THE GEOLOGY OF THE WEST FORK
OF THE MADISON RIVER AREA,
MONTANA

By John Lemish

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CONTENTS

Page

LIST OF ILLUSTRATIONS

ABSTRACT

The West Fork of the Madison River area lies in the southern part of the Gravelly Range. The rocks of the area, which range from pre-Cambrian to Tertiary in age, have a thickness of over 4,668 feet. The structure of the Gravelly Range resembles a large titled fault block of Laramide or Tertiary age. Two erosion surfaces extend across the highest elevations of the Gravelly Range. An early Tertiary surface underlies the present surface which is being eroded on volcanic flows.

INTRODUCTION

Purpose

In the summer of 1947 several parties of students from Rocky Mountain Field Station of the University of Michigan at Camp Davis, Wyoming, studied the geology of various areas in southwestern Montana under the direction of Dr. A. J. Eardley. The author and William Vaughn studied the geology of an area in the Gravelly Range which was within the Ph. D. thesis area of Mr. Fred Honkala. The work done was intended to become material for a master's thesis in geology.

Location

The area under consideration in this thesis consists of township T 12 S, R 39 E, Madison and Beaverhead Counties, southwestern Montana, and the adjacent sections surrounding the township.

Township T 12 S, R 39 E is in the southern part of the Gravelly Range which extends northward from the Centennial Valley (Plate I). The Ruby River Valley and the Snow Crest Range border the area on the west, and the Madison River Valley lies on the east.

The township lies within the east half of the Beaverhead National Forest, and the southern boundary of the township coincides with the southern boundary of the National Forest. The West Fork Ranger Station lies within the township.

PLATE I

E. Raisz

INDEX MAP

The best route to the thesis area is first, by way of U. S. Highway 91 to Monida, Montana, thence by a graded road eastward into the Centennial Valley to either the Metzel Creek Road or the Long Creek Road. Both turn off northward from Centennial Valley. The Long Creek Road is followed to a junction just north of the Divide Creek Ranger Station and then east on the Eureka Basin Road into the township.

Description

Elevations within the area range from approximately 7,000 to 10,000 feet. The area is deeply dissected in places (Plate II), but much of it, especially the approaches from the Centennial Valley, are rounded, sagebrush covered hills.

Sheep and cattle graze the area in the summer months. Placer gold has been found in small amounts in the valley gravels, but only panning has been attempted since the Thompson Placer Mine closed during the war.

Acknowledgments

The field work was carried out under the supervision and guidance of Prof. A. J. Eardley and his assistant Dr. Helen Foster. I wish to acknowledge the helpful suggestions of Prof. Eardley and Dr. Eugene Walker in the preparation of the thesis. I am also indebted to Prof. J. E. Thornton of the Department of Engineering English for his criticism of the manuscript.

Valuable assistance in the field was offered by Fred Honkala and his field assistant, Hal Meadow. During the

Plate II. Looking north from Landon Ridge up the canyon cut by Cascade Creek.

last ten days in the field, the author was aided by Dean Cummins and William T. Smith, both of the University of Michigan.

The author is indebted to M. V. Denny for his advice and assistance in preparing the photographs and to Dr. E. W. Heinrich of the Department of Mineralogy for his aid in thin section analyses.

STRATIGRAPHY

General stratigraphy

The rocks range in age from pre-Cambrian to Tertiary and have a total thickness of over 4,668 feet.

The major unconformities which were observed in the area are the angular unconformity between the Cambrian and pre-Cambrian rocks, the disconformity between the Cambrian and Devonian systems, and the angular unconformity between the Tertiary and the older underlying rocks.

The regional dip is 10° SW, and the West Fork of the Madison River flows approximately normal to strike exposing almost a complete section (Plate II).

Pre-Cambrian system

Metamorphic rocks of pre-Cambrian age, exposed in the area near the Landon Ranger Station, form a major angular unconformity with the overlying Paleozoic strata. The pre-Cambrian rocks consist of gray-white, dense, fine-grained quartzites, and black schists. The metamorphic rocks appear similar to the Pony Series (personal communication from Honkala; also Tansley, 1933). The thickness of the pre-Cambrian rocks is unknown.

TABLE I

Stratigraphic Column of the West Fork of the Madison River Area, Township T 12 S, R 39 E

Age	Formation	Thickness in feet
Tertiary	Volcanics Gravels	unknown unknown
Lower Cretaceous	Kootenai	905+
Upper Jurassic	Undifferentiated (Ellis or Morrison ?)	244
Lower Triassic	Thaynes Woodside Dinwoody	163 350 325
Permian	Phosphoria	235
Pennsylvanian	Quadrant	195
Lower Penn.—Upper Miss.	Amsden	152
Lower Mississippian	Madison	940+
Upper Devonian	Three Forks Jefferson	197 160
Upper Cambrian	Dry Creek Shale Pilgrim	67 210
Middle Cambrian	Park Shale Meagher Wolsey Shale Flathead Quartzite	150 75 100 200
Pre-Cambrian	Pony Series (?)	unknown

Total 4,668+

Cambrian system

The Cambrian system was mapped by the author as an undifferentiated unit because of poor exposures and limited knowledge of the Cambrian system at the time of mapping. Basal quartzite, dolomitic cliff-forming limestones with covered slopes, and a red calcareous siltstone at the top were observed as undifferentiated Cambrian, 810 feet thick. Later Honkala differentiated the Cambrian rocks into six formations which correspond with the Barker formation (Weed, 1899) and the rocks in the Three Forks, Montana region (Peale, 1893).

Flathead quartzite.—The Flathead quartzite was observed in the gorge cut by the West Fork of the Madison River. The Flathead consists of a thin-bedded to massive fine-grained white sandstone with red-brown and green inclusions. It measured 200 feet thick. The formation was named by Peale (1893, pp. 20-21) for exposures in Flathead Pass of the Three Forks, Montana region. It is Middle Cambrian in age and lies at the base of the Paleozoic rocks forming an angular unconformity with underlying pre-Cambrian metamorphics.

Wolsey formation.—A covered unit 100 feet thick overlies the Flathead quartzite in a stratigraphic position corresponding to the Wolsey shale, first described by Weed (1900).

Meagher formation.—Along the West Fork of the Madison River the Meagher formation, a gray to buff, thin-bedded to massive, dolomitic limestone approximately 75 feet thick, overlies the Wolsey shale. It was first described by Weed (1899) and recognized in central Montana as Middle Cambrian.

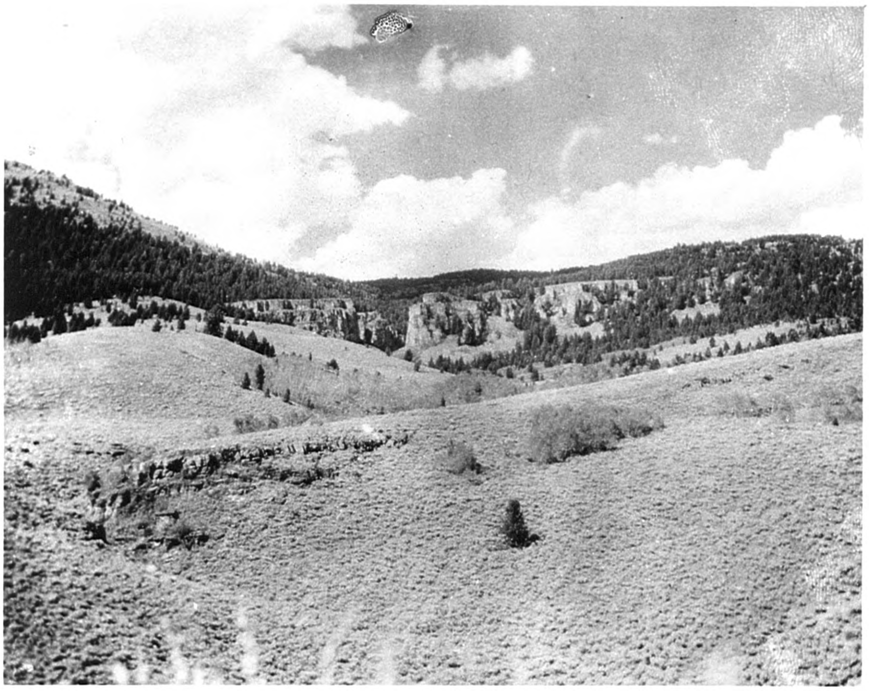


Fig. 1. Looking north at the canyon cut by Portal Creek in the Pilgrim formation. Older Cambrian strata are in the foreground.

Fig. 2. Looking south down the canyon of Portal Creek at the Pilgrim formation.

Plate III. Views of Cambrian strata

Park shale.—A covered interval 150 feet thick above the Meagher formation corresponds on the basis of stratigraphic position to the Park shale described by Weed (1899). The Park shale is Middle Cambrian in age and is widespread throughout central and southern Montana.

Pilgrim formation.—The Pilgrim formation is a massive cliff former in the area (Plate III). It is a buff, coarse grained, dolomitic limestone, blocky and massive at outcrops. The formation is Upper Cambrian in age, and 210 feet thick. It is widespread in the Fort Benton and Little Belt Mountain regions where it was first named by Weed (1899).

Dry Creek shale.—The Dry Creek shale overlying the Pilgrim formation extends throughout central, southern, and west central Montana. It consists of a red calcareous siltstone pierced by calcite veins. Its color varies from a red to an orange, and upon weathering the Dry Creek shale is very friable and pink in color. It is exposed along the West Fork of the Madison River where it is 67 feet thick.

A. C. Peale (1896) first described the formation in his Three Forks, Montana Folio.

Devonian system

The Devonian rocks overlie the Cambrian strata unconformably in the West Fork area. The Cambrian Dry Creek shales underlie the rocks of upper Devonian age (Sloss and Laird, 1947, p. 1404).

A. C. Peale (1893, pp. 25-32) who originally described the Devonian rocks of the Three Forks area considered the Jefferson formation Middle Devonian in age and the overlying Three Forks shales Upper Devonian. Recent studies by Sloss and Laird (1947, pp. 1404-31), however, lead them to place both formations in the Upper Devonian.

Jefferson formation.—The Jefferson formation is widespread in Montana, western Wyoming, Idaho, and northern Utah. Along the West Fork of the Madison River it is 160 feet thick and overlies the Dry Creek shale with no apparent unconformity. A disconformity must exist, however, to separate the Cambrian and Devonian systems. The Jefferson formation consists of a dark gray, fossiliferous, thin-bedded to massive limestone. The Jefferson limestone was named by Peale (1893, pp. 27-29) for exposures of the formation along the Jefferson River in the Three Forks, Montana region.

Three Forks formation.—The Three Forks formation is rather widespread in Montana, western Wyoming, southeastern Idaho, and northern Utah. At the type locality (Peale, 1893, pp. 29-32) at Three Forks, Montana, the Three Forks formation consists, in descending order, of:

5. Sandstone—yellow laminated
4. Limestone—dark bluish drab or black argillaceous
3. Shale—fissile, black argillaceous and calcareous
2. Limestone—gray brown compact
1. Shales—red, brown, and yellow, calcareous and argillaceous

Along the West Fork of the Madison River, the Three Forks formation measured 197 feet thick and consisted of 4 main exposed units. These units, in descending order, are:

4. Limestone—tan thin-bedded fossiliferous
3. Limestone—thin-bedded gray to buff fossiliferous
2. Limestone—lithographic gray
1. Shale—red calcareous

Mississippian system

Madison formation.—The Madison formation is one of the thickest and most conspicuous formations in the area. It forms cliffs approximately 1,000 feet high along Cascade Creek and Elk River, and measures 940 feet thick along the West Fork of the Madison River. In other places it appears to be thicker. The rock from parts of this formation has a characteristic petroliferous odor on freshly fractured surfaces.

The basal part of the formation consists of a dark gray to black, dense, thin-bedded limestone followed by alternating thin-bedded to massive blue gray limestone. A massive gray limestone with frequent chert nodule inclusions forms the upper part of the formation.

The formation was named after the Madison Range (Peale, 1893, pp. 33-39) where it is well exposed. It is considered lower Mississippian (Kinderhook) in age. The Madison formation is widespread throughout Montana, Wyoming, Idaho, and northern Utah.

Pennsylvanian system

Amsden formation.—The Amsden formation overlying the Madison limestone extends over Montana and Wyoming. The Amsden is considered Upper Mississippian in age at the base and Lower Pennsylvanian at the top (Berry, 1943).

Originally the Amsden formation was included in the Quadrant formation which was introduced by Peale (1893, pp. 39-43). Subsequent investigation (Berry, 1943) has led to the recognition that the lower part of the Quadrant is the Amsden formation corresponding to what Darton (1904, pp. 396-97) described in Wyoming.

Along the West Fork of the Madison River the Amsden formation is 152 feet thick. The lithology which varies considerably consists of three major units, named in descending order:

3. Limestone—grading from a gray limestone with red chert nodules at the top to a gray mottled limestone with yellow spots, to gray coarsely crystalline limestone and to a lithographic limestone at the base.
2. Sandstone—cream to buff, calcareous cement.
1. Covered slope of reddish yellow shale or sandstone.

Beneath the overlying Quadrant and above the top cherty limestone unit is a covered slope with some red sandstone float.

Quadrant formation.—Along the West Fork of the Madison River and in other areas of township T 12 S, R 39 E the Quadrant formation, consisting mostly of quartzite, overlies the Amsden formation.

The Quadrant, which is 195 feet thick, has 4 main units which can be observed along the West Fork of the Madison River; the outcrops are partly hidden by covered intervals and talus slopes. In descending order these units are:

4. Alternating quartzitic sandstones and dolomites mostly covered by talus
3. Sandstone—white quartzitic
2. Limestone—light gray dolomitic
1. Sandstone—white quartzitic

The Quadrant formation was named after Quadrant Mountain in the Gallatin Range (Weed, 1896). Originally the Quadrant included all rocks of Upper Mississippian and Pennsylvanian age which rest on the Madison formation in the Montana area (Peale, 1893, pp. 39-43). Scott (1935, p. 1019) and Berry (1943, pp. 19-20) consider the basal part of the Quadrant formation equivalent to the Amsden formation. The upper part of the Quadrant is considered the westward extension of the marine Tensleep sandstone (Darton, 1904, pp. 396-97; and Condit, 1918, pp. 111-21) of the Wyoming region. For the purposes of this thesis, the Quadrant is considered the equivalent of the Tensleep.

Permian system

Phosphoria formation.—Within the thesis area the Phosphoria formation consists of the Rex Chert member, which is composed of a yellow to buff colored massive chert bed and underlying gray quartzitic sandstones, but lacks the phosphatic shales and limestones generally found in it. The formation, which is 235 feet thick, overlies the Quadrant formation.

The Phosphoria formation is found over a large area which includes northeastern Utah, eastern Idaho, central western and southwestern Montana, and western Wyoming. It was named after Phosphoria Gulch, Meade Park, Idaho, where the formation is typically exposed (Richards and Mansfield, 1912, pp. 683-89).

Triassic system

Dinwoody formation.—At the base of the Triassic and overlying the Permian Phosphoria formation is the 325 feet thick Dinwoody formation. The formation is exposed in the thesis area along Fossil Creek where it consists of alternating shales and calcareous sandstones at the base and thin-bedded tan sandy limestone above.

The fossils found in this formation have been identified by Honkala as:

1. *Anadontophora fossaensis* (Wissman)
2. *Lingula borealis* Bittner
3. *Monotis*
4. *Aviculopectin* sp.
5. *Eumorphotis multiformis* Bittner
6. *Myalina postcarbonica* Girty

The Dinwoody formation (Blackwelder, 1918, p. 425) represents the lower Triassic in western Wyoming and extends into Idaho.

Woodside formation.—The Woodside formation forms a lithologic unit which consists of 350 feet of fine grained, thin-bedded, brick-red siltstones and shales. The Woodside is exposed along Fossil Creek where it can be seen overlying the Dinwoody formation.

The Woodside (Boutwell, 1907, pp. 439-458) represents the Lower Triassic in northeastern Utah, southwestern Wyoming, southeastern Idaho, and in parts of southwestern Montana.

Thaynes formation.—The Lower Triassic formation found above the Woodside is the Thaynes formation. The Thaynes is very well exposed along Fossil Creek where it is 163 feet thick. It consists mainly of alternating red shales and thin-bedded, cream-white limestones.

The Thaynes formation (Boutwell, 1907, pp. 439-458) was named after Thaynes Canyon in the Park City District, Utah. It extends over Utah, Wyoming, and Idaho, but is not commonly found in southwestern Montana.

The Thaynes formation was measured in detail by Vaughn and the author in a tributary of Fossil Creek about 1 mile north of Fault Lake where the formation was exceptionally well exposed. The south fork of the tributary where the section was measured lies on the north border of the township and extends from section 4 of T 12 S, R 39 E into section 33 of T 11 S, R 39 E. Beginning with the uppermost unit, the detailed section consists of the following units, named in descending order:

Unit		Thickness in feet	
15.	Shale—light gray, thin-bedded, weathers lighter gray	2'	6"
14.	Shale—maroon, thin-bedded	2'	6"
13.	Shale—gray, thin-bedded, weathers white to cream	24'	9"
12.	Shale—red, calcareous, thin-bedded	6'	4"

Unit		Thickness in feet	
11.	Limestone—cream to white, massive, thin-bedded, weathers tan, white, and yellow; 4'3" below base of unit 12 a 6" fossiliferous limestone bed is found containing gastropods, pelecypods, and a <u>Meekoceras</u> cephalopod.	49'	7"
10.	Siltstone—red, calcareous, thin-bedded	15'	
9.	Limestone—white, upper 4" massive	3'	7"
8.	Shale—calcareous, red shales alternating with white, thin-bedded limestone	27'	6"
7.	Shale—calcareous, red shales alternating with white, thin-bedded limestone	3'	8"
6.	Alternating limestones and red shales	13'	10"
5.	Limestone—white, thin-bedded	2'	10"
4.	Alternating limestone and red shale	2'	11"
3.	Limestone—white		6"
2.	Shale—red	3'	
1.	Limestone—white	1'	11"

Below unit 1 red calcareous shales and siltstones of the Woodside are found.

A number of fossils were collected by Vaughn and the author from unit 11 of the Thaynes where the formation was measured. The fossils identified by Honkala are:

1. <u>Meekoceras gracilitatis</u> White
2. <u>Monotis thaynesiana</u>
3. <u>Myalina postcarbonica</u> Girty

4. *Terebratula*
5. *Gastropod* sp. indet.
6. *Monotis* sp.
7. *Aviculopectin* sp.
8. *Natica* sp.

Jurassic system

Above the Thaynes formation and below the Kootenai formation are 244 feet of shales, limestones, and sandstones which have been tentatively classified as undifferentiated Jurassic. The section was measured in detail, but no fossil evidence to aid in naming these beds was found. The Jurassic consisted of gray green shales, gray limestones, and light colored sandstones. The lithology of these beds suggests features of the Rierdon, Ellis, and Morrison formations.

The Jurassic was measured in detail at the same locality where the Thaynes formation was measured, in section 4 on the south tributary of upper Fossil Creek. The section consists of the following units, in descending order:

Unit		Thickness in feet	
44.	Shale—greenish-gray, deeply weathered, 6" yellow shale bed 6" from bottom of unit	16'	
43.	Sandstone—pinkish-gray, not well indurated, has a green shale parting 1' from bottom	16'	5"
42.	Shale—greenish-gray, arenaceous	1'	8"
41.	Sandstone—multicolored, not well indurated, weathers readily; colors varying from green at bottom to a red which grades into a pink with thin yellow bands, to a green again (weathering may cause yellow bands)	2'	8"

Unit		Thickness in feet	
40.	Shale—gray shale; various colors seen in bed from yellow to brown-red	27'	1"
39.	Sandstone—massive, light gray	2'	3"
38.	Shale—gray	3'	
37.	Limestone—lithographic; pitted, rounded surface on weathering		11"
36.	Shale—gray-green, 3" red shale bed included	1'	4"
35.	Limestone—green to light gray	2'	6"
34.	Shale—pale green	2'	4"
33.	Shale—red		6"
32.	Shale—gray with greenish tint; interbedded with thin, pale green lithographic limestone	27'	6"
31.	Shale—red		6"
30.	Shale—gray-green	4'	5"
29.	Shale—red		6"
28.	Shale—green; fissile to arenaceous	5'	9"
27.	Shale—red	1'	8"
26.	Limestone—light gray to light green arenaceous limestone, top 1'8" thin-bedded	4'	3"
25.	Shale—dark gray-green, arenaceous	3'	4"
24.	Shale—red-brown to maroon; waxy smooth appearance on fresh surface; concoidal fracture; very dense	4'	8"
23.	Shale—light gray with greenish tint; arenaceous	13'	10"
22.	Shale—red-brown		10"
21.	Shale—gray; weathers light buff to white	5'	11"

Unit		Thickness in feet	
20.	Limestone—gray, arenaceous, massive, blocky	12'	5"
19.	Shale—gray		10"
18.	Limestone—gray; lithographic; weathers lighter gray	1'	
17.	Shale—gray-green	1'	9"
16.	Shale—red to maroon; waxy smooth on fresh surfaces	3'	7"
15.	Shale—green; fissile	2'	8"
14.	Limestone—green "glauconitic-like" pebbles and calcite veins	2'	1"
13.	Shale—green; fissile		10"
12.	Limestone—argillaceous, with green pebble inclusions one-eighth inch in diameter		9"
11.	Limestones and shales—gray-green; interbedded	1'	8"
10.	Same as unit 12	1'	3"
9.	Covered—probably green fissile shale	6'	
8.	Shale—gray-green, dense to fissile with small green pebble inclusions; bottom 1'6" is a shaley conglomerate composed of limestone pebbles	3'	9"
7.	Shale—green, fissile, grades into a shaley conglomerate	3'	
6.	Limestone—gray-green, blocky, dense; has black shiny spots (bitumen?), also zones of greener color which resemble a pebble conglomerate	3'	2"
5.	Covered—(shale or sandstone?) green-gray sands cover slope	39'	8"
4.	Sandstone—massive dark gray-green, argillaceous, weathers rounded; iron stained	2'	6"

Unit	Thickness in feet
3. Covered—gray-green sand, very fine grained, covers slope (probably a sandstone)	5' 5"
2. Conglomerate—white calcareous matrix, contains white limestone pebbles	11"
1. Conglomerate—maroon matrix; limestone pebbles, calcite veins common	1'

Unit 15 of the Thaynes formation lies below unit 1.

Cretaceous system

Kootenai formation.—The Lower Cretaceous of southern Alberta, British Columbia, and Montana consists of the Kootenai formation. The name Kootenai was applied to a series (5,000 to 7,000 feet thick) of coal-bearing shales and sandstones of the Bow Valley region by Dawson (1885, pp. 331-32) after a tribe of Canadian Indians. Fisher (1908, pp. 47-99), in correlating the coal-bearing formations of Montana, defined the Kootenai as consisting of a lower part which contained a tripartite arrangement of sandstone, red shale, and sandstone, and an upper part which contained red shales alternating with thin beds of sandstones. Lee (1927, p. 41) considers the Kootenai formation the equivalent of the middle part of the Cloverly formation of Wyoming.

In the Gravelly Range the Kootenai formation is found at the crest of the range and is partially exposed in areas of nivation and on cuesta-like ridges. Within the thesis area it is found on the west side of upper Fossil Creek, where it caps the highest elevation in the area and dips toward the west forming a dip slope. Beds of the Kootenai crop out in many places, but because of weathering it was difficult to obtain a complete section. However, the units were measured as completely as possible in 2 areas.

In section 4 of T 12 S, R 39 E and section 33 of T 11 S, R 39 E about 1½ miles north of Fault Lake, the Kootenai is partially exposed in a nivated area where contrasting red and white zones are seen between sandstone beds. It was measured in the area beginning from the top of the Jurassic at the extreme end of the south tributary of upper Fossil Creek. The formation was measured up to the gastropod limestone member. In descending order these units are:

Unit		Thickness in feet	
11.	Limestone—gastropod horizon, coarsely crystalline, fractured	10'	6"
10.	Shale—gray, blocky, weathers white to gray, similar to unit 8	63'	
9.	Limestone—dense, blocky, pebble inclusions	2'	
8.	Shale—gray, deeply weathered slope	105'	
7.	Shale—red, deeply weathered	63'	
6.	Sandstone—white, fine grained, pinkish cast on fresh surface; weathers brown, shows excellent crossbedding, fractures into flagstone slabs; basal part pebble conglomerate 3" thick	94'	5"
5.	Shale—gray to buff, calcareous, deeply weathered	26'	3"

Unit		Thickness in feet
4.	Shale—transition zone from white to red shale, clastic dikes seen, conglomeritic in places, shale dense to fissile, 1' thick pebble limestone 5'3" from top; deep maroon color slope seen at 5'3" from bottom	43' 5"
3.	Covered—white slope, probably calcareous shales and sandstone, greenish-gray when wet; gastroliths present	52' 6"
2.	Sandstone—white to light gray, dark grain inclusions fewer than unit 1, massive where outcrops appear on covered slope	42'
1.	Covered—sandstone, coarse grained salt and pepper type weathering light gray, seen on covered slopes; basal conglomerate of pebbles in a coarse, gray to tan, salt and pepper type sandstone matrix lying on Jurassic	168'
	Total	670' 11"

Beyond unit 11 a covered interval occurs which forms the crest of the hill. In a dip slope direction (west) about one-half mile beyond unit 11 lies a cliff of shale and sandstone which is considered part of the Kootenai formation (personal communication from Honkala). The shales are dark gray to black and measure 234 feet thick. A massive to thin-bedded, tan, cross-bedded sandstone overlies the shales. The sandstone is probably the same sandstone which forms a graben-like valley at Fault Lake (Plate IV). The minimum thickness of the Kootenai is 904 feet.

Another section of the Kootenai was measured near the source of Buford Creek, 1 mile due west of Fossil Peak in section 17 of T 12 S, R 39 E where a cliff of alternating

Plate IV. Looking east down a graben-like valley cut in the upper Kootenai sandstone.

limestone and carbonaceous shales are exposed. The lack of detailed exposures in the Fossil Creek section (cf., p. 23) prevents the location of the Buford Creek section within the Kootenai formation. The section can be tentatively placed between units 8 and 10 of the Fossil Creek section. In descending order the Buford Creek section consists of:

Unit		Thickness in feet	
20.	Limestone—dense to lithographic, thinly bedded, weathers white, forms a partly covered slope	5'	3"
19.	Shale and limestone—paper-thin shale and crenulated limestone; limestone contains gastropods	1'	
18.	Limestone—lithographic, blue-gray		9"
17.	Limestone—gray; gastropods present	1'	
16.	Shale and limestone—carbonaceous unit; weathered yellow shale bed at bottom 1" thick; crenulated fossiliferous limestone, 2" gray-white shale at top	1'	6"
15.	Limestone—gray, dense, weathers white; thin-bedded bed in center with black paper-thin shales	4'	4"
14.	Shale—gray, fissile; 5" carbonaceous shale unit in center	25'	
13.	Limestone—gray, thin-bedded, weathers white		5"
12.	Shale—black, paper-thin		7"
11.	Limestone—gray; gastropods		5"
10.	Limestone—alternating limestones and paper-thin shales	16'	
9.	Shale—gray to black, paper-thin, carbonaceous, fucoidal	5'	8"

Unit		Thickness in feet	
8.	Limestone—massive, fossiliferous (gastropods, pelecypods), weathers with pitted surface	5'	8"
7.	Shale—brown to gray, paper-thin	8'	2"
6.	Shale—carbonaceous shale and coal interbedded with crenulated limestone	1'	6"
5.	Limestone—buff, massive, top thin-bedded	5'	11"
4.	Shales—paper-thin and gray fissile shales	1'	6"
3.	Limestone—massive, gray	2'	2"
2.	Shale—dark gray, partly covered	2'	6"
1.	Limestone—gray, massive to thin-bedded, cut by calcite veins, weathers white	4'	7"
	Total	93'	11"

These sections show that the lithology of the Kootenai is varied and complex. The non-marine nature of part of the Kootenai, at least, is indicated by the presence of coal. Gastroliths and "salt and pepper" sandstones suggest a non-marine origin for other parts also. Berry (1943, pp. 1-30), who reports 1,500 feet of non-marine Kootenai in the Three Forks, Montana region, considers the lower part equivalent to the Morrison and Cloverly formations (Darton, 1904, pp. 394-401).

Tertiary system

Gravels.—There are no definite Tertiary formations within the area except volcanic flows and unconsolidated gravels. The gravels are generally composed of detrital material from nearby older rocks. Along the crest of the Gravelly Range and other high elevations within the area small deposits of gravels are found. The gravels contain rounded pre-Cambrian quartzite, gneissic boulders, and representatives of younger rocks (Atwood, 1945, pp. 191-200). In places the gravels underlie the mid-Tertiary vocanic flows and overlie the older formations.

Volcanic rocks.—Volcanic flows overlie Tertiary gravels and older formations unconformably over a large area of the Gravelly Range. Within the thesis area the flows form the highest elevations, such as Fossil Peak, Cascade Mountain, Patchtop Mountain, Divide Mountain, and Landon Ridge. The thickness of the flows is not uniform throughout the area; at Lobo Mesa they range from a few feet to over 400 feet thick. The age of the volcanic rocks is considered mid-Tertiary (Atwood, 1945, pp. 191-200), but no fossil evidence is known to date.

A megascopic examination of the volcanic rocks shows that they consist mostly of black basalts and a few pinkish-gray, light colored rocks. The texture of the basalts varies from a dense, fine grained type to an amygdaloid in which calcite or small geodes fill rounded cavities. Common to nearly all of the basalts are small brown phenocrysts which represent some type of alteration. The few light, pinkish gray rocks, however, were all very dense and fine grained. The lighter rocks were tentatively identified as sanidine trachytes because of the glassy feldspar phenocrysts which are very evident in a hand specimen.

A thin section analysis of a black, finegrained basalt from Landon Ridge, section 34, T 12 S, R 39 E, indicates that it is an olivine basalt porphyry. The plagioclase feldspar, which forms a groundmass of lath-shaped crystals, is labradorite (Ab_{40}) in composition. Other essential minerals are olivine and two pyroxenes, augite and pigeonite. The accessory minerals consist of magnetite and apatite. Calcite, serpentine, and iddingsite are the alteration products. The iddingsite forms a red-brown border about the olivine phenocrysts which it partly or wholly replaces.

A microscopic analysis of an amygdaloidal basalt from Landon Ridge shows that it is of the same composition as the fine grained basalt. Labradorite, olivine, augite, and pigeonite are present along with magnetite and apatite. Iddingsite, serpentine, and calcite are the alteration products. The olivine is very badly altered into the red-brown iddingsite. Calcite occurs in thin veins or over wide areas throughout the thin section.

A study of a light, pinkish-gray rock from Lobo Mesa, section 11, T 12 S, R 39 E, indicates that it is an acidic extrusive porphyry with potash feldspar phenocrysts. The optical properties of the potash feldspar phenocrysts show that the feldspar is biaxial negative, the indices of refraction are less than Canada balsam, and the axial angle (2V) is about 30° which is too high for sanidine (2V of 0° to 12°) and too low for orthoclase (2V of 69° to 72°). The optical properties appear to favor anorthoclase (2V of 43° to 54°) to some extent. A few other phenocrysts of quartz, sodic plagioclase, augite, and magnetite are present in a dense, fine grained groundmass which is in part glass. The flow structure of the groundmass which is seen about the phenocrysts could indicate movement of the rock while it was cooling.

STRUCTURAL GEOLOGY

Regional setting

The Gravelly Range lies in the northern Rocky Mountain Province of Laramide structures. It is flanked by the broad Centennial Valley and Range to the south, the Madison Valley and Range to the east, and the Snow Crest Range and Ruby River Valley to the west. The surrounding mountain ranges and valleys produce a regional setting somewhat similar to that of the Basin and Range Province of southwestern United States. Some of the valleys appear to represent down-dropped segments.

Tansley, Schafer, and Hart (1933) consider the Gravelly Range and its northern extension, the Tobacco Root Mountains, to represent a Laramide anticlinal dome. They maintain that Early Tertiary deformation consisting of faulting and tilting produced the present topography; as a result, the down-dropped segments are the Jefferson, Madison, and Ruby River valleys, and the uplifted segments form the surrounding ranges.

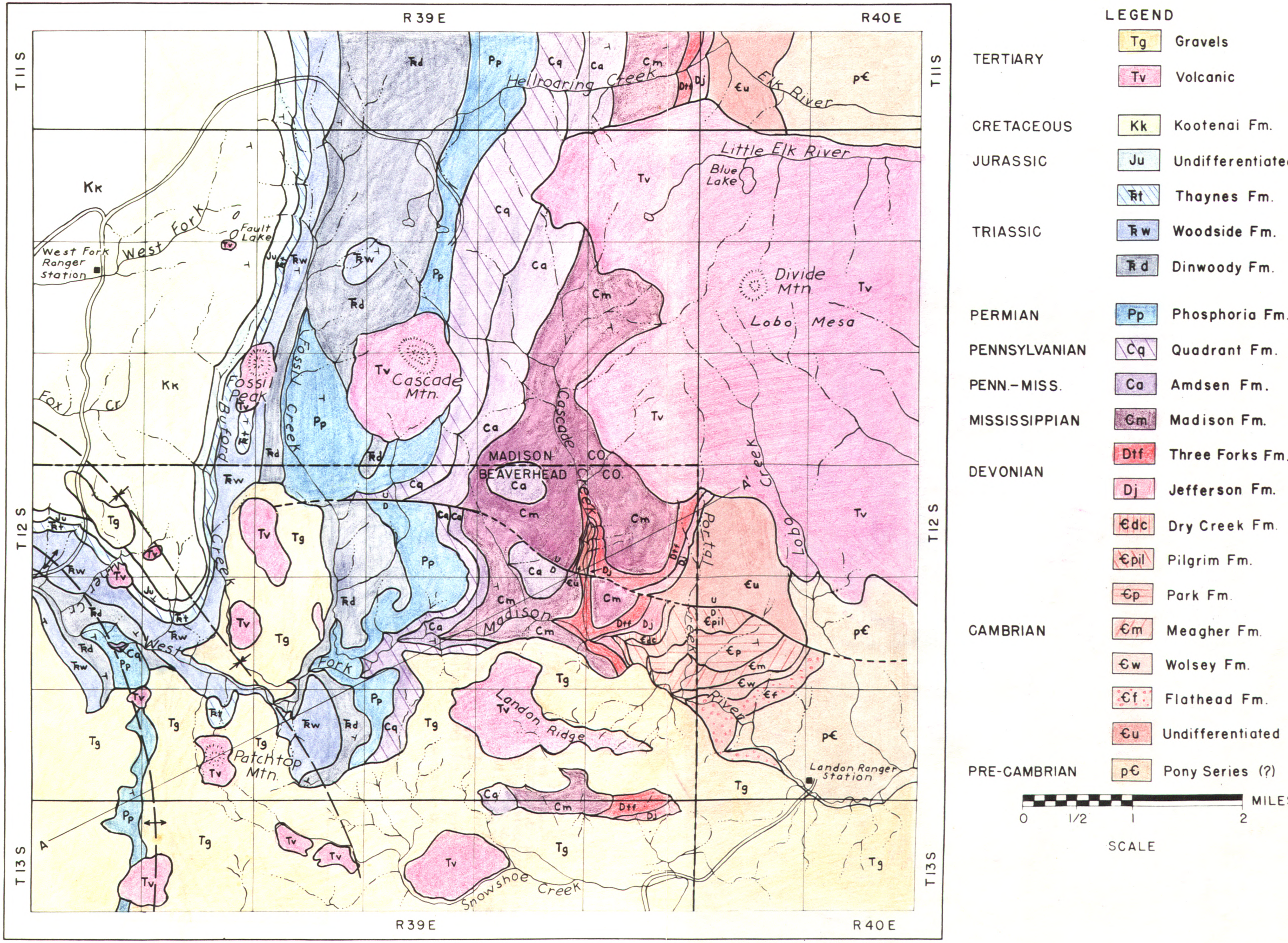
Within the thesis area the strata dip uniformly 10° SW, and all the sedimentary strata are exposed as well as a great thickness of pre-Cambrian rocks which form the eastern front of the range. The structure resembles a large tilted fault block that corresponds to the postulated Tertiary basin and range type of faulting, but the area to the east (personal communication from Eardley) has not been mapped and the required fault not located. The tilting may, therefore, be Laramide.

Metzel Creek anticline

The Metzel Creek anticline is a major anticlinal fold located in the southwestern corner of township T 12 S, R 39 E. The axis of this anticline parallels the West Fork of the Madison River from Anderson Creek to Miner Creek where it then curves west of Patchtop Mountain and changes its axial direction to the south, parallel to Metzel Creek (Plate V).

The axis of the Metzel Creek anticline has a gentle downward pitch from Anderson Creek to Miner Creek. From Miner Creek to Patchtop Mountain the axis of the anticline pitches sharply upward. Beyond Patchtop Mountain the axis pitches gently downward again toward the Centennial Valley. These changes in the pitch of the axis form a saddle near Patchtop Mountain. The Metzel Creek anticline is slightly

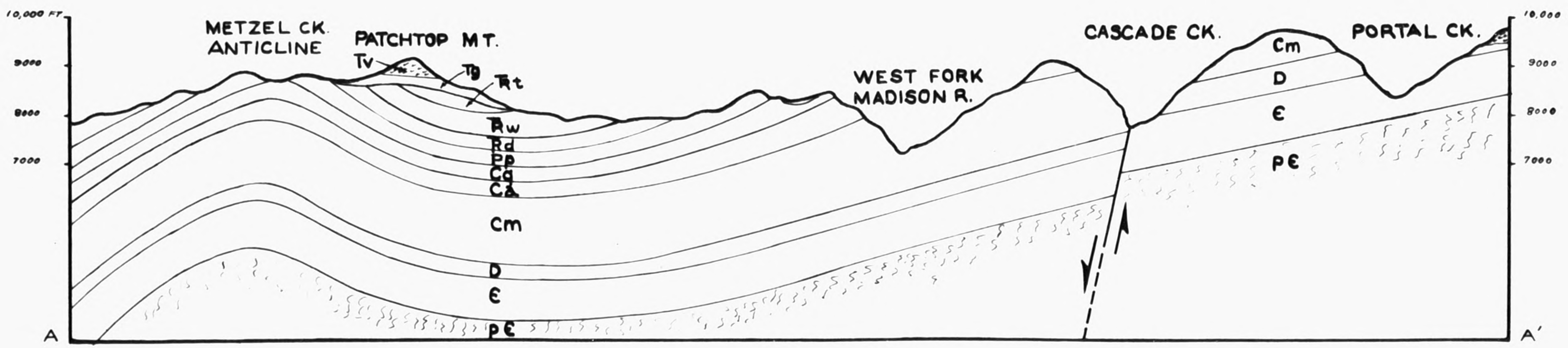
PLATE V



Base: Beaverhead Co., Planimetric map from aerial photographs; Madison Co., Control from U.S. Forest Service map, Beaverhead National Forest, Montana 1947

Geologic Map
West Fork Madison River area
MONTANA

Geology by W. Vaughn, J. Lemish



CROSSECTION ALONG A-A′
PORTAL CREEK TO METZEL CREEK ANTICLINE

EXPLANATION

Tv - VOLCANNICS
Tg - GRAVELS
TRt - THAYNES FM.
TRw - WOODSIDE FM.
TRd - DINWOODY FM.
Pp - PHOSPHORIA FM.
Cq - QUADRANT FM.
Ca - AMSDEN FM.
Cm - MADISON FM.
D - THREE FORKS FM. - JEFFERSON FM.
Є - UNDIFFERENTIATED
pЄ - QUARTZITES & SCHISTS (PONY SERIES ?)

PROFILE AND ELEVATIONS ARE APPROXIMATED

HORIZONTAL SCALE
1 MILE

PLATE VI

asymmetrical to the east.

Strata ranging from the Quadrant to the Kootenai have been deformed by the anticline and are visible at the surface. From the position of volcanic flows and gravels on Patchtop Mountain, the dating of the folding can tentatively be set as Laramide or Early Tertiary in age.

Buford Creek syncline

The Buford Creek syncline is a shallow synclinal fold with an axial trend parallel to the Metzel Creek anticline. It lies 1 to 1½ miles east of the anticline.

East of Patchtop Mountain the pitch of the synclinal axis reflects the sharp upward pitch of the anticline. The eastern flank of the syncline gradually merges into the regional dip of the strata of the Gravelly Range. The Buford Creek syncline is a broad gentle downfold (Plate VI) compared to the more asymmetric nature of the Metzel Creek anticline.

The Dinwoody formation is the oldest formation exposed in the syncline; the Kootenai is the youngest. The age of the structure is Early Tertiary, coinciding with the age of the Metzel Creek anticline.

High-angle fault

In township T 12 S, R 39 E a high-angle fault (Plate V) is located approximately 1 mile north of and parallel to the east-west direction of the West Fork of the Madison River. It can be partially traced for a distance of 5 miles from

Fossil Creek across Cascade and Portal Creeks to a point beyond Lobo Creek.

The strike of the fault trends roughly east and west and is approximately normal to the regional dip of the sedimentary strata. The north side of the high-angle fault is upthrown. The displacement of several formations can best be seen in the gorges cut by Lobo, Cascade, and Fossil Creeks. At Lobo Creek, pre-Cambrian rocks have been upthrown against rocks of Cambrian age. In Cascade Creek (Plate VI) the Cambrian Pilgrim dolomite of the upthrown block is opposite the Madison formation on the downthrown side. Just east of Fossil Creek the Phosphoria formation is displaced against the Dinwoody formation. The average displacement of the high-angle fault is 600 feet.

Although the age of the high-angle fault is difficult to determine, west of Fossil Creek the fault ends under volcanics which are mid-Tertiary in age. From this evidence the faulting can be said to have occurred before the deposition of the volcanics.

PHYSIOGRAPHY

High erosion surfaces

A Tertiary erosion surface extends across the highest elevations of the Gravelly Range. Evidence for the erosion surface consists of the relatively uniform summit of the Gravelly Range and the waterworn gravels containing pre-Cambrian quartzite boulders which are found on these high areas. Basaltic flows, which form the highest elevations within the thesis area and to the north of it, overlie the gravels. Seven miles north of the thesis area Black Butte, a basaltic mass forming the highest elevation (10,560 feet) in the Gravelly Range, lies on the gravels (Atwood, 1945, pp. 191-200). The volcanic flows overlie an irregular surface eroded across rocks that range in age from Cretaceous to pre-Cambrian.

Atwood (1945, pp. 191-200) considers the gravels to be remnants of an Eocene moraine. He postulates that the deposition of the gravels in an Eocene basin is due to mountain glaciers descending from Eocene or Laramide mountain ranges. After peneplaination of the Eocene highlands a subsequent uplift of the basin, where the moraine was deposited, formed the present Gravelly Range with their highland gravels. From a study of the thesis area, however, the author does not believe the old gravels resemble glacial till. Lack of glacial evidence, such as the presence of striated boulders and bedrock, is absent.

In the northeastern corner of the thesis area, basaltic flows cover a wide area of underlying Paleozoic and pre-Cambrian rocks. The flows form a smooth, rolling surface about 9,500 to 10,000 feet high. The present surface is called Lobo Mesa. It is slowly being dissected and destroyed by headward erosion of the drainage and by the weathering of the volcanic rock. It is evident that two high surfaces (Plate VII) must be distinguished in future studies, namely; the one buried by

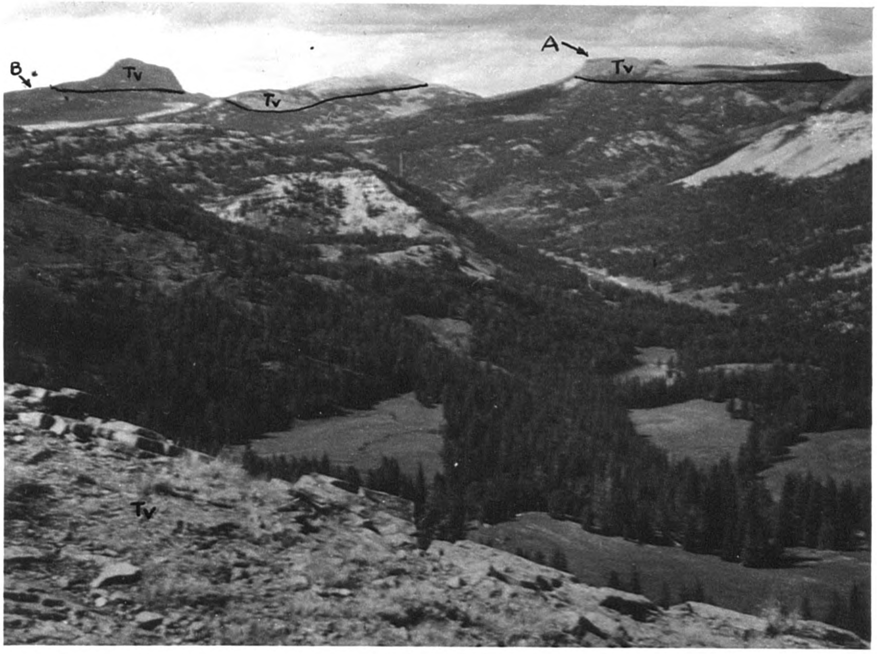


Fig. 1. Looking northwest from Lobo Mesa toward Black Butte and the deep gorge cut by Elk River. A—the present surface on Tertiary volcanics. B—old Tertiary surface below the volcanics.

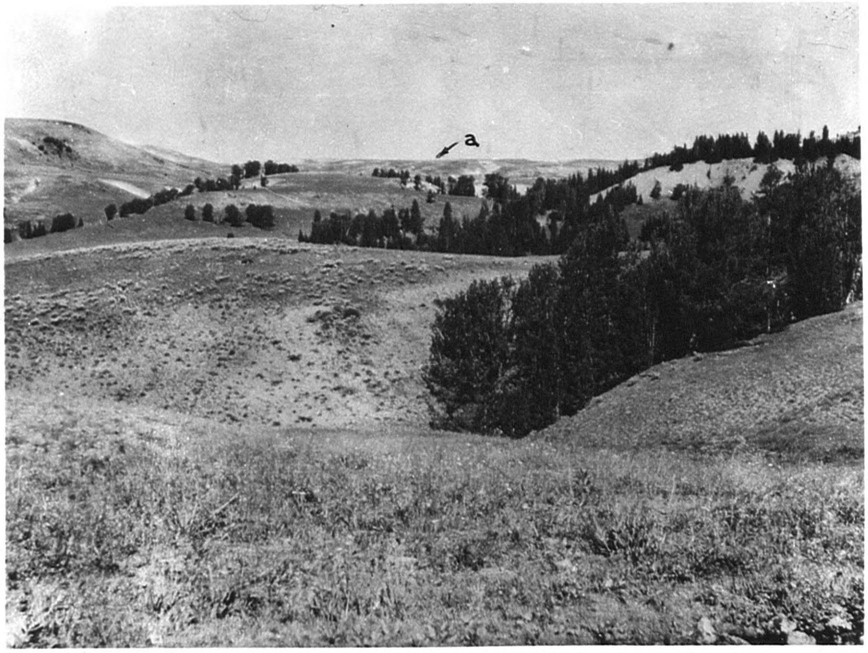


Fig. 2. The area near the south tributary of upper Fossil Creek where (a) the old Tertiary surface is present.

Plate VII. Erosion surfaces in the Gravelly Range the gravels and flows, and the one subsequently eroded on the flows. The present surface is the latter, but in the process of erosion, stripping of the flows and gravels has exposed areas of the former.

The gravels are most surely not morainal deposits, as Atwood (1945, pp. 191-200) suggests, but detailed study must cover more of the Gravelly Range before extended discussion is profitable.

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