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

by William J. Vaughn Jr.

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ABSTRACT

This report describes the geology in the vicinity of the West Fork of the Madison River in the southern part of the Gravelly Range, Beaverhead and Madison Counties, Montana. The region is in the Northern Rocky Mountain physiographic province and is characterized by steep V shaped valleys and generally flat topped mountain summits. The strata exposed within the area range in age from pre-Cambrian to Tertiary. Volcanic activity in the late Tertiary has produced lavas that have covered extensive areas in the region.

Laramide folding and mid-Tertiary block faulting have produced the major structural features in the area. Late-Tertiary regional uplift and subsequent erosion and dissection by the West Fork and its tributaries have produced the present mountains and valleys of the Gravelly Range.

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INTRODUCTION

Location of area

The area mapped is in the vicinity of the West Fork of the Madison in T 12 S, R 39 E and surrounding sections, Madison and Beaverhead Counties, Montana. It lies just north of the Centennial valley and is in the eastern half of the Beaverhead National Forest and the southern boundry coincides with the southern boundry of the National Forest. (Plate I)

Accessibility

The thesis area is reached by U. S. Highway 91 to Monida, Montana, thence eastward by graded road into the Centennial valley to the junction with the Long Creek road. The Long Creek road joins the Eureka Basin road north of the Centennial valley and provides access to the northern portion of the area. The Metzel Creek road turns northward from the Centennial Valley and provides access to the western portion of the area. The access roads are generally impassable during rainy weather. There are no roads in the interior of the thesis area and, therefore, it must be reached on foot.

Description of area

The topography within the thesis area is quite varied and can be divided roughly into three sections. The southern portion bordering the Centennial valley consists of low, rounded, sagebrush covered hills. The area through which

PLATE I

E Raisz

INDEX MAP

the West Fork of the Madison River flows has been deeply dissected by the West Fork and its major tributaries, causing striking gorges to be cut in some of the more resistant rock formations in the area. The northern portion of the area is one generally of high but subdued relief as it is less dissected, and portions of an extensive erosion surface are preserved. Elevations in the thesis area range between 7,000 and 10,000 feet above sea level.

Sagebrush is the dominant type of vegetation although some extensive conifer forests occur, especially in areas of extrusive volcanic rock.

Sheep are grazed in the summer months in the northern portion of the area. Placer gold deposits have been found in the stream gravels of the West Fork of the Madison River.

Previous work

Very little previous work has been done in the thesis area. D. D. Condit worked in the nearby Centennial Valley and Range and Snowcrest Range in 1918. Tansley, Schafer, and Hart worked in the Tobacco Root Mountains, the northern extension of the Gravelly Range, in 1933. Harold Scott and Atwood and Atwood worked in the Gravelly Range in 1938 and 1945 respectively, but were only concerned with the erosion surface in the area. The author could find no record of detailed mapping of the area in the literature and it is, therefore, assumed that none had previously been undertaken.

Purpose of study

The purpose of the study of the area under consideration was to map it in detail and work out the geology, so as to obtain material for a Master's thesis in Geology for the author at the University of Michigan.

Acknowledgments

The field work for this report was done in August, 1947 under the supervision of Dr. A. J. Eardley, Professor of Geology at the University of Michigan and Dr. Helen Foster. Dr. Eardley also supervised the writing of this report and preparation of the accompanying map. The work was done in conjunction with John Lemish, a graduate student at the University of Michigan, who accompanied the author in the field while mapping the area.

Valuable assistance in the field was offered by Fred Honkala, a graduate student at the University of Michigan within whose Ph. D. thesis area the author's area was located. During the last ten days in the field the author was assisted by Dean Cummins and William T. Smith, both of the University of Michigan.

The author is indebted to John Lemish and Dr. E. W. Heinrich of the Department of Mineralogy who studied thin-sections of the volcanic rocks of the area.

STRATIGRAPHY

General stratigraphy

The rocks in the West Fork of the Madison River area consist of consolidated sedimentary rocks, extrusive igneous rocks, pre-Cambrian schists and quartzites and unconsolidated gravels.

The formations range in age from pre-Cambrian to Tertiary and have a total thickness of over 4,668 feet. The regional dip is generally 10° SW varying slightly from place to place. (Plate II) The West Fork of the Madison River flows approximately normal to strike, thus exposing almost the complete stratigraphic section.

The rocks of the sedimentary sequence were laid down under changing geographic and environmental conditions. The Paleozoic rocks were deposited on the eastern margin of the Cordilleran geosyncline whose axis trended north-south and extended from southwestern Montana through southeastern Idaho and into western Utah. The geosyncline began it's subsidence in early Paleozoic time and reached its maximum amount of subsidence in Mississippian time (Eardley, unpublished data). The approximately 1000 feet of sediments deposited in the shelf area reflects the amount of subsidence in the main part at this time. Orderly deposition continued in the geosynclinal shelf area throughout the remainder of Paleozoic time, but the sediments did not reach the thickness of Mississippian time.

Deposition continued in the geosynclinal shelf area in Mesozoic time but not in such an orderly fashion as in Paleozoic time. The red beds of the Woodside formation suggest a period of continental deposition in a warm and relatively dry climate between two periods of marine deposition.

Conglomerates at the base of the Jurassic system and

Plate II. View looking north from Landon Ridge showing the regional dip 10° S.W. off the crest of the Gravelly Range. The West Fork of the Madison River is in the left foreground.

Lower Cretaceous Kootenai formation suggest periods of tectonic disturbance in this area. A major period of deformation of all the Paleozoic and Mesozoic sediments occurred at the close of the Cretaceous period and was responsible for the development of the major mountain ranges in this area.

The Tertiary was a period of continental deposition in southwestern Montana in which the mountain ranges were alternately high and low. Conglomerates and fine clastics were deposited in intermontane basins and considerable amounts of volcanic materials were extruded unconformably over the older sedimentary rocks. The Tertiary rocks present in the thesis area are represented by volcanic basalt flows and unconsolidated gravels.

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	Unknown
	Gravels	Unknown
Unconformity		
Lower Cretaceous	Kootenai	905
Unconformity		
Upper Jurassic	Undifferentiated (Ellis or Morrison)	244
Unconformity		
Lower Triassic	Thaynes	163
	Woodside	350
	Dinwoody	325

Permian	Phosphoria	235
Pennsylvanian	Quadrant	195
Lower Penn., Upper Miss.	Amsden	152
Lower Mississippian	Madison	940
Upper Devonian	Three Forks	197
	Jefferson	160
Disconformity		
Upper Cambrian	Dry Creek Shale	67
	Pilgrim	210
Middle Cambrian	Park shale	150
	Meagher	75
	Wolsey shale	100
	Flathead quartzite	200
Unconformity		
Pre-Cambrian	Pony (?) Series	Unknown
	Total	4,668

Pre-Cambrian system

Rocks of pre-Cambrian age crop out in the southeastern portion of the thesis area in the vicinity of the Landon Ranger Station and in the northeastern part in the Elk River Canyon. Rocks of the Cambrian system rest unconformably on them. They consist of schists and gray-white, dense, fine grained quartzites and appear to have characteristics similar to the pre-Cambrian rocks of the Pony Series of pre-Beltian Age described and named by Tansley (1933 p.8) from outcrops near the town of Pony, Montana in the Tobacco Root Mountains. The thickness of pre-Cambrian rocks is unknown.

Cambrian system

Rocks of the Cambrian system are found in the valley of the West Fork of the Madison River just west of the Landon Ranger Station and also in the Elk River Canyon. The Cambrian system was first mapped as undifferentiated by the author because of the lack of adequate information about the various members of the system. Later Honkala differentiated the system into the six members which correspond to those mapped by Weed (1899) in the Fort Benton quadrangle, Montana and Peale (1893) in the Three Forks quadrangle, Montana.

Flathead quartzite. The Flathead quartzite was observed in a gorge cut by the West Fork of the Madison River near the Landon Ranger Station. (Plate III) It consists of thin bedded to massive, fine grained, whitish, quartzitic sandstone which contains reddish brown and green inclusions. It is 200 feet thick. The formation was named by Peale (1893, p.20) for exposures in Flathead Pass in the N.E. corner of the Three Forks quadrangle, Montana. It is Middle Cambrian in age and overlies unconformably the pre-Cambrian metamorphic rocks.

Wolsey shale. The Wolsey shale does not form definite outcrops in the area, but is represented by a covered slope that represents 100 feet of beds. The shale overlies the Flathead quartzite and underlies the Meagher formation. It was named by Weed (1900, p.285) from exposures near Wolsey, Montana. It is Middle Cambrian in age.

Meagher formation. The Meagher formation which overlies the Wolsey shale in the report area is a gray to buff, thin bedded to massive dolomitic limestone and measures 75 feet

Plate III View looking east down the West Fork of the Madison River showing the canyon cut through the Flathead quartzite in the background and Pilgrim dolomite in the foreground.

in thickness. It was first described by Weed (1899) in the Little Belt Mountains folio and mapped as part of the Barker formation. Large exposures occur in Meagher County, Montana. It is Middle Cambrian in age.

Park shale. The Park shale forms a covered slope in the valley of the West Fork of the Madison River approximately 150 feet high. The Park shale was first described by Weed (1899) and included in the Barker formation. It is Middle Cambrian in age.

Pilgrim formation. Outcrops of the Pilgrim formation in the vicinity of the West Fork of the Madison River form massive cliffs. The rock is a buff, coarse grained dolomitic limestone, blocky and massive at outcrops. The formation is 210 feet thick. It was first described and named by Weed (1899) from exposures in Pilgrim Creek in the S.W. corner of the Fort Benton quadrangle, Montana. It is Upper Cambrian in age.

Dry Creek shale. The Dry Creek shale overlies the Pilgrim formation in the uppermost formation of the Cambrian system in the thesis area. It consists of red calcareous siltstone with seams of calcite. 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 67 feet thick in the thesis area. The formation was named by Peale (1893) from exposures in Dry Creek N.E. corner of the Three Forks quadrangle, Montana.

Devonian system

Jefferson formation. The rocks of the Devonian system overlie the Cambrian Dry Creek shale disconformably in the thesis area. The Cambrian Dry Creek shales underlie rocks of Upper Devonian age (Sloss and Laird, 1947, p.1404).

The formation was originally described and named by Peale (1893, pp. 25-32) from exposures in the Three Forks area, Montana, who considered the Jefferson formation Middle Devonian in age and the overlying Three Forks shales Upper Devonian. Studies by Sloss and Laird (1947, pp.1404 -1431), however, lead them to place both formations in the Upper Devonian. The Jefferson formation consists of a dark gray, fossiliferous, thin bedded to massive limestone, 160 feet thick.

Three Forks formation. The Three Forks formation is rather widespread in Montana, western Wyoming, southeastern Idaho and northern Utah. Where exposed along the West Fork of the Madison River it measures 197 feet in thickness and is composed of four lithologic units, as follows in descending order:

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

The formation was named by Peale (1893, p.29) from exposures in the Three Forks quadrangle where he found five lithologic units consisting of the following in descending order:

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

Mississippian system

Madison formation. In the thesis area the Madison formation is one of the most conspicuous, and forms cliffs approximately 1000 feet high along the Elk River canyon and Cascade Creek. Along the West Fork of the Madison River it is 940 feet thick.

Parts of the formation have 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 and massive blue gray limestone. A massive gray limestone with abundant chert nodule inclusions forms the upper part of the formation.

The formation was named by Peale (1893, p.32) from exposures in the Madison Range, Montana, and is widespread throughout Montana, Wyoming, Idaho, and northern Utah. It is considered lower Mississippian (Kinderhook) in age.

Pennsylvanian system

Amsden formation. The Amsden formation overlying the Madison limestone crops out along the West Fork of the

Madison River where it was measured to be 152 feet thick. Four major lithologic units were found in the West Fork area, as follows in descending order:

4. Covered slope, contains red sandstone fragments
3. Limestone, gray with red chert nodules at top of unit grading into gray limestone mottled with yellow spots in the center portion and a lithographic limestone unit at the base
2. Sandstone, cream to buff calcareous
1. Covered slope, contains reddish yellow shale and sandstone fragments

The formation was originally described and named by Darton (1904, p. 396) from exposures along the Amsden Branch of the Tongue River, Wyoming. The lower portion of the formation is considered Upper Mississippian in age and the upper portion is Lower Pennsylvanian (Berry, 1943, pp. 19-20).

The Amsden was included in the lower portion of the Quadrant formation described by Peale (1893) but later investigation by Berry (1943) has revealed it to be equivalent to the Amsden described by Darton.

Quadrant formation. The Quadrant is found along the West Fork of the Madison River and overlies the Amsden formation. Here it consists mostly of quartzitic sandstones and dolomitic limestones and measures 195 feet in thickness. The outcrops are partially hidden by quartzitic sandstone talus slopes.

The Quadrant formation was named by Peale (1893, pp.39-43) from exposures in the Quadrant Mountain in the Gallatin Range, Montana. It originally included all rocks of Upper Mississippian and Pennsylvanian age which rest upon the Madison limestone in the Montana area (Peale, 1893). Berry (1943, pp.19-20) and Scott (1935, p.1019) consider the basal part of the Quadrant formation equivalent to the Amsden formation named by Dārton (1904). The upper part of the Quadrant formation is considered a westward extension of the Tensleep formation of Wyoming (Darton, 1904, p.397 and Condit, 1918, pp. 111 - 121).

Permian system

Phosphoria formation. Within the thesis area the Phosphoria formation forms very conspicuous outcrops, capping small buttes and bold escarpments. The formation consists mainly of the Rex chert member which is composed of a yellow to buff massive, chert bed and an underlying gray, quartzitic sandstone and lacks the phosphatic shales and limestones characteristic of the formation in other areas. It measures 235 feet in the area and overlies the Quadrant formation without apparent unconformity. The Phosphoria formation was named after Phosphoria Gulch near Meade Park, Idaho, where exposures were described by Richards and Mansfield (1912, p. 684).

Triassic system

Dinwoody formation. The Dinwoody formation is the basal Triassic unit in the thesis area, overlying the Permian Phosphoria formation. It consists of a tan sandy limestone at the top with alternating shales and calcareous sandstone at the base.

Fossils collected from this formation have been identified by Honkala as:

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

The formation was named by Blackwelder (1918, p.425) for Dinwoody Canyon, Wyoming where it is typically exposed. It is lower Triassic in age.

Woodside formation. The Woodside formation is exceptionally well exposed in the northwestern part of the thesis area along Fossil Creek where it was measured by John Lemish and the author. It is composed of 350 feet of fine grained, thin bedded, brick-red siltstones and shales forming one continuous lithologic unit.

The formation was named from exposures in Woodside Gulch, Park City District, Utah, byBoutwell (1907, pp.439 - 458). It is Lower Triassic in age.

Thaynes formation. The Thaynes formation is found overlying the Woodside formation conformably and is well exposed along Fossil Creek in the same locality as the Woodside. It has a thickness of 163 feet.

The Thaynes formation was named after exposures in

Thaynes Canyon, Park City District, Utah by Boutwell (1907, p.448). It extends over Utah, Wyoming, and Idaho but is not commonly recognized in southwestern Montana.

The Thaynes formation was measured in detail by Lemish and the author along a tributary of Fossil Creek in section 4 of T 12 S, R 39 E and into section 33 T 11 S, R 39 E. In descending order from the uppermost unit the formation consists of the following units:

Unit		Thickness in feet
15.	Shale, light gray, thin bedded	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"
11.	Limestone, cream to white, weathers tan and white; 4' 3" below unit 12 a 6" fossiliferous yellow limestone bed is found containing gastropods, pelecypods and a _Meekocerus_ cephalopod.	49' 7"
10.	Siltstone, red, calcareous, thin bedded	15' 0"
9.	Limestone, white, thin bedded	3' 7"
8.	Shale, calcareous, red shales alternating with thin bedded limestone stringers	27' 6"
7.	Shale, calcareous, red shales alternating with white thin bedded limestone	3' 8"
6.	Alternating limestone 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' 0"
1. Limestone, white 1' 11"

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

Fossils collected by Lemish and the author from unit 11 were identified by Honkala as follows:

1. Meekoceras gracilitatis White
2. Monotis thaynesiana
3. Myalina postcarbonica Girty
4. Terebratula
5. Gastropod sp. indet.
6. Monotis sp.
7. Aviculapectin sp.
8. Natica sp.

Jurassic system

Above the Thaynes formation is a section of 244 feet of shales, limestones and sandstones that have been tentatively identified as undifferentiated Jurassic by the author. The lithology of this sequence resembles features of the members of the Ellis group; however, no fossil evidence was found to correlate the sequence with the Ellis. At the base of the Jurassic section is a one foot thick conglomerate that may represent an episode of erosion and peneplantion that has been reported by Condit (1918, p.120) in Montana before Late Jurassic time.

The section was measured in detail by Lemish and the author along Fossil Creek in section 4 of T 12 S, R 39 E, and into section 33 of T 11 S, R 39 E. 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' 0"
43.	Sandstone, pinkish-gray, not well indurated, green shale parting 1' from bottom of unit	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 green again	2' 8"
40.	Shale, gray shale; various colors seen in bed from yellow to reddish brown	27' 1"
39.	Sandstone, massive, light gray	2' 3"
38.	Shale, gray	3' 0"
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 inter - bedded 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; 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"
20.	Limestone, gray, arenaceous, massive, blocky	12' 5"
19.	Shale, gray	10"
18.	Limestone, gray, lithographic, weathers lighter gray	1' 0"
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.	Limestone, argillaceous, with green pebble inclusions one-eighth inch in diameter	1' 3"
9.	Covered unit, shaley	6' 0"

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 3' shaley conglomerate	3'	0"
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 unit, (shale or sandstone) gray green sands cover slope	39'	8"
4.	Sandstone, massive dark gray-green argillaceous, weathers rounded, iron stained	2'	6"
3.	Covered, gray-green sandy covered slope	5'	5"
2.	Conglomerate, white calcareous matrix, contains white limestone pebbles		11"
1.	Conglomerate, maroon matrix, limestone pebbles, calcite veins common	1'	0"

Unit 15 of the Thaynes formation lies below unit 1.

Cretaceous system

Kootenai formation. Unconformably overlying the Jurassic rocks in the thesis area is a thick series of rocks of continental origin consisting of a basal conglomerate, coarse sandstones, shales and fresh water gastropod limestones. The basal conglomerate was also reported by Winchell (1914) in the Dillon Quadrangle. These rocks are found in the northwestern part of the area and cap the higher portions of the Gravelly Range and the westward dipping slope (Plate IV). This series is the Lower Cretaceous Kootenai formation which was first described by J. W. Dawson (1885, pp. 531-532) from exposures in southern Alberta where it contains coarse

Plate IV Looking southwest down a graben like valley cut in the Kootenai formation on the crest of the Gravelly Range. Ridge in background is west flank of Buford Creek syncline.

sandstones, shales and conglomerates with seams of coal in places. The name Kootenai was proposed by G. M. Dawson (1885, p.162 B) from a tribe of Indians of that name who hunted over this area of the Rocky Mountains. The formation was placed in the Lower Cretaceous on evidence from fossil flora by G. M. Dawson (op.cit.).

Overlying the Kootenai are remnants of Tertiary volcanic lava flows and gravels. The Colorado shale which is usually found overlying the Kootenai in western Montana is absent in the thesis area. The formation was measured in detail by Lemish and the author in the same general area as where the Triassic and Jurassic systems were measured. In descending order the section consists of the following units:

Unit		Thickness in feet	
11.	Limestone, gastropod horizon, coarsely crystalline, fractured	10'	6"
10.	Shale, gray, blocky, weathers white to gray	62'	0"
9.	Limestone, dense, blocky pebble inclusions	2'	0"
8.	Shale, gray, deeply weathered slope	105'	0"
7.	Shale, red, deeply weathered	63'	0"
6.	Sandstone, white, fine grained, pinkish cast on fresh surface, weathers brown, shows excellent cross-bedding, fractures into flagstone slabs, basal part pebble conglomerate 3" thick	94'	5"
5.	Shale, gray to buff, calcareous deeply weathered	26'	3"

4.	Shale, transition zone from white to red shale, clastic dikes and conglomeritic in places, shale dense to fissile; 1' thick pebble limestone 5' 3" from top; deep maroon slope covers bottom 5' 3" of unit	43'	5"
3.	Covered, white slope, probably calcareous shales and sandstones, greenish-gray when wet, gastroliths found in unit	52'	6"
2.	Sandstone, white to light gray, coarse grained, massive where outcrops appear on slope	42'	0"
1.	Covered, sandstone, coarse grained salt and pepper, weathering light gray, basal conglomerate of pebbles in coarse, gray to tan salt and pepper type sandstone matrix.	168'	0"
	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 minimum thickness of the Kootenai formation in the area is 904 feet.

Another section of the Kootenai was measured near the source of Buford Creek, in section 17 T 12 S, R 39 E where a cliff of alternating limestone and carbonaceous shales occurs. The lack of detailed exposures in the Fossil Creek section (cf.p.24) prevents the location of Buford Creek section within the Kootenai formation. The section, however, 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 partially covered slope	5' 3"
19.	Shale and limestone, paper-thin shale and crenulated limestone limestone contains gastropods	1' 0"
18.	Limestone, blue-gray, lithographic	9"
17.	Limestone, gray, gastropods present	1' 8"
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, paper thin, black shales in center of unit	4' 4"
14.	Shale, gray, fissile, 5" carbonaceous shale unit in center	25' 0"
13.	Limestone, gray, thin bedded, weathers white	5"
12.	Shale, black, paper thin	7"
11.	Limestone, gray gastropods present	5"
10.	Limestone, alternating limestones and paper thin shales	16' 0"
9.	Shale, gray to black, paper thin carbonaceous	5' 8"
8.	Limestone, massive, fossiliferous (grastropods and 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, gray, fissile, paper thin	1'	6"
3. Limestone, gray, massive	2'	2"
2. Shale, dark gray, partly covered	2'	6"
1. Limestone, gray, massive to thin bedded cut by calcite veins	4'	7"
Total	93'	11"

Tertiary system

Gravels. The Tertiary was a period of erosion and continental deposition in southwestern Montana. Intermontane basins were filled with conglomerates and fine clastics and considerable amounts of extrusive igneous rocks. Within the thesis area the only representatives of the Tertiary are unconsolidated gravels and volcanic lavas which lie unconformably upon the older Paleozoic and Mesozoic rocks.

Unconsolidated gravels consisting of pre-Cambrian quartzites and schists as well as younger Paleozoic and Mesozoic rocks are found scattered throughout the thesis area. There is a thin veneer of these gravels lying on the Kootenai formation on the relatively flat summit of the Gravelly Range which has been reported as Eocene till by Atwood (1945, pp.191-200) and Scott (1935, pp.1011-1031); Honkala, Lemish and the author found no evidence, however, to support this theory. Rather, the gravels are thought to be pediment or channel gravels of a late Tertiary erosion surface. More detailed and regional work is necessary to determine their age and origin.

Volcanic lavas. 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 as Fossil Peak, Cascade Mountain, Patchtop Mountain and Divide Mountain. The thickness of the flows is not uniform within the area and range between a few feet to over 400 feet. The age of the volcanic rocks is considered mid-Tertiary by Atwood (1945, pp. 191 - 200), but without fossil evidence.

A megascopic examination of the volcanic rocks show that they consist mostly of dark basalts and a few pinkish gray, light colored rocks. The texture varies from a dense, fine grained type to the amygdaloidal variety in which calcite and small geodes fill the cavities. Small brownish-red phenocrysts are present in most of the dark basalts which represents some type of alteration. The lighter colored volcanic rocks appear to be sanidine trachytes because of the glassy feldspar phenocrysts present.

A thin section analysis of a black, fine grained 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 minerals present are olivine and two pyroxenes, augite and pigeonite. 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 the accessory minerals magnetite and apatite. Iddingsite, serpentine and calcite are the alteration products. Calcite occurs in thin veins or over wide areas throughout the thin section.

A microscopic study of the lighter colored volcanic rocks 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 or 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, seen about the phenocrysts, could indicate movement of the rock while cooling.

Depositional environment

The Paleozoic and Mesozoic formations in the thesis area have an aggregate thickness of about 4,700 feet, thus indicating clearly they were not deposited in a geosynclinal trough. Stewart R. Wallace and Henry H. Krusekopf, graduate students at the University of Michigan, mapped an area in Tendoy Mountains fifty miles due west of the Gravelly Range and found generally the same formations have an aggregate thickness of about 14,000 feet. It is, therefore, evident that the Paleozoic and Mesozoic formations in the Gravelly Range were deposited in a marginal or shelf zone whereas those in the Tendoy Mountains represent deposition in a geosynclinal zone.

Structure

Regional features

The mountain ranges of southwestern Montana have a diverse arrangement. The Lemhi and Beaverhead Mountains trend northwest-southeast, the Tendoy and Red Rock Mountains trend generally north-south, the Snowcrest, Ruby and Gravelly Ranges trend northeast-southwest, and the Centennial Mountains trend east-west. (Plate I). A complex structural history is thus expected.

The structural features of the Gravelly Range indicate two periods of orogeny; one of Laramide time and one of mid-Tertiary time. The Laramide structures are represented generally by northwest-southeast trending folds, whereas the Mid-Tertiary structure is represented by high angle, normal faulting.

The Gravelly Range lies between two major zones of Laramide thrusting. To the west is the Tendoy thrust mapped by Wallace (1947) which may be a northern extension of one of the major thrust sheets mapped by Kirkham (1929, pp.26-29) in Idaho. To the east along the Rocky Mountain Front is a second major thrust zone which has been mapped by Bevan (1929, pp. 427-456).

Laramide structures

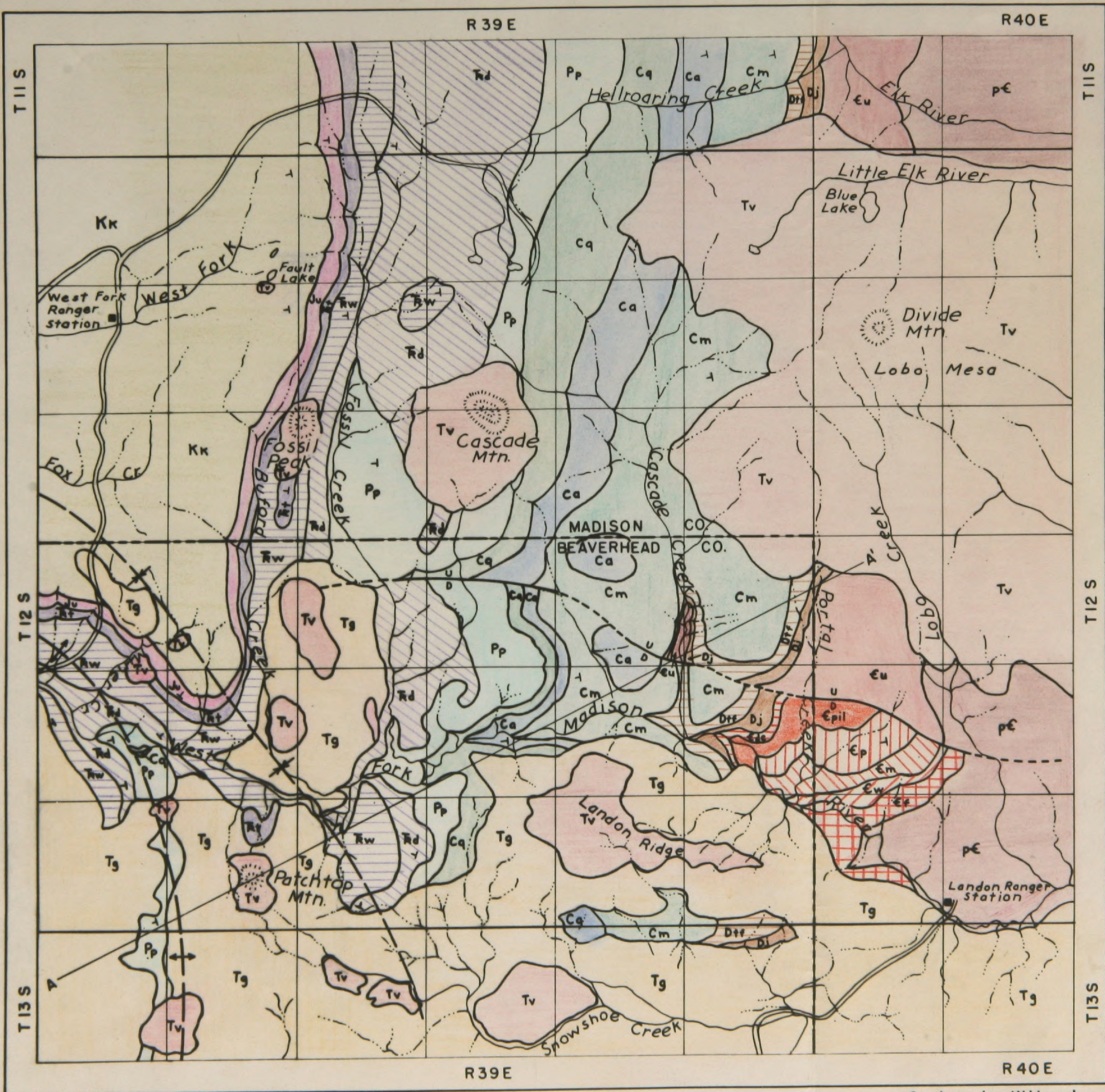
It appears evident from field investigation that the

Gravelly Range suffered deformation during a part of the Laramide orogeny as all the Paleozoic and Mesozoic rocks in the thesis area are uniformly folded. The deformation was less severe in the Gravelly Range and surrounding areas than it was in the Tendoy Mountains to the west, which were thrust faulted, as evidenced by the presence of lignite coal in the Mesaverde formation (?) of Upper Cretaceous age in the Ruby River valley between the Gravelly and Snowcrest Ranges, (Fred Honkala, personal communication).

The Paleozoic and Mesozoic strata dip uniformly 10° to the southwest off the summit of the Gravelly range (Plates II &VI) and pass into two northwest-southeast trending folds. Tansley (1933, pp. 1-22) considers the Gravelly Range the southern extension of a north-south trending, doubly plunging anticline whose axis passes close to the crest of the Range. The gently dipping limbs are all that remain of the eroded structure today. The author did not see the eastern side of the Gravelly Range and, therefore, cannot corroborate Tansley's statements. However, a westward dipping slope is present which lends the suggestion that it is the western flank of an eroded anticline or at least a monoclinal fold.

The westward dipping slope of the Gravelly Range passes into two northwest trending folds; the Buford Creek syncline and the Metzel Creek anticline. (Plate V) The Metzel Creek anticline is located in the southwestern corner of T 12 S, R 39 E. The West Fork of the Madison River flows along the axis of the Metzel Creek anticline to a point about one mile

PLATE V



LEGEND

TERTIARY	Tg	Gravels
	Tv	Volcanic
CRETACEOUS	Kk	Kootenai Fm.
JURASSIC	Ju	Undifferentiated
TRIASSIC	Ћt	Thaynes Fm.
	Ћw	Woodside Fm.
	Ћd	Dinwoody Fm.
PERMIAN	Pp	Phosphoria Fm.
PENNSYLVANIAN	Cq	Quadrant Fm.
PENN.-MISS.	Ca	Amdsen Fm.
MISSISSIPPIAN	Cm	Madison Fm.
DEVONIAN	Dtf	Three Forks Fm.
	Dj	Jefferson Fm.
CAMBRIAN	€dc	Dry Creek Fm.
	€pil	Pilgrim Fm.
	€p	Park Fm.
	€m	Meagher Fm.
	€w	Wolsey Fm.
	€f	Flathead Fm.
	€u	Undifferentiated
PRE-CAMBRIAN	p€	Pony Series (?)

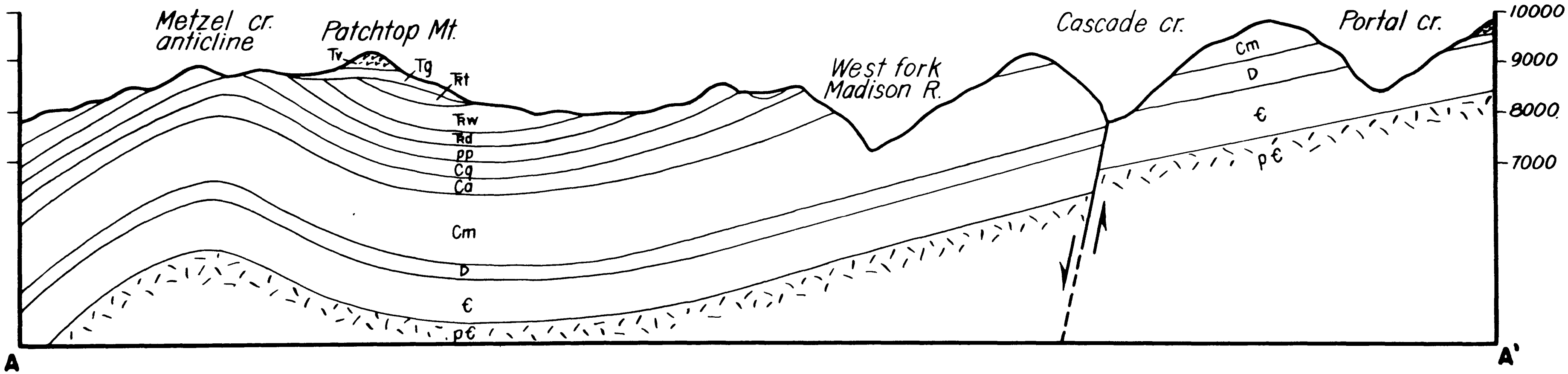
0 1/2 1 2 MILES

SCALE

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



SECTION ALONG A-A'
PORTAL CREEK TO METZEL CREEK ANTICLINE

EXPLANATION

Tv	VOLCANICS	Cq	QUADRANT FM.
Tg	GRAVELS	Ca	AMSDEN FM.
₸t	THAYNES FM.	Cm	MADISON FM.
₸w	WOODSIDE FM.	D	THREE FORKS FM.
₸d	DINWOODY FM.		JEFFERSON FM.
Pp	PHOSPHORIA FM.	€	UNDIFFERENTIATED

P€ QUARTZITES & SCHISTS (PONY SERIES)

PROFILE AND ELEVATIONS ARE APPROXIMATED

HORIZONTAL SCALE

1 MILE

W. VAUGHN J. LEMISH

PLATE VI

to the south of Miner Creek where it cuts across to the east as the axis of the anticline curves to the south just west of Patchtop mountain. The anticline is doubly plunging and slightly asymmetrical with the steeper flank on the east. The Quadrant formation is the oldest formation exposed in the core of the anticline.

About 1 to 1½ miles to the east of the Metzel Creek anticline and following the same general axial direction is the Buford Creek syncline. The eastern flank of the syncline gradually merges into the dip of the strata of the western slope of the Gravelly Range. The syncline is a broad gentle downfold as compared to the asymmetric nature of the Metzel Creek anticline. The oldest formations exposed in the syncline is the Dinwoody formation of Lower Triassic age and youngest formation is the Kootenai of Lower Cretaceous age.

Post-Laramide (?) faulting

Approximately one mile north and generally paralleling the West Fork of the Madison is a high angle normal fault. The fault can be partially traced for about six miles, starting from a point near Fossil Creek on the west to near Lobo Creek on the east. The north side of the fault is the upthrown side having a displacement of approximately 600 feet. The displacement can best be observed near Fossil Creek where the Phosphoria formation of Permian age and the Quadrant formation of Pennsylvanian age are in contact with the Dinwoody formation of Lower Triassic age, and in Cascade Creek where the Madison formation of Mississippian age is in contact with the Pilgrim formation of Upper Cambrian age.

The dating of the fault is made difficult by the fact it is observed only displacing rocks of Paleozoic and Mesozoic age and only appears to pass under some Tertiary volcanic lavas whose age is not accurately determined. The faulting may be of Miocene age which is the age of other Tertiary normal faulting in southwestern Montana; however, there is no conclusive evidence to point to this.

Tentative Summary of events in the
Geologic History of S. W. Montana

Paleozoic	Fairly uniform deposition in subsiding geosynclinal trough and shelf zone
Triassic	Continental and marine deposition
Jurassic	Local uplift and erosion in post-Triassic; marine deposition in U. Jurassic
L. Cretaceous	Uplift and erosion. Continental deposition
Upper Cretaceous and E. Paleocene	Early Laramide thrusting and folding of Paleozoic and Mesozoic Rocks
Paleocene	Erosion of thrust sheets and deposition of Red Rock conglomerate
Late Paleocene	Continued Laramide folding Deformation of Red Rock conglomerate
Eocene	Erosion to mature stage and development of intermontane basins
Upper Eocene	Deposition of Sage Creek formation
Oligocene	Continued deposition in intermontane valleys
Miocene	Deposition of Ruby River Reservior beds accompanied by vulcanism
Upper Miocene	High angle normal faulting
Pliocene	Development of high erosion surface
Pleistocene	Regional uplift and mountain glaciation
Recent	Erosion producing present topography

Physiography

General features

The Gravelly Range is located in the Northern Rocky Mountain physiographic province, Fenneman (1931). The Range forms a ridge approximately ten miles wide which divides the Ruby drainage from the Madison. It extends northward 35 miles from the Centennial Valley to Virginia City. The northern extension of the range beyond Virginia City is known as the Tobacco Root Mountains. The elevations range from about 7,000 to 10,000 feet above sea level.

Within the thesis area a variety of landscapes may be found. The southern portion of the area north of the Centennial Valley is characterized by low rounded hills with few rock outcrops and is drained by intermittent streams. (Plate VII).

North of Landon Ridge the area has been deeply dissected by the West Fork of the Madison River and its tributaries which have formed steep sided valleys and gorges where the streams have crossed resistant formations. (Plate III).

In the northern section of the area where the permanent streams head, the features are more subdued and dissection is much less pronounced. Several extensive high surfaces are found in the northern portion which have been postulated to be remnants of an old erosion surface.

Glaciation

Within the limits of the thesis area no evidence of Pleistocene glaciation, such as U shaped valleys, cirques or morainal material was found by the author; however,

Plate VII The southern portion of the thesis area north of the Centennial Valley showing the low rounded hills and generally subdued landscape.

Tansley (1933, p.6) found ample evidence of Pleistocene glaciation in the Tobacco Root Mountains, the northern extension of the Gravelly Range. Honkala (personal communication) found several glaciated valleys and small terminal moraines in the Snowcrest Range immediately to the west of the Gravellys.

In the vicinity of Fault Lake a thin veneer of gravelly material overlies the relatively flat crest of the range composed of quartzites, schists, gneisses with some Paleozoic rocks. Scott (1938, pp.628-636) and Atwood (1945, pp.191-199) have referred to these gravels as remnants of an Eocene moraine that was deposited on what is now the crest of the Gravelly Range. Eardley (personal communication) states that the climate of the Eocene in the Rocky Mountain region was a warm and humid one; it was incompatible for the existence of either mountain or sheet glaciers, and that the gravels are either coarse pediment or channel clastics related to an old erosion surface. Since the highest erosion surfaces in northwestern Wyoming are considered Pliocene or early Pleistocene in age, it seems unlikely that the gravels could be Eocene.

Erosion surface

In the northern portions of the thesis area are several remnants of a high level erosion surface approximately 9,500 feet above sea level. This surface is exceptionally well developed on Lobo Mesa in the vicinity of Divide Mountain (Plate VIII) and north of Fault Lake. The surface on Lobo Mesa is cut on lava flows of Miocene age (?) while at the

Plate VIII Looking north on Lobo Mesa showing a remnant of the erosion surface cut on Tertiary lavas. Elevation approximately 9,800 feet.

Fault Lake area it has been cut on the Kootenai formation of Lower Cretaceous age. In both places a thin veneer of gravels cover the surfaces. Scott (1938, pp.628-636) and Atwood (1945, pp.191-199) have referred to this surface as well as the gravels which cover it as Eocene in age. Rich (1916, pp. 89-90) disagrees with the Eocene dating of similar erosion surfaces in Idaho and Montana by Umpleby (1912, pp.139-197) and Atwood (1916, pp.697-740). He points out that the basins in which Miocene sediments were deposited suffered deformation before the peneplain was cut. As the surface developed on Lobo Mesa is on lavas of Miocene age (?), the surface must be dated at least post-Miocene and it is probably Pliocene in age.

Subsequent uplift in Pleistocene and Recent time have caused the West Fork of the Madison River to cut across on the underlying structure, and together with its tributaries has dissected the surface leaving only a few remnants within the thesis area.

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