GEOLOGY OF THE McKENZIE CANYON AREA

May 20, 1949

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Dr Eardley
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thesis of R. L. Davis
written with Planck

Dan Bradley

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May 20, 1949

Submitted in partial fulfillment of the requirements of a Master of Science Degree in Geology, University of Michigan.

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ABSTRACT

The McKenzie Canyon Area is in the extreme southwestern part of Montana. The sedimentary rocks exposed in this area are upper Paleozoic, Mesozoic and Tertiary in age. Metamorphic pre-Cambrian rocks are also present. Tertiary mineralization has occurred along high angle fault contacts. Vulcanism is represented by tuffs and breccias. The two major periods of orogenies are Laramide and mid-Tertiary. Early Laramide deformation caused northeasterly trending folds. This was followed by the deposition of the Red Rock conglomerate in Paleocene (?) time. Further Laramide deformation took place, after which Laramide thrusting from west to east occurred, forming the Medicine Lodge and Tendoy thrusts (which overlay the Red Rock conglomerate) and the Beaverhead thrust. Erosion and the deposition of basin beds followed, accompanied by volcanic activity. During this time, mid-Tertiary high angle faulting took place of the horst and grabben type. The Tendoy Mountains are formed by a horst block while the Medicine Lodge valley is a grabben. The three erosional surfaces in the area are believed to correlate with surfaces described by Blackwelder in Wyoming and have tentatively been called Blackrock, Circle, and present surfaces.

INTRODUCTION

Location of Area

The McKenzie Canyon Area is located in Beaverhead County in the southwestern corner of Montana. Most of the area is in Township 17 North and Ranges 10 and 11 West. See index map, plate 2. The northern boundary lies in the middle of Township 17 North and the southern boundary is the line between Townships 16 and 17 North except for the eastern third of the area which extends four miles south of this line. The eastern limit of the area is two miles west of the boundary between Ranges 9 and 10 West. The area extends westward to include the river bottom of Medicine Lodge Creek.

Description of Area

The McKenzie Canyon Area includes about fifty square miles and has a local relief of approximately 2,500 feet. The lowest part of the area, with an elevation of about 5,500 feet, is the valley of the Red Rock River to the east. A few peaks in the area rise above a broad rolling upland surface with an elevation of about 8,000 feet. The upland is broken by abrupt escarpments of Madison Limestone which have formed along high angle faults and thrust faults.

There are no permanent streams in the mountains themselves, but Medicine Lodge Creek on the west and Red Rock River on the east are permanent streams and part of the head waters of the Missouri River.

U. S. Highway 91 which parallels the east front of the Tendoy Mountains and the Medicine Lodge Road paralleling the west front of the mountains are the only two roads in the immediate area which are passable in rainy weather. The Medicine Lodge Road may be reached from U. S. Highway 91 by the Salmon River Road which connects with the Highway at Armstead. See index map, plate 2. There are many wagon trails which may be used in dry weather to reach the inner parts of the area. Perhaps the best of these are the Bell Canyon Road on the east and the Deer Canyon Road on the west.

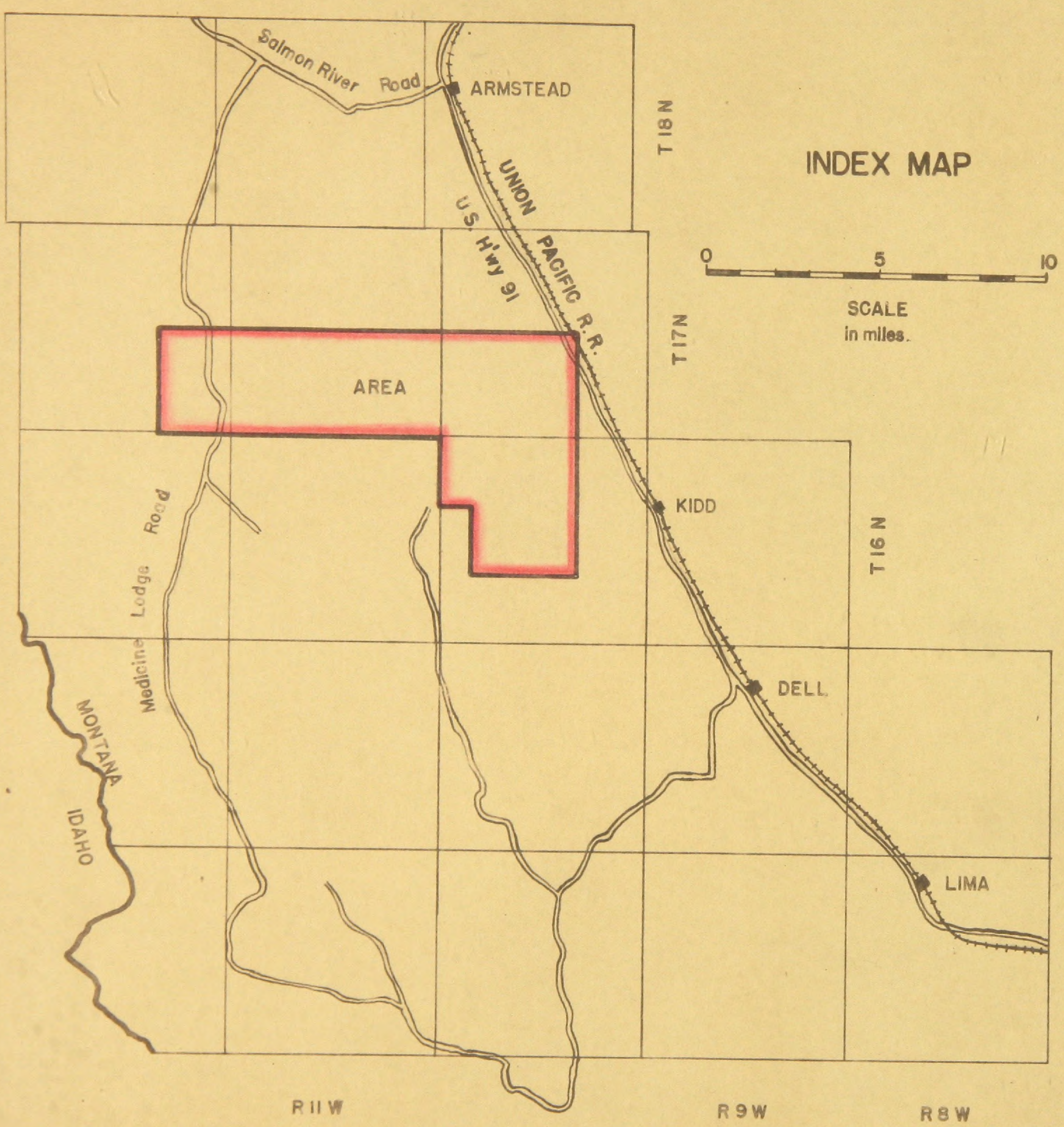
The area has an arid climate with an annual average precipitation of 9.27 inches. The January average temperature is 16.3°F. and the July average temperature is 62.9°F. The annual mean temperature is 39.3°F. These data have been taken from "Climate of the States, Montana", Agriculture Yearbook, Separate Number 1844, Washington 1941, and were obtained from observations by the U. S. Weather Bureau at Lima, Montana. The dominant vegetation in the area is sage brush. However, conifers are present on the higher slopes, indicating considerably more rainfall in the higher portions of the area. The valleys are utilized in the growing of wild hay, and sheep and cattle graze on the slopes in the summer time, being fed by the harvested hay in the winter.

Previous Work and Study

The first work in this area of any importance was done during the summer of 1946 by E. S. Perry and Juno M. Sahinen of the Montana School of Mines. This work was a reconnaissance map of a large area which includes the McKenzie Canyon Area. During the same summer, W. Lowell mapped part of the area in detail but the result of this work is as yet unobtainable. In 1947 a group of students from the University of Michigan working on Masters of Science in Geology degrees mapped areas to the south and east of the McKenzie Canyon Area. In the summer of 1948, W. T. Smith and D. L. Cummings, also from the University of Michigan, mapped the area immediately to the south. Part of this area is included in the geologic map of the McKenzie Canyon Area with a few changes which became necessary when further study revealed a different structural picture. J. A. Seglund and G. F. Bowers of the University of Michigan worked in the area to the north of the McKenzie Canyon Area at the same time. Also during the summer of 1948, W. D. Kupsch mapped the general area of the Tendoy Mountains as a doctor's thesis for the University of Michigan.

Acknowledgments

This report was written under the direction of Professor A. J. Eardley of the University of Michigan in partial fulfillment of the requirements for a Master of Science degree in Geology. The author is also indebted to Professor Eardley for his assistance in the compilation of the geologic map of the McKenzie Canyon Area. The geologic mapping was done jointly by Robert I. Davis and the author. Additional assistance was given by Dr. E. W. Heinrich of the University of Michigan and W. O. Kupsch, graduate student at the University of Michigan.


INDEX MAP
Salmon River Road
ARMSTEAD
UNION PACIFIC R.R.
U.S. H'wy 91
AREA
KIDD
DELL
LIMA
Medicine Lodge Road
MONTANA
IDAHO
T 18 N
T 17 N
T 16 N
T 15 N
T 14 N
R 11 W
R 9 W
R 8 W
0
5
10
SCALE
in miles.

STRATIGRAPHY

Stratigraphic Column

The McKenzie Canyon Area is composed essentially of three thrust sheets and the stratigraphic column for the area is rather incomplete. The pre-Cambrian is represented and three formations of the late Paleozoic. The entire Mesozoic is missing and only two formations of the Tertiary are represented. A brief description of the remaining formations in the stratigraphic column of the region is included in this report even though these formations are not found in the McKenzie Canyon Area.

Of the formations represented in the area, only the Amsden is complete. Even so, its boundaries are difficult to determine. Since detailed stratigraphic work was done in the region in 1947 by graduate students of the University of Michigan, the sections found in this report are the ones measured by them.

Stratigraphic Column of
The McKenzie Canyon Area

Age	Formation	Thickness
Quaternary	Alluvium	Unknown
Quaternary	Landslide	Unknown
Upper Eocene (?)	Sage Creek-Cook Ranch Formation	Unknown
Paleocene (?)	Red Rock Conglomerate	2,000' ±
Pennsylvanian	Quadrant Formation	1,000'
Pennsylvanian and Mississippian (?)	Amsden Formation	300'
Mississippian	Madison Limestone	5,000' ±
Pre-Cambrian	Cherry Creek Gneiss	Unknown

Pre-Mississippian Systems

Pre-Cambrian The pre-Cambrian is represented in the McKenzie Canyon Area by a unit of the Cherry Creek Series (Dr. E. W. Heinrich of the University of Michigan, personal communication). It is exposed in the Beaverhead thrust sheet, and has been thrust from the west over Madison limestone. This formation is a pink granite gneiss. It has a coarse crystalline structure and in some places the grains have become elongated. Thick layers of quartz are found in places in the formation. It weathers to a rusty brown color and disintegrates on weathering to form slopes of coarse quartz and ferromagnesian sand. Weathering has progressed deeply into the rock and the surface is fairly friable.

Paleozoic Systems Prior to Mississippian There are no representatives of the Paleozoic prior to the Mississippian in the McKenzie Canyon Area. However, the Flathead quartzite, the Kinnikinic quartzite and the Threeforks formation occur in the region and they will be described briefly here.

The Flathead quartzite is of Middle Cambrian age and is believed to rest unconformably upon pre-Cambrian rocks. It is reddish brown to maroon in color, well bedded, and, in some places, cross-bedded. Flat pebble conglomerates, which are excellent marker beds, are present at several horizons. Kupsch (1948, p.13) reports that the Flathead quartzite is approximately 900 feet thick at exposures in Trail Creek Canyon and along the west side of Nicholia Creek Canyon. J. R. Peterson (personal communication) however, reports a thickness of only 15 feet a few miles west of Armstead, Montana.

The Kinnikinic quartzite is of Upper Ordovician age. It is white to light grey in color but locally stained by iron to pink and light yellow. The Kinnikinic quartzite may be distinguished from the underlying Flathead quartzite by its lack of bedding planes. In some localities there is a conglomeratic layer at the base of the formation. The thickness of this formation is estimated at 800 feet. (Kupsch, 1948, p.15)

The Threeforks formation is Upper Devonian in age. W. O. Kupsch (1948, p. 17) describes the Threeforks as yellow to grey calcareous shales containing brown lumpy inclusions. The lower part contains a purplish cherty shale while the upper beds become increasingly calcareous, containing thinly bedded limestones with chert layers. The formation is eroded quite easily and it is very difficult to obtain complete lithologic descriptions or accurate measurements of thickness as it usually forms gentle concealed slopes. The thickness of the formation is roughly 600 feet.

Mississippian System

Madison Limestone The Madison limestone is of Lower Mississippian age. It was named by A. C. Peale (1893, p.33-39) for exposures in the Madison Range, Montana. No satisfactory section is exposed in the Madison Range according to L. L. Sloss and R. H. Hamblin (1942, p.313) and they propose a section at Logan, Montana as the type locality. The Madison is now considered to be a group, composed of the Lodgepole and the Mission Canyon formations. This division is made on lithologic grounds, as the Lodgepole is thinly bedded and the Mission Canyon very massive. Although both members were recognized in the McKenzie Canyon Area, no attempt was made to map them as separate units.

The outcropings of Madison in the McKenzie Canyon Area are predominantly of massive blue-grey limestone with numerous calcite veins and some chert inclusions. The limestone effervesces freely when dilute hydrochloric acid is applied to a fresh surface. It is a cliff former, and is very resistant to erosion in the arid climate of this region. Some portions are highly fossiliferous. The usual weathered surface is light to dark grey, tan or white, and the calcite veins stand out in relief upon the weathered surface.

The following section was measured by Scholten and Kupsch (1948, p.21) but is only a part of the total section. The minimum thickness estimated by them is 3,000 feet, which compares favorably with a measured section of 3,500 feet of Mississippian rocks by Shenon (1928 p.7) in Idaho. However, in the McKenzie Canyon Area it is estimated that approximately 5,000 feet of Madison is exposed in the eastern part of the area on the Tendoy thrust. The bottom is not exposed as it is covered by the aluvium of the Red Rock River.

Madison Formation Measured in Sections
7, 8, 9, 17, T. 17 S., R. 19 W.

12. Limestone, medium to dark grey, thin bedded, bands of dark chert, cliff forming.......................... 350'

11. Limestone, dark grey, weathers differentially to light grey and tan, laminated in grey colors, bedding of intermediate thickness, scattered chert nodules, crinoid stems and large cup corals, bryzoa and gastropods. The crinoids decrease, corals increase in quantity in higher parts of unit............. 200'

10. Limestone, light to medium grey, massive, strongly jointed, almost entirely built up of fossils, mainly crinoids, calcite veins, chert layers........... 160'

9. Limestone, medium grey, weathers tan and light grey to white, bedding of intermediate thickness, strongly jointed, calcite veins, chert layers, few fossils...................................... 30'

8. Limestone, light grey, weathers white, massive, no chert, completely built up of crinoid stems......... 30'

7.	Limestone, light grey, laminations in grey colors, cliff forming, calcite veins, chert, very fossiliferous, crinoid stems, corals, bryozoa, brachiopods..................................	50'
6.	Limestone, grey, thin bedded, slope forming, chert nodules, calcite veins...........................	15'
5.	Limestone, dark grey to black, fan-like laminations, breccia layers, regular chert beds, calcite veins, fossiliferous.............................	100'
4.	Limestone, grey, weathering pink, laminations in brown and red colors, massive, chert nodules, calcite veins, corals................................	30'
3.	Limestone, dark grey, thin bedded, chert and calcite, fossiliferous................................	25'
2.	Shale, brown and sandstone, violet-pink................	30'
1.	Limestone, dark grey, breccia with sandstone fragments, rusty brown, few fossils, some lenses of recrystallized crinoid stems................	60'
	Total Thickness	980'

Pennsylvanian System

Amsden Formation N. H. Darton (1904, p.398-401) named the Amsden formation for exposures along the Amsden Branch of the Tongue River in Wyoming.

The Amsden formation has been proven by fossil evidence to lie in the Upper Mississippian and Lower Pennsylvanian systems. However, a definite line between the two ages has not been established. C. P. Branson (1936, p. 391-392) has called the lower part of the Amsden the Sacajawea, but it is not a mapable unit and is therefore in disfavor. Ruth Brachrach (1945, p.67) proposed that all units below the Darwin sandstone be considered Mississippian and the Darwin and higher units be called Pennsylvanian. No attempt has been made by the author to map the separate units and, since the larger part is considered to be Pennsylvanian, it is treated as such in this report.

The formation consists mainly of interbedded grey, massive, crystalline limestones and grey calcareous shales with some units of tan, poorly cemented sandstones. High in the column there is a red chert layer (Smith, 1948, p.12). A characteristic of the Amsden in Northwestern Wyoming is the many beds of gypsum. They are absent in this area although W. L. Adam and R. W. Benner of the University of Michigan report mineable gypsum in the Lima Peaks area of Montana (Smith, 1948, p.12). Some beds of the formation are very fossiliferous.

The formation forms gentle slopes which are usually covered by Quadrant talus. The Amsden in the McKenzie Canyon Area is the only formation represented that is complete. However, there were no good sections available for detailed measurement because of the vegetation and talus of Quadrant that covered the exposure. The total thickness in this area is approximately 300 feet. Further south, the formation thickens appreciably.

The following section was measured in the Northwest Quarter, Section 36, Township 13 South, Range 10 West, by H. H. Krusekopf and S. R. Wallace (1947).

29.	Limestone, dark grey, weathering to light grey, fine grained..	2'
28.	Sandstone, light tan friable..........................	6'
27.	Limestone, dark grey, weathering to light grey, fine grained..	8'
26.	Covered interval......................................	58'
25.	Limestone, dark grey, weathering to light grey, massive, dense......................................	10'
24.	Covered interval......................................	139'
23.	Limestone, dark grey weathering to buff color, crystalline, well bedded, contains numerous thin bands of chert..................................	43'
22.	Shale, grey, grades upward into brown shales, upper part of bed covered............................	389'
21.	Sandstone, light brown, thin bedded, calcareous, thickness of individual beds vary considerably, in places weathers a reddish purple color.............	120'

20.	Sandstone, tan, weathers to rusty brown, massive, friable..	24'
19.	Covered interval - covered by Quadrant Quartzite talus..	269'
18.	Limestone, dark grey, finely crystalline, contains numerous organic fragments....................	12'
17.	Limestone, dark grey, weathering to buff, argillaceous, thin bedded with some inter-bedded chert..	38'
16.	Limestone, grey brown, weathering to buff, finely crystalline, fossiliferous.....................	62'
15.	Shale, grey, thin bedded calcareous, contains numerous pelecypods..................................	80'
14.	Sandstone, light tan, weathering to orange buff, hard...	3'
13.	Shales, grey, calcareous, thin bedded.................	29'
12.	Limestone, dark grey, weathering to buff, crystalline, contains productids......................	21'
11.	Grey shales interbedded with limestones, grades upwards into brownish and buff beds............	106'
10.	Limestone, argillaceous, grey, interbedded with shales, dark grey weathering to light grey, thin bedded, calcareous, some gypsum fragments...	245'
9.	Limestone, medium grey, medium grained, highly fractured..	29'
8.	Shale, dark grey, weathering to light grey, calcareous, thin bedded, interbedded argillaceous limestones...............................	67'
7.	Limestone, light to medium grey, weathering to buff, finely crystalline, highly fractured, fractures filled with secondary calcite...............	14'
6.	Shale, dark grey, weathering to light grey, calcareous, thin bedded, interbedded argillaceous limestones...............................	43'

5.	Limestone, grey, thin bedded, argillaceous............	67'
4.	Limestone, buff colored, thin bedded, silty...	10'
3.	Limestone, dark grey, fine grained, petroliferous...	4'
2.	Shale, grey, weathering to lighter grey, thin bedded, calcareous, contains pelecypods..........	86'
1.	Limestone, dark grey weathering to buff, dense, compact..	48'
	Total Thickness	2022'

<u>Quadrant Quartzite</u> A. C. Peale (1893 p.32-43) first named the Quadrant formation. The type locality is on the southeast side of Quadrant Mountain in the northwestern part of Yellowstone National Park. This formation as it was first named included all those beds lying above the Mississippian Madison formation and below the Jurassic Ellis group. D. D. Condit (1918, p.11), H. W. Scott (1935, p.1013) and W. H. Weed redefined the Quadrant and narrowed it down considerably to exclude rocks of different ages and lithology. The Quadrant quartzite as it is considered here includes all beds above the Amsden formation and below the Phosphoria. This places it as Pennsylvanian in age. The Quadrant is believed to correlate with the Tensleep sandstone of Northwestern Wyoming.

The Quadrant formation is composed of thick, massive, quartzitic sandstones with thinner layers of more friable sandstones. The sand is fine and even grained, usually white to light tan, with some pink and purple banded quartzites. Near the top of the formation some grey to light tan, finely crystalline, massive limestones appear. Layers of white to light grey dolomite are present near the top also, with a few interbedded chert layers. The Quadrant is very resistant in many localities and makes up the high peaks of adjoining areas. In intervening areas between peaks, the Quadrant forms low slopes and is difficult to recognize, probably because of a lessening of the induration. Slopes formed by the talus of the harder portions of the Quadrant are easily recognized because of the abundance of black lichens that grow on the talus blocks. The total thickness of the Quadrant just west of Armstead, Montana is 980 feet (Brant, personal communication), but it thickens rapidly toward the south and west.

The following Quadrant section was measured by Krusekopf, Lipp and Becker (1947) in the East Half, Section 35, Township 13 South, Range 10 West.

12. Sandstone, dark grey, massive, calcareous cement.. 26.3'

11. Covered interval, dolomite and chert layers present... 280.9'

10. Limestone, more pitted than before, otherwise similar to unit 8.......................... 8.8'

9.	Dolomite..	15.5'
8.	Limestone, finely crystalline, dense, slightly pitted, grey to light tan, weathers white to tan..	5.0'
7.	Dolomite, dense at base, white to light grey, chert near top, sandy..................................	54.9'
6.	Sandstone, soft, white, easily weathered, forms rolling slope..................................	131.0'
5.	Sandstone, (first exposure), dense, white to light grey, weathers to brownish tan, becomes light tan toward top..........................	1724.9'
4.	Sandstone, friable, massive, dark tan, weathers to yellowish tan, many black lichens, covered talus slope near top..................	913.6'
3.	Sandstone, friable, massive, light tan, weathers to light grey, interbedded with 2 inch thin layers of more quartzitic sandstone and slightly dolomitic near center. Also another member of quartzitic slightly dolomitic sandstone near top..........................	109.4'
2.	Sandstone, quartzitic, very dense, grey to buff, weathers to tan, thinly bedded with 3 inch shaley sandstone layers.........................	5.0'
1.	Sandstone, white to buff, friable, mottled slightly reddish, fine well sorted sand, weathers to light grey, becomes more dense near top, massive, cross bedded.......................	42.8'
	Total Thickness	3319.9'

Post-Pennsylvanian Formations To Tertiary

Permian System None of the Permiam system is represented in the McKenzie Canyon area although the Phosphoria formation outcrops about three miles to the north. The formation in the area to the north consists of massive grey limestones and dolomites interbedded with sandstones and siltstones. The characteristic oolitic phosphorite layers are absent in this region, but the formation is characterized by abundant chert layers and inclusions. R. A. Brant (personal communication) states that the Phosphoria is approximately 300 feet thick near Armstead, Montana. Smith (1948, p. 18), in studies of an area immediately to the south of the McKenzie Canyon area, reports that several fossil beds, one containing Bucksonia sp. are present, and that the thickness of the formation in this locality is about 800 feet.

Triassic System The Dinwoody, Woodside, and Thaynes formations represent the Triassic system in the region, although none of these is present in the McKenzie Canyon Area. The Dinwoody formation consists of reddish brown to brown shales and a limestone that weathers almost black. In the West Half, Section 26, Township 13 South, Range 10 West, Lipp and Becker (1947) reported a section 553 feet thick.

The Woodside formation consists of red, brown and grey sandstones, shales and limestones. Lipp and Becker (1947) measured a section 354 feet in thickness in the West Half, Section 26, Township 12 South, Range 10 West.

The Thaynes formation is represented for the most part by grey to buff massive limestone. There are some layers of tan calcareous siltstone and finely crystalline silty limestone. In the West Half, Section 26, Township 13 South, Range 10 West, Wallace, Krusekopf, Lipp and Becker (1947) found 792 feet of Thaynes.

West of Armstead, Montana, R. A. Brant and J. R. Peterson (1948) found that the whole Triassic sequence measured only approximately 800 feet.

Jurassic System The Sawtooth and Rierdon formations are not present in the McKenzie Canyon Area and are not found further north. Smith and Cummins (1948) report thicknesses of 252 and 116 feet respectively in the Tendoy-Medicine Lodge Area which is immediately to the south.

The Sawtooth formation is composed of grey to buff, thinly bedded shales, buff siltstones and a few lenses of brown limestones.

The Rierdon formation consists of interbedded, calcareous, brown shales and grey to buff, oolitic limestones.

Cretaceous System The Kootenay formation representing the Cretaceous System is not present in the McKenzie Canyon Area although west of Armstead, Montana it is present (Brant, personal communication). The thickness in this locality is unknown. Wallace (1948, p.28) states that the formation is over 2,200 feet thick in the East Half, Section 9, Township 13 South, Range 10 West. This section includes the shales below the "salt and pepper sandstones, and it is debatable whether they belong to the Kootenay or the Morrison formations. The beds of the Kootenay are mostly reddish to purple shales with interbedded Arkosic "salt and pepper" sandstones. There are some thin beds of grey limestone that weather dark brown. The "salt and pepper" sandstones are easily recognizable and are excellent marker beds for this formation.

Tertiary System

Red Rock Conglomerate The Red Rock Conglomerate is composed of three units. The lower and the upper are coarse conglomerates, and the middle unit is a fresh water limestone. The name of Red Rock has been tentatively assigned to this formation pending further study (Eardley, personal communication). The age of the formation has not been definitely established as no fossils have been found in it. However, it is generally assumed to be Paleocene. It is younger than certain upper Cretaceous beds in the region and underlies the upper Eocene Sage Creek formation unconformably. It postdates the first Laramide movements but predates the Laramide thrusting.

The upper and lower members consist mainly of coarse conglomeratic pebbles and boulders of Paleozoic and Mesozoic formations. In some locations, Madison limestone makes up 75 percent of the mass. The matrix is fine-grained and is cemented by calcium carbonate. The conglomerate contains a high percentage of iron in the cement which gives the formation a red appearance on a weathered surface.

The middle member of the Red Rock is a massive, fresh water limestone containing numerous algal concretions. It is light blue grey and weathers light grey to white. Kupsch (personal communication) reports that an exposure of the middle member just south of the McKenzie Canyon Area is 250 feet thick. Eardley states that the thickness of the Red Rock is approximately 2000 feet on the Lima Anticline (Wallace, 1948, p.31), but exposures along the east front of the Tendoy Mountains indicate a much thicker section and the exposure at the Lima Anticline is probably a minimum thickness.

<u>Sage Creek-Cook Ranch Formations</u> The Tertiary beds in this area, except for the Red Rock, were originally named Bozeman Lake beds by Peale (1893, p.32-43). However, W. P. Haynes (1916, p.270-290) showed that the beds were not all of Lacustrine origin, but were in part sub-aerial fluviatile deposits. Atwood (1916, pp. 705,706 and 712) reported that these basin beds in places were mainly glacial outwash deposits, but this conclusion is probably in error. The beds were formerly believed to be upper Miocene or Lower Pliocene in age but recent studies indicate that they are probably equivalent to Sage Creek and Cook Ranch beds of Upper Eocene and middle Oligocene age (Cummins, 1948, p.27). It is probable that the beds in the various basins in southwest Montana were interconnected before the mid-Tertiary block faulting.

The basin beds comprise a great variety of rocks which are fairly well consolidated. The various beds include sandstones, shales, siltstones, conglomerates, breccias, bentonite, rhyolite tuffs and fresh water limestones. The thickness of the deposits are unknown and probably vary somewhat from basin to basin. Kupsch (1948, p.30) estimates a thickness of the basin beds in Nicholia

Creek basin of at least 5000 feet, barring repetition of beds.

Several good specimens of plant fossils have been found in the basin beds but as yet they have not been used in correlation.

Quaternary System

Two Quaternary units were mapped, landslide and alluvium. The landslide is represented by a small area on the high upland surface and is of relatively little importance. The alluvium is restricted to the stream valleys. In the basins, however, there is enough alluvium to permit the cultivation of wild hay. The thicknesses of the landslide and alluvium are not known.

STRUCTURE

Laramide Structures

Folds The first stage of Laramide folding took place after the deposition of the upper Cretaceous Mesa Verde formation. This deformation was in a northwest-southeast direction causing the major trend of folding to strike to the northeast.

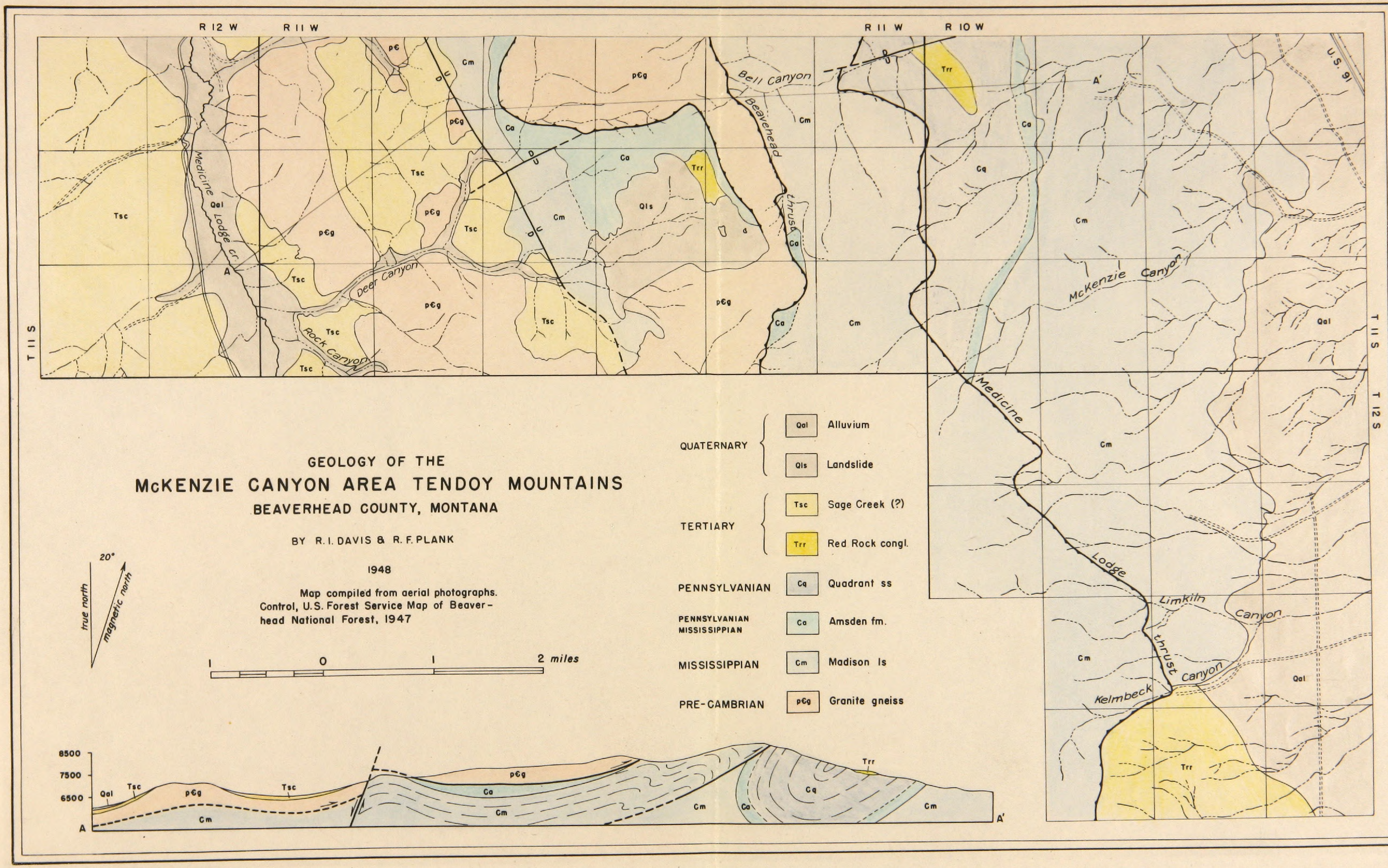
After the deposition of the Red Rock conglomerate in Paleocene (?) time, folding on this same trend continued on a smaller scale. The folding is evidenced very well in the Snow Crest Range southeast of Dillon, Montana and in the Little Water syncline southeast of the McKenzie Canyon Area. Dips as high as 45 degrees have been noted on the flanks of anticlinal structures in this region.

Thrusts With the end of the Laramide episode of folding, the direction of orogenic movement changed from northwest-southeast to northeast-southwest, and extensive thrusting occurred. In places, the throw of the thrusts is twenty miles to the northeast. There are three thrust sheets in the McKenzie Canyon Area. One of these thrusts is buried under the alluvium of the Red Rock Valley, however, and was not mapped. The three thrusts are the Beaverhead thrust, the Medicine Lodge thrust, and the Tendoy thrust.

The Beaverhead thrust, whose thrust front is in the middle of the area, is a pre-Cambrian thrust sheet. It overrides the Madison limestone and the Amsden formation in this area. Erosion has left the thrust front as a klippe and has exposed the Red Rock conglomerate below the thrust sheet, indicating that the thrust also overrode the Red Rock. The thrust sheet disappears to the west under the Sage Creek-Cook Ranch formation and the alluvium of the Medicine Lodge Valley.

The Medicine Lodge thrust is a Madison limestone thrust sheet. It forms the high steep slopes on the east flank of the mountains, and overrides the Madison, Amsden, Quadrant and Red Rock formations. This thrust sheet carried the Red Rock conglomerate with it, as evidenced by the exposure of Red Rock uncovered by erosion behind the Beaverhead thrust klippe. This thrust has the most well developed front of the three in this region. Local thrusting in the Madison may be observed in this thrust sheet in the Keimbeck and Limekiln Canyons. The thrust sheet is overlain by the Beaverhead thrust to the west.

Although the Tendoy thrust front is buried under the alluvium of the Red Rock Valley, the thrust sheet is exposed in front of the Medicine Lodge thrust. The base of the thrust sheet is Madison limestone and it is thrust over Quadrant to the south


GEOLOGY OF THE
McKENZIE CANYON AREA TENDOY MOUNTAINS
BEAVERHEAD COUNTY, MONTANA
BY R. I. DAVIS & R. F. PLANK
1948
Map compiled from aerial photographs. Control, U.S. Forest Service Map of Beaverhead National Forest, 1947
QUATERNARY
Qal Alluvium
Qls Landslide
TERTIARY
Tsc Sage Creek (?)
Trr Red Rock congl.
PENNSYLVANIAN
Cq Quadrant ss
PENNSYLVANIAN MISSISSIPPIAN
Ca Amsden fm.
MISSISSIPPIAN
Cm Madison ls
PRE-CAMBRIAN
p€g Granite gneiss
20°
true north
magnetic north
1 0 1 2 miles
R 12 W
R 11 W
R 11 W
R 10 W
T 11 S
T 11 S
T 12 S
U.S. 91
Bell Canyon
Beaverhead thrust
Medicine Lodge cr.
Deer Canyon
Rock Canyon
McKenzie Canyon
Medicine Lodge thrust
Limkiln Canyon
Kelmbeck Canyon
A
A'
8500
7500
6500

of the area. North of the area, the base of the thrust is Quadrant, and it is thrust over Quadrant. This thrust, like the Medicine Lodge thrust, carried Red Rock conglomerate on top of the thrust sheet. The sheet is overlain by the Medicine Lodge thrust on the west.

Mid-Tertiary Structures

High Angle Faults In the middle of the Tertiary, block faulting of the horst and graben type developed in the region. The major faults have a north to northwestward trend. Minor local faulting took place at the same time at right angles to the major trends. The Tendoy Mountain Range is bounded on the west by the Muddy Basin fault which is downthrown to the west. On the east flank of the mountains, extensive high angle faulting has downthrown the Red Rock Valley.

These high angle faults are not continuous in the northern end of the Tendoy Mountains in the region around the McKenzie Canyon Area, but are well developed to the south. A continuation of the Muddy Basin fault appears in the south-western part of the McKenzie Canyon Area trending northwest, and dies out just north of the area. On the eastern flank of the mountains, the fault dies out to the south of the McKenzie Canyon

Area and reappears immediately to the north of the area. Although these high angle faults are discontinuous, the Tendoy Mountain Range is essentially a horst. Two of the minor cross faults are present in the McKenzie Canyon Area, one on the east flank and one on the west flank of the mountains.

Age Relationships

Folds After the deposition of the Mesa Verde formation in upper Cretaceous time, the first period of Laramide folding took place. The Red Rock conglomerate rests uncomformably upon these folds that have been truncated by erosion. The folding is pre-Red Rock and, since the Red Rock has tentatively been dated as lower Paleocene, the first stage of Laramide folding was late upper Cretaceous.

The second period of folding took place after the deposition of the Red Rock conglomerate, as the Red Rock has been deformed in the same trend as the pre-Tertiary formations. Since the Laramide folding was completed before the Laramide thrusting began, the second period of folding must have taken place in middle Paleocene time.

Thrusts The Laramide thrust sheets rest upon the Red Rock conglomerate (lower Paleocene) in places and the

Sage Creek formation (upper Eocene) rests unconformably on the thrust sheets. This dates the thrusting between lower Paleocene and upper Eocene time. However, since a large cycle of erosion took place after thrusting and before the deposition of the Sage Creek formation, the thrusting has been dated upper Paleocene and lower Eocene while the erosion took place in lower and middle Eocene.

<u>Block Faults</u> The first stage of block faulting took place after the deposition of the Cook Ranch formation (middle Oligocene) and before the deposition of the Passamari formation (lower and middle Miocene). This is supported by the greater displacement of Cook Ranch beds than Passamari beds along the fault planes. The first stage of block faulting is, therefore, upper Oligocene.

The second stage of block faulting occurred after the deposition of the Passamari formation (lower and middle Miocene) and before and during the early part of the deposition of the Madison Valley formation (upper Miocene and lower Pliocene) which dates it as upper Miocene. This evidence is borne out by the absence of the Passamari formation on one side of the fault and the presence of the Madison Valley on both sides.

After the deposition of the Madison Valley formation, block faulting continued until the present time. Well preserved fault scarps can be noted in several places along the sides of the valleys to bear out this conclusion.

PHYSIOGRAPHY

In late upper Cretaceous time the first folding of the Laramide orogeny uplifted and distorted the formations that had once been covered by a Cretaceous sea. (During the Tertiary all deposition was of continental origin.) A great highland was raised to the west, and erosion, taking place as the folding progressed, truncated the formations and the Red Rock conglomerate was deposited unconformably on the folded beds in lower Paleocene time. At this time the land forms were fairly well subdued but once again Laramide folding on a smaller scale distorted the terrain. Further Laramide movement created large thrust sheets which overrode the area from the west. Once again erosion reduced the physiographic features and a high, broad, upland surface remained.

The Sage Creek formation was laid down upon the high surface with the accompanying deposition of volcanic tuffs and breccias. The volcanic activity continued throughout the middle Tertiary. At the end of Sage Creek deposition, local deformation and erosion occurred, and the deposition of the Cook Ranch formation started, ending in middle Oligocene time.

In upper Oligocene time the first episode of block faulting took place, after which erosion again subdued the area to an extensive surface of moderate relief. In some places this surface was co-extensive with the early pre-Sage Creek surface. The Passamari and Madison Valley formations were then deposited with an episode of block faulting taking place between the deposition of the two.

In middle Pliocene time uplift of the region accelerated erosion, and large pediment slopes were formed. Continued block faulting also gave rise to the deposition of great alluvial fans. The uplift continued through the Pleistocene and dissection of the pediments took place. The alluvial fans continued to form as a result of renewed movement along the faults. There is no evidence of glaciation in the McKenzie Canyon Area but surrounding areas have glacial-fluvial outwash remnants exposed that were deposited during the Pleistocene.

During Recent time there has been further dissection of the mountains and pediment slopes, and gravel terraces have formed along the river bottoms in the region. The major streams in the region, including the Red Rock River and Medicine Lodge Creek, are antecedent streams. These streams are in their mature stage at the present time while their intermittent tributaries are still young. The Tendoy Mountain range is in its late youth and the broad upland pre-Sage Creek surface is fairly narrow, with a few monadønocks, such as Ellis Peak to the south of the area, rising above the general summit level. The pediment surface is well dissected but easily recognizable east of the Red Rock River. The alluvial fans have coalesced in most places and are starting to be dissected, although fresh fault scarps can be noted at many points along the sides of the valleys indicating very recent movement. Most of the slopes in the mountains are fairly gentle except for the massive cliffs of Madison limestone. In places the Quadrant forms small cliffs and talus slopes of fairly steep dip.

SUMMARY OF EVENTS

Recent	Dissection to form modern gravel terraces and river bottoms.
Middle and Upper Pleistocene	Further regional uplift with dissection of pediments, glaciation and deposition of outwash in two stages. More movement along block faults and continued alluviation.
Middle Pliocene to Lower Pleistocene	Regional uplift forming pediment slopes with local continued block faulting and formation of alluvial fans.
Upper Miocene and Lower Pliocene	Second episode of block faulting and deposition of Madison Valley formation.
Middle Miocene	Continued deposition of the Passamari formation.
Lower Miocene	Erosion to extensive surface of moderate relief. In places co-extensive with early pre-Sage Creek surface. Some deposition of Passamari formation.
Upper Oligocene	First episode of block faulting.
Middle Oligocene	Deposition of Cook Ranch formation.
Lower Oligocene	Local deformation and erosion.
Upper Eocene	Deposition of Sage Creek formation.
Lower and Middle Eocene	Erosion to form extensive, high pre-Sage Creek surface.

Upper Paleocene and Lower Eocene	Laramide thrusting from west to east, forming the Beaverhead thrust on the west, the Tendoy thrust on the east, and the Medicine Lodge thrust between the two. These thrusts created the early Tendoy and Beaverhead Mountains.
Middle Paleocene	Further deformation of northeastward trending folds.
Lower Paleocene	Erosion of highlands and deposition of Red Rock conglomerate.
Upper Cretaceous	Major Laramide deformation producing northeastward trending folds and probably lifting a highland up to the west.

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