-flowing consequent streams in the northern half of the quadrangle is attributed to the northeastward tilting of the basalt flows during the early Pliocene. Once initiated, a canyon is rapidly enlarged due to the addition of groundwater to the stream. Headward erosion is aided by sapping where springs issue from the flow contacts. The importance of the addition of groundwater from these scoriaceous zones is shown by the abrupt increase in volume of many streams where one of these aquifers is crossed.

Preserved Structural Surface (Grouse Flats)

Grouse Flats is a preserved remnant of a structural surface on the southern limb of the Blue Mountains anticline. It consist of gently rolling hills with a general slope to the south-southeast. The flats occupy about nine square miles in the extreme southwest corner of the quadrangle. They extend for several miles to the west and south of the map area.

Relief on the flats does not exceed twenty feet in the southern portions, increasing to one hundred feet nearer the mountains bordering the flats to the north. Several intermittent streams cross the flats. In the lower reaches of many of these the surface layer of loess has been removed to expose the underlying Yakima basalt. In other places a thin layer of reworked loess and basalt cobbles fills the valley floors. The undissected condition of the flats may be attributed to the low dip and the high permeability of the loess and underlying flows. Preservation of the loess may also be due to the high permeability and low slope of the surface.

Mature Surface of the Lake Beds

About 400 to 500 feet below the surface of Grouse Flats, and surrounding it to the west, south, and east, is a bench cut in the Grouse Creek diabase. This bench occupied by late Miocene to early Pleistocene lake beds. The surface on which the beds were deposited was one of moderate to low relief.

Since their deposition the lake beds have been eroded until hills of the underlying diabase protrude above them. Intermittent streams have carved the lake beds into a gently-rolling series of low hills.

The drainage is well integrated and is mature. The surface contrasts sharply with the steep-walled mature valleys cut in the more resistant basalt and diabase. As a result the lake beds form a conspicuous geomorphic unit.

Entrenched Canyon of the Grande Ronde River

The Grande Ronde River, pronounced Grand Round by local inhabitants, flows eastward across the southeastern corner of the quadrangle. This clear, swift-flowing stream has excavated a canyon as much as 2,000 feet below Grouse Flats, along the southern margin of the Blue Mountains anticline. The walls of the canyon are 4 to 5 miles apart. The tributaries, most of them ephemeral, have carved steep gorges extending several miles into the high country on either side of the canyon. Between the tributaries, precipitous ridges extend far into the canyon of the Grande Ronde, ending in steep terraced cliffs. Along these cliffs ledges of nearly horizontal Yakima basalt form conspicuous outcrops. The Grande Ronde winds around these spurs in a series of tight meanders. The sinuous curves traced by the Grande Ronde River resemble the meanders of a mature stream. It is evident that the river had at some time in the past reached a greater stage of maturity than it now exhibits. The meanders of this stage have been preserved in the resistant basalt flows. In reconstructing the history of this fascinating river one can imagine two cycles of erosion. First, a broad flat-floored valley was cut at the level of the lake beds. On this surface the river attained a stage of maturity in which it meandered over a broad flood plain between precipitous walls. This period was brought to a close by the uplift of the Blue Mountains to the north and west,

resulting in the rejuvenation of the river. Subsequent rapid erosion trapped the Grande Ronde River in its meanders, which today are preserved in the canyon. Remnants of the flood plain are now to be seen in the spurs and the surface on which the lake beds are deposited. From the brief history outlined above it is obvious that the Grande Ronde, at least in its lower reaches, is antecedent to the Blue Mountains anticline.

Shield Volcanoes

In the central part of the extreme eastern edge of the quadrangle lie two small shield volcanoes, Little Butte and Big Butte. Little Butte, the smaller of the two, lies entirely within the quadrangle, while only the western slopes of Big Butte extend into the study area. Little Butte is a broad elliptical mound resembling a shield. It is about $1\frac{1}{4}$ mile wide and 2 miles long. It rises 250 feet above the general level of the Clarkston Plateau. Big Butte is similar in all respects except that it is slightly larger. Elongation of both volcanoes is northwesterly, approximately parallel to the general strike of the dikes. The slopes of the volcanoes are relatively undissected, presenting smooth, curved surfaces rising above the Clarkston Plateau. Streams flowing northeastward in canyons cut in the plateau are diverted around the base of the volcanoes.

Erosional Scarp

A prominent east-west-trending scarp as much as 2,500 feet high crosses the central part of the quadrangle, about six miles north of the Grande Ronde River. The scarp is the result of the headward erosion by tributaries of the Grande Ronde River into the northward-dipping beds

underlying the Clarkston Plateau. The consequent nature of the lower reaches of these streams suggest that they developed on the steeply dipping south limb of the Blue Mountains anticline, maintaining their initial steep gradients as they extended themselves northward. In the present headwaters of these streams the slope of the surface of the interstream divides and the dip of the flows is to the north, opposite the direction in which the streams flow.

GEOLOGIC HISTORY

During middle Miocene to late Pliocene times numerous fissures opened in southeastern Washington and northeastern Oregon. From these fissures great volumes of tholeiitic basalt poured forth on the then-rugged landscape. Eventually these lavas completely inundated the land, leaving only the highest mountains protruding above a nearly flat lava plain.

In the Saddle Butte Quadrangle these lavas, the Yakima basalt, are seen as thick parallel sheets exposed in cliffs along the canyon walls. Dikes which fed the flows are present in large numbers, some of them many miles long. The lack of pyroclastic material indicates that the lavas welled quietly from the fissures.

Toward the close of the volcanism a thick sill-like body was emplaced between the upper flows of the basalt. This body, the Grouse Creek diabase, probably was intruded along flow contacts within the basalts. Alternatively, it may have been erupted onto the surface, attaining its great thickness behind a natural dam.

At the close of the eruption of the Yakima basalt what had once been a rugged mountainous region had been transformed into a monotonous lava plain. By late Pliocene to early Pleistocene time streams had cut a few canyons in this plain, some of them up to 500 feet deep. The general level of the surface had been reduced by as much as 200 feet. Because of the original flatness and the uniformity of the rock, the surface was still a plain, cut here and there by small canyons.

At this point in the history of the region volcanism was renewed. This time the eruptions were confined to two centers near the eastern

edge of the map area. From these vents flows of fluid olivine basalt spread for long distances over the plain, filling the canyons and forming a thin cap over the Yakima basalt. Near the vents the lava piled up to form low shield volcanoes.

At the time these vents were active the Grande Ronde River was cutting a broad shallow valley about 6 miles to the south. Within this valley the river meandered over a flood plain as much as 4 miles wide. At times the river, a tributary of the Snake, was dammed and sands and silts were deposited over parts of the flood plain. This period of maturity, now represented by remnants of the flood plain covered by the lake beds, probably coincided with the Asotin Stage of the Snake River as described by Lupper and Warren (1942). The Snake River was dammed by floods of Pleistocene lava forming an extensive lake upstream from Asotin. The level of the dam was probably high enough to cause deposition in the valley of the Grande Ronde River.

Toward the close of the Pliocene-Pleistocene volcanism the region was subjected to north-south compression. As a result of these forces two prominent east-west-trending asymmetric folds and associated faults developed. The southernmost of these crosses the quadrangle about 6 miles north of the Washington-Oregon border. Deformation at this time resulted in the rejuvenation of the Grande Ronde River and the cutting of canyons by consequent streams on the Clarkston Plateau. Cutting of the canyons has continued to the present. Periods of alluviation of the major stream valleys are recorded in two levels of river terraces preserved in the canyon of the Grande Ronde. These may be the result of alluviation during the Clarkston stage of the Pleistocene in the Pacific

Northwest, during the last glacial stage, Lupper (1945) reported that up to 400 feet of sediments were deposited in the Snake River near Lewiston. This would be sufficient to cause alluviation of the Grande Ronde River for some distance upstream from the confluence with the Snake River.

At the same time the Blue Mountains anticline was forming, pre-Wisconsin loess was deposited over much of the area. Except for much of the north limb of the Blue Mountains anticline and patches on Grouse Flats and Mallory Ridge, the loess has since been removed by erosion. The loess closely resembles the Palouse formation and is probably equivalent, if not actually part of it.

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PLATE 1

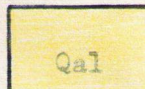
GEOLOGIC MAP OF THE SADDLE BUTTE QUADRANGLE,
SOUTHEASTERN, WASHINGTON

GEOLOGIC MAP OF THE SADDLE BUTTE QUADRANGLE SOUTHEASTERN WASHINGTON

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

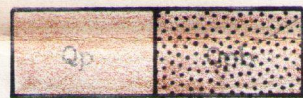
LEGEND

SEDIMENTARY ROCKS



Qal-Alluvium, mostly unconsolidated silt, sand and gravel, includes low lying terrace deposits and artificial fills.

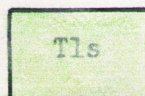
Recent



Qp-Periglacial eolian, buff to light brown loessial silt, probably early Pleistocene

Pleistocene

Qpb-Periglacial eolian, loessial silts with residual basalt boulders.



Tls-Lake beds; poorly consolidated lacustrine clays, silts, and sands, contains low grade coal, probably late Miocene to early Pliocene.

Pliocene
Miocene

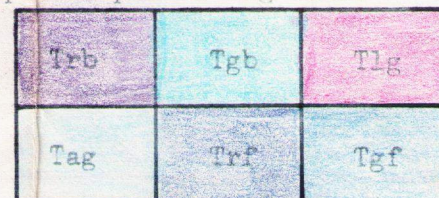
VOLCANIC ROCKS



Tor-Lost Cabin Ridge flow, fine grained olivine basalt flow from Big Butte.

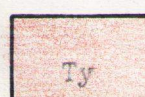
Pleistocene

Tbb-Big Butte Basalt, dense black glassy basalt forming upper slopes of Big Butte



Pliocene

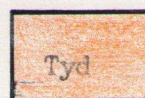
Trb-Red volcanic breccia forming throat of volcano
Tgt-Dense, black, glassy basalt of upper slopes.
Tlk-Olivine basalt flow on eastern slope.
Tag-Valley filling olivine basalt flow.
Trf-Reddish olivine basalt flow on southern slope.
Tgf-Valley filling olivine basalt flow.



Ty-Yakima Basalt; dark gray to black basalt flows; forty to seventy feet thick; commonly columnar, some flows vesicular, grading to scoriaceous.

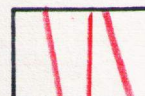
Pliocene
Miocene

INTRUSIVE ROCKS

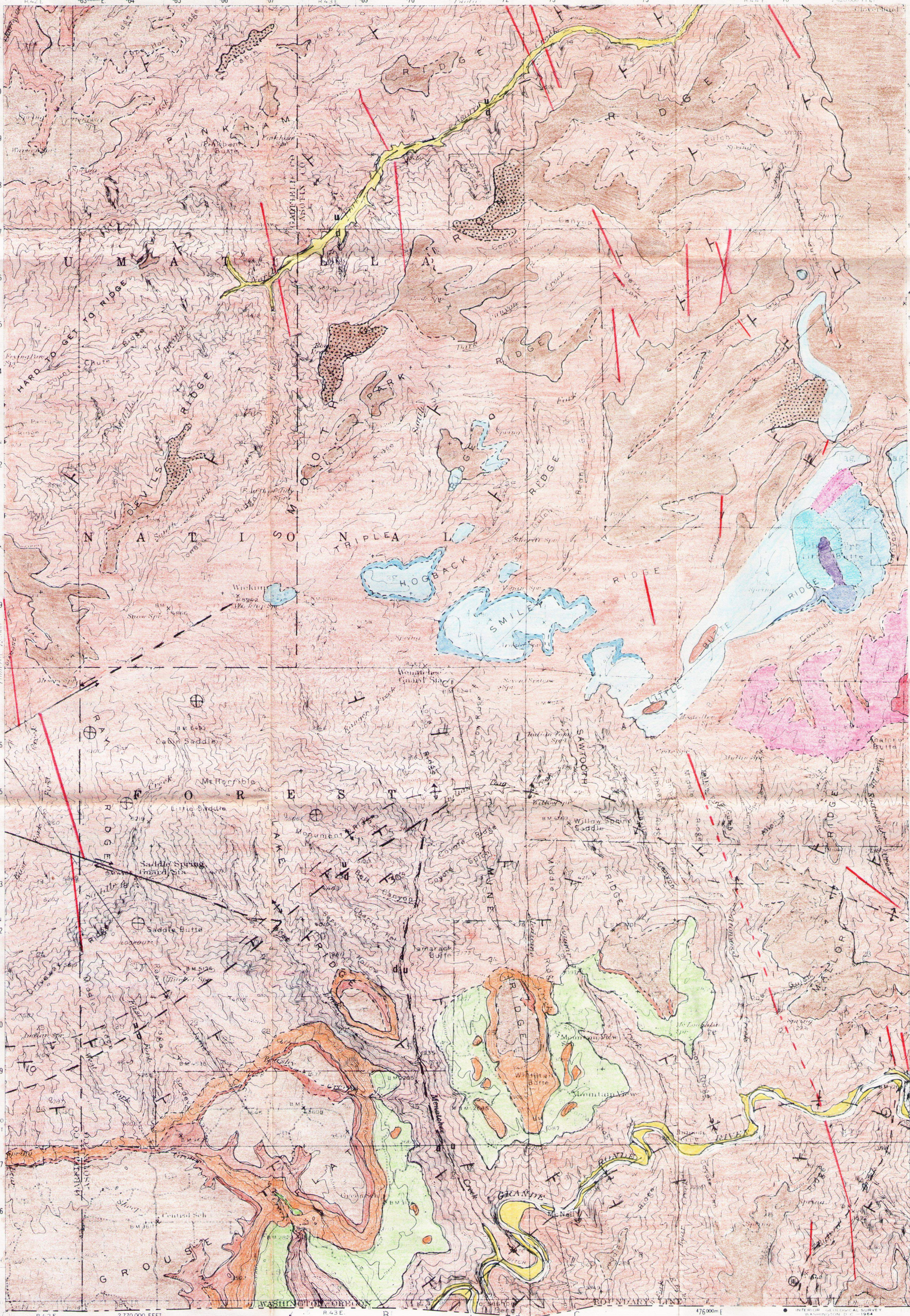
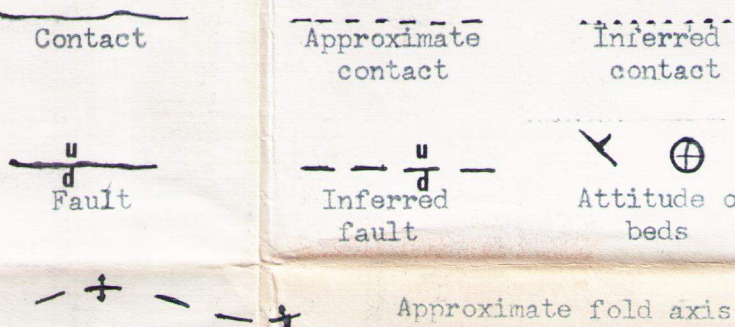


Tyd-Complexly jointed, diabasic, sill like body within the Yakima Basalt.

Pliocene
Miocene



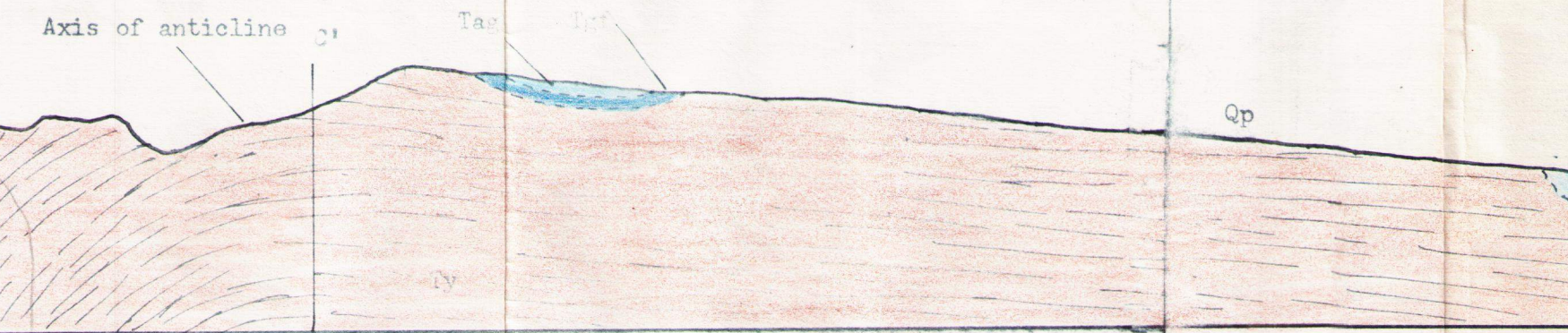
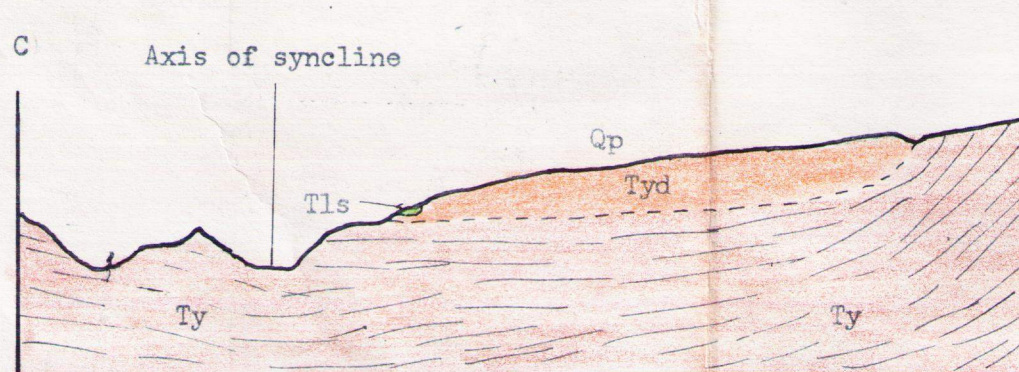
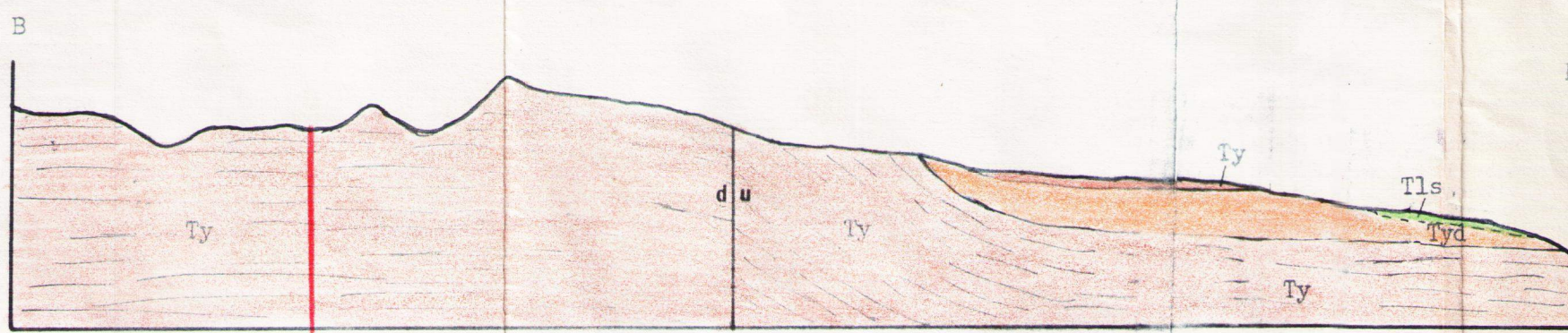
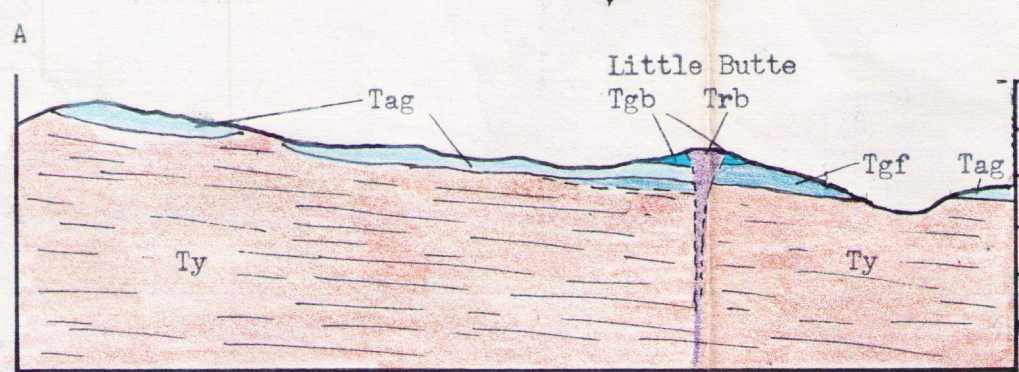
Dikes, commonly vertical; most show well developed horizontal columns; mostly tholeiitic basalt and diabase, some with more than ten percent olivine.



Topography by the U.S. Geological Survey 1943

Geology by P. S. Hubbard 1966-1967

Contour interval 50 feet



No vertical exaggeration

No dip numbers shown with usual dependence