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# THE GEOLOGY OF THE MCKENZIE CANYON AREA, BEAVERHEAD COUNTY, MONTANA

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## ABSTRACT

The McKenzie Canyon area is located in the southwestern part of Montana in Beaverhead County. The area includes fifty square miles centered in the Tendoy Mountains, and was mapped during the summer of 1948 by Robert I. Davis and Robert F. Plank, graduate students at the University of Michigan. The rocks exposed in the area range from pre-Cambrian to Recent, although no Mesozoic formations are present. The outstanding structural features of the area are two westward dipping thrust faults which cut across a series of early Laramide northeast-southwest folds. The Medicine Lodge thrust was recognized prior to work in the field, but identification of pre-Cambrian rocks within the area indicated a second thrust fault which has been termed the Beaverhead thrust. High angle faulting occured throughout the area during the Tertiary. Mineralization in the Madison limestone is believed to be due to metamorphism which resulted from solutions ascending along channelways provided by high angle fault planes.

CONTENTS

# INTRODUCTION

## Location of the area

The McKenzie Canyon area is located in the extreme southwestern corner of Montana in Beaverhead County. It lies about ten miles southwest of the town of Armstead, and about fifteen miles northwest of Lima, Montana. It includes portions of Townships 11 and 12 south, Ranges 10, 11, and 12 west. The area as mapped, is roughly bordered by Kelmbeck Canyon to the south, U.S. Highway 91 on the east, Bell Canyon on the north, and Medicine Lodge Creek to the west. The locality includes approximately fifty square miles, the south-central portion of which lies within the boundaries of the Beaverhead National Forest.

The area is readily accessible from the south by U.S. Highway 91 from Lima, and the town of Armstead which lies to the north east. From Armstead, the western limits of the area may be reached by the Lehmi Pass and Medicine Lodge Creek roads. In addition to these easily traveled, all weather roads, the interior portions of the area may be covered by numerous foot and wagon trails, some of which are passable to light motor vehicles during dry weather.

## Geography

Surface features: The outstanding topographical feature of the McKenzie Canyon area is the Tendoy Mountain range which trends north-south through the central part of the area. Within the area concerned, the upland surfaces of the range attain a maximum elevation of approximately 8500 feet. Although bordered by relatively steep sides, the highlands are gently rolling grazing land, with few distinguishable peaks. The mountains are dissected along the flanks by numerous narrow, steep-walled canyons.

The range is bordered on the east by the broad, shallow Red Rock basin, which has an elevation at Armstead of 5496 feet. On the west, the north-south trending valley of Medicine Lodge Creek has an average elevation of 5400 feet. This broad, intermontane valley separates the Tendoy Mountains from the Beaverhead Range along the Idaho-Montana boundary to the west.

Drainage: The McKenzie Canyon area, which lies immediately to the east of the Continental Divide, belongs to the drainage system of the Missouri River. The eastern slopes of the area drain by numerous intermittent streams into the northward flowing Red Rock River. The only permanent stream in the western part of the region is Medicine Lodge Creek, which flows north to empty into the easterly flowing Horse Prairie Creek. The junction of the latter stream with Red Rock River at Armstead forms the headwaters of the Beaverhead River which is a tributary in the upper reaches of the Missouri river.

## Previous work

The McKenzie Canyon area has not been previously mapped in detail. A reconnaissance map, covering the general area of the Tendoy Mountains was made during the summer of 1946 by E. S. Perry and U. M. Sahinen of the

Montana School of Mines, and a portion of the area to the south was mapped in detail by W. Lowell during the same period. However, none of this work has been published. During the summer of 1947 and the early summer of 1948, much of the area of the Tendoy Mountains to the south of McKenzie Canyon was mapped and described by E. G. Lipp, R. W. Becker, H. H. Krusekopf, S. R. Wallace, W. T. Smith, and D. L. Cummings; all graduate students at the University of Michigan. A portion of the area immediately to the south of the McKenzie Canyon area, mapped by Smith and Cummings, has been incorporated into the map accompanying this report. This has been done because of a considerable change in the interpretation of the structural features of the area since their work was completed.

## Purpose of investigation

The study of the geology of the McKenzie Canyon area of southwestern Montana was undertaken as a partial fullfillment of the requirements of a master of science degree in geology at the University of Michigan. This work represents a continuation of the program of geologic mapping of southwestern Montana set up by the Department of Geology of that University. The report is intended to serve as one more link in evolving a tectonic history for the region, and as a guide to problems which require further research.

## Method of investigation

Approximately two weeks were spent in the field during the summer of 1948. The area was mapped by a series of traverses across the Tendoy Mountains. Contacts and other pertinent data were plotted directly on aerial photographs. Horizontal control was obtained by plotting section corners. The final map was prepared by superimposing a grid obtained from the U. S. Forest Service map of Beaverhead National Forest upon the photographs, by stereoptic projection.

Vertical control for the cross-section which appears on Plate I, was obtained by aneroid barometer readings. The settings of the barometer were based on elevations determined by the U. S. Coast and Geodetic Survey.

Emphasis during field work was placed upon the study of structural relationships. Because of time limitations, no attempt was made to investigate the physiographic history of the area unless some particular feature was encountered which had not been discussed in previous reports about the general area. Consequently, the pertinent points of physiography and topographic expression are included in the section of this report to which they are most applicable.

## Acknowledgments

The writer is indebted to Professor Armand J. Eardley of the faculty of the University of Michigan who supervised the work in the field and the compilation of the map, and who has made numerous helpful suggestions regarding the preparation of this report. Mr. Robert F. Plank, graduate student at the University of Michigan collaborated with the author in mapping the area. Mr. Walter O. Kupsch, who is preparing a detailed report on an area which encompasses the McKenzie Canyon area, has been especially helpful with suggestions pertaining to the interpretations of the

structural features present in the area. Dr. E. William Heinrich, of the Mineralogy department at the University of Michigan has kindly furnished much information from his study of the pre-Cambrian rocks of Montana.

# STRATIGRAPHY

## General statement

The formations which are exposed in the McKenzie Canyon area range from early pre-Cambrian gneisses to Recent alluvial sediments. However, the section is not complete, for much of the Paleozoic and all of the Mesozoic section is absent from the stratigraphic column. Since the primary purpose of this paper is to discuss the geology of the area mapped in the field, and because the subject has been covered adequately elsewhere, (Cummings, Wallace, etc.), only those formations mapped in the field will be described here.

It will be noted in reading the description of the various formations found in the writer's area, that no thicknesses are given. No complete sections suitable for measurement are exposed in the area of McKenzie Canyon. Although Wallace and Krusekopf (1948) measured and described rather completely the Paleozoic section as exposed a few miles to the south of the writer's area, it is felt that these figures are not applicable near McKenzie Canyon. It became apparent after a few days in the field that the thicknesses of the Paleozoic formations in this area do not approach those reported by Wallace and Krusekopf. No attempt is made to explain this sudden change in the thickness of the formations, for additional field work is necessary, which must include a detailed study of the structural and stratigraphic relationships of the various formations.

Conclusions pertaining to the paleogeographical history of the area are beyond the scope of this paper, but it should be noted that evidence is present in southwestern Montana which indicates thickening of the Paleozoic formations to the west. (Ross, 1947). Ross, (1947, p. 1126) further states that in the Beaverhead Mountains, immediately to the west of the Tendoy Mountains, no Mesozoic rocks exist. The Tendoy Mountains represent the approximate western boundary of the Mesozoic sedimentation.

## Pre-Cambrian system

Granite-gneiss: The most abundant rock type present in the McKenzie Canyon area is a pink granite-gneiss, which crops out over much of the western half of the region. Originally thought to represent an intrusive related to the Laramide orogeny, it is now believed that the gneiss is representative of one of the pre-Cambrian rock types which are abundant throughout western Montana. In the area with which this report is concerned, the pre-Cambrian rocks have been exposed by erosion of the Beaverhead thrust sheet. (see Structure). Dr. E. W. Heinrich, (personal communication) believes the gneiss to belong to the Blacktail granite-gneiss, a large batholith whose outcrops appear throughout the pre-Beltian areas from the Ruby Range, northeast of Dillon, Montana, southward to the Idaho boundary.

In brief, the pre-Cambrian rocks of western Montana fall into four main groups. The oldest consists of a series of banded gneisses of the Pony series, and are probably Archeozoic in age. The oldest of the Proterozoic rocks is the Cherry Creek series which includes a group of marbles, schists, and quartzites. The Pony and Cherry Creek series are cut by the red granite-gneiss of the Blacktail granite-gneiss batholith (Heinrich, 1949). The Beltian rocks form the youngest series of the pre-Cambrian rocks and include a series of metamorphosed sedimentary rocks, typified by quartzites and argillites, with which are associated some igneous rock types, (Bevan, 1929).

The granite-gneiss as it appears in the McKenzie Canyon area is a distinctive dark red, coarse-grained rock. The constituent minerals visible to the naked eye include red and pink feldspar, quartz, and biotite. The gneissic structure of the rock is well developed, due to the parallel arrangement of the flakes of biotite along the foliation planes.

Henrich, (personal communication) regards the granite-gneiss of the McKenzie Canyon area as a metamorphosed granite whose foliation is secondary. He cites occurrences in which the gneiss contains roof pendants and reworked inclusions of a darker gneiss that are probably remains of one or both of the older series.

## Mississippian system

Madison limestone: The use of the term Madison for a series of limestones and shales was first proposed by A. C. Peale (1893, p. 33-39) based on a study of this series near Three Forks, and Gallatin, Montana in 1893. The name was apparently derived from the nearby Madison Range.

Regionally, the Madison is composed of a widespread series of lower Mississippian sediments which were deposited in the Cordilleran geosyncline and the adjoining western part of the continental interior. They are found throughout Montana wherever a Paleozoic section is exposed or penetrated. (Sloss, Hamblin, 1942). In the McKenzie Canyon area a group of Madison limestones make up the greater part of the outcropping sedimentary rocks, and on the east flank of the Tendoy Mountains the rocks are almost exclusively limestones belonging to the Madison group.

Throughout most of Montana, the Madison limestones overlie the Devonian Three Forks formation conformably, but as they are traced south and southeastward, they are found to overlie Ordovician and Cambrian strata, and in southeastern Wyoming they are known to rest on the pre-Cambrian basement complex. Following deposition of the sediments, a period of erosion is recognized throughout the region by the appearance of angular fragments of the limestones in the overlying Amsden formation, and by apparent Amsden sandstones which occur in solutions cavities in the Madison. To the east in the area of the Big Horn Basin, the Pennsylvanian formations rest with pronounced angular unconformity on the Madison. (Sloss, Hamblin, 1942).

Locally, the relationship between the Madison and underlying formations cannot be determined, since no formation older than Mississippian was observed. However, local studies substantiate the regional picture of an erosional interval following deposition. Solution cavities containing clastic sediments are common in the upper part of the formation, and broken, angular fragments of the Madison are found surrounded by a sandy matrix. Further evidence of an erosional interval is the apparent slight thickness of the overlying Amsden formation.

According to Sloss and Hamblin (1942) the determination of the lower limits of the Mississippian is based on conodont fauna in the basal shale, and preliminary work by D. L. Blackstone, Jr. (1934) on the brachiopod fauna of the limestones has indicated an early Mississippian age for the group. The upper limit of the Mississippian in Montana is not satisfactorily determined.

Peale's use of the term Madison originally pertained to a series of three limestones which were recognized by him. W. H. Weed (1896) later included a shale member in the Mississippian rocks, but he reserved the term Madison to include only the limestone members. The first use of the term "group" for Mississippian formations was by A. J. Collier and S. H. Cathcart (1922). They eliminated the three classifications proposed by Weed, and divided the group into the Lodgepole and Mission Canyon members, and it is this classification that Sloss and Hamblin (1942) suggest be adopted. Unless the "wavy" limestone, which is described below, is to be considered separately from the two members, nothing was observed in the writer's area to suggest further subdivision.

The two members, Lodgepole, and Mission Canyon, can be recognized in the McKenzie Canyon area, and in some portions the distinction is enough marked to divide them into mappable units, but this is not true throughout the area. The older member of the group is the Lodgepole, which is characterized in the type section mentioned by Sloss and Hamblin, at Logan, by a series of black fissile shales, and uniformly bedded limestones separated by 1-3 inch shale partings. This is overlain by thin bedded, dense limestones, separated by calcareous shales, shaly limestones, and chert lenticules. Locally,the Lodgepole is distinguished by a dark gray, crystalline limestone in which is included lenticules of black chert which range from one-half to two inches thick. From a distance, the rock appears to be distinctly layered, but close examination reveals this to be a result of differential weathering. Rather than occurring in regular bands, the chert is present as closely spaced lenticules. Because of the abundance of the chert and its dark color, this member is readily apparent and distinct from the overlying Mission Canyon member. In no place were black shales observed in either the Lodgepole or the Mission Canyon member, but in the lower part of the Mission Canyon, a light brown to buff, calcareous shale layer was observed cropping out in a stream gully.

Outstanding feature of the Mission Canyon member of the Madison group is the high rugged cliffs. Throughout the area, canyons are bounded by steep walls rising in some places to a hundred or more feet, which are Madison limestone. In general, the Mission Canyon member is typified by a more dense, massive limestone, varying in color from a light gray to nearly black. Chert is commonly present, but appears to be localized in zones which are not persistent over any extended area. The best exposures of Mission Canyon are found in the canyons cutting the east flank of the Tendoy Mountains, and here it was noted that in all samples taken, a definite fetid odor is present on the freshly broken surface.

Another typical feature of the Mission Canyon member is the abundance of solution cavities. Solution cavities are particularly well exposed in the canyon walls on the eastern side of the range where they are colored by yellowish stains, presumably as a result of infiltration of solutions from the overlying Amsden. Sloss and Hamblin (1902) report the occurrence of large filled solution caverns in the Madison which contain recemented fragments of the limestone, and they also cite the occurrence of large clastic sills and "dikes" in the formation near Livingston, Montana, which are made up of fragments of the red Amsden formation. Solution cavities are numerous in the cliffs of Madison on the western side of the range, and here red stains appear on the cliff faces. The solution cavities, red and yellow stains, solution breccia, and the terrestrial material contained in many of the cavities, seems to be strong evidence for concluding that the formation underwent a widespread emergence at the end of Mississippian time.

A discordent feature in the Madison sequence is a series of strongly plicated folds of limestones which appear along the eastern flank of the Tendoy Mountains. Lying beneath the Medicine Lodge thrust sheet, the series is striking because of the folding and white weathered surfaces, compared to the dark gray, cherty limestones below it. Lithologically, the "wavy" limestones do not appear to differ from the Mission Canyon which occurs above it. It is a massive type, generally light to dark gray in color, and has a fetid odor on the freshly broken surface. Toward the top of the sequence thin beds of red, shaly sandstones are noted, which are also involved in the folding.

In no place in the area is the base of the Madison exposed, and for this reason, plus the fact that the section is complicated by thrust and block faulting, no attempt was made to measure the thickness of the formation.

Pennsylvanian system

Amsden formation: The Amsden formation, which occurs in scattered patches throughout the McKenzie Canyon area was first described by H. H. Darton (1904, p. 398-401). The formation was named for exposures along the Amsden branch of the Tongue River west of Dayton, Wyoming.

The Amsden formation is present throughout southwestern and central Montana, as well as in southeastern Idaho, and the northwest and central portions of Wyoming. Locally the formation occurs along the eastern slopes of the Tendoy Mountains where it is found cropping out below the Medicine Lodge thrust sheet. (Plate I). Outcrops of the formations in this area are sparse however, for the greater part of the formation is covered. Scattered outcrops of the formation are noted along the contacts of the Beaverhead thrust where it is traced along the highland portions of the range. The formation is also present along the western slopes of the mountains where it again is found beneath the pre-Cambrian of the Beaverhead thrust sheet.

Stratigraphic relationships of the Amsden formation vary throughout Montana and Wyoming. In central Montana where the formation is particularly well exposed, the Amsden overlies the Big Snowy group with apparent unconformity, (Scott 1935). The Mississippian Big Snowy group correlates with the Brazer of Wyoming which lies beneath the Amsden in that region. Neither the Brazer formation nor the Big Snowy group are present in southwestern Montana, and the Amsden formation rests unconformably upon the Madison limestone formation. This is the situation as it is found in the McKenzie Canyon area as well as in those areas studied immediately to the south. (Cummings, Becker 1949). Locally, the Quadrant Quartzite overlies the Amsden unconformably, as it does throughout the southwestern part of Montana and northwestern and central Wyoming.

The dating of the Amsden formation in Montana and Wyoming has been a subject of considerable controversy for many years, due in part to an indefinite terminology regarding the individual members of the formation. H. W. Scott (1945) originally considered the formation to be of Mississippian age, and Branson and Gregor (1918) describes it thusly in its occurrence in the Wind River Mountains of Wyoming. Upon further work, Scott (1945) assigned some of the units of the Amsden to the Pennsylvanian on the basis of the discovery of the fusulinid Millerella. It is generally accepted that the formation described as Amsden spans the upper Mississippian and lower Pennsylvanian. C. C. Branson, (1937, p. 391-392) suggests that the term "Sacajawa" be used for the Mississippian members, while Amsden be reserved for the strata, distinct from Quadrant or Tensleep, that are Pennsylvanian in age.

Because much of the Amsden formation is covered throughout the area, or has been removed by erosion, a complete section upon which lithological studies may be made is not available. The description of the formation as it is given here is based on the few scattered outcrops that are found in the area. Along the western slopes of the Tendoy Mountains the unit mapped as Amsden is typified by a conglomerate which is made up of sub-angular to rounded fragments of a light brown quartzite, which has been cemented with calcite. Fragments range in size from a fraction of an inch in diameter to slightly rounded boulders six inches across. Cropping out from beneath the easternmost trace of the Beaverhead thrust are two small outcrops of a calcareous, sandy shale which is light brown to reddish in color. This friable, thinly bedded strata was mapped as Amsden. Exposures of the Amsden formation along the eastern margin of the Tendoy Mountains beneath the Medicine Lodge thrust are few, but scattered outcrops indicate the presence of a series of thinly bedded, reddish-purple shales, quartzitic sandstones, and a thin layer of white, crystalline limestones, lying in that order above the Madison formation. Localized layers of gypsum are reported in the Amsden formation as it occurs to the south of the McKenzie Canyon area (Adams, Wallace, 1948) but none were found in the area concerned.

The absence of exposures prevented any measurement of the thickness of the Amsden formation within the McKenzie canyon area. However, it is readily apparent from a study of the approximate location of the contacts in the area, that the thickness of the formation does not approach that measured by Wallace and Krusekopf in Section 36, T 16 S, R 10 W, where they report 2022 feet. (1948) Based on the approximate width of outcrop, and calculation of thickness by trigometric functions, the writer does not believe the thickness of the Amsden formation in the McKenzie Canyon area to exceed 700 feet.

<u>Quadrant</u> <u>quartzite</u>: The term Quadrant was first applied to a series of sandstones, quartzites, and shales by A. C. Peale (1893, p. 32-43) for exposures near Yellowstone National Park. The term was further defined by the work of I. P. Iddings and W. H. Weed (1894), based on outcrops near Quadrant Mountain of the Gallatin Range in the northwest part of Yellowstone National Park. The Tensleep formation, which will be mentioned below, was named by N. H. Darton (1904) for exposures found in the Big Horn Mountains.

Regionally, the Quadrant formation is present throughout the southwestern and west-central portion of Montana. (Scott, 1935). In the McKenzie Canyon area, the only exposures of the formation are found along the eastern flank of the Tendoy Mountains where they appear beneath the Medicine Lodge thrust sheet. Although not appearing in the western portion of the writer's area, extensive outcrops of the formation have been mapped by Smith and Cummings (1948) in the vicinity of Ellis Peak near Medicine Lodge Creek. The Quadrant formation occurs within the McKenzie Canyon area where it supports steep, grass covered slopes. To the north (Bowers, personal communication) the formation is typically a cliffformer, as it is to the south; and the red and purple quartzites may be readily identified from a distance.

Throughout the greater part of southwestern and west-central Montana, the Quadrant formation is separated from the underlying Amsden formation by an erosional unconformity. Covered slopes prevent the observation of the contact of these two formations in the writer's area, but the slight thickness of the Amsden formation in this area would seem to indicate an erosional unconformity.

H. W. Scott (1935) reports that the Phosphoria formation of Permian age overlies the Quadrant conformably in most of the region. W. R. Calvert (1909) however, reports a distinct erosional unconformity near Livingston, Montana. Since the top of the Quadrant is cut by the Medicine Lodge thrust in the McKenzie Canyon area, its relation to the Phosphoria could not be ascertained.

The dating of the Quadrant formation is uncertain, due chiefly to differences in interpretation of the lithological units of the formation. Work by M. L. Thompson and H. W. Scott (1941) on the fusulinids found in the type section at Quadrant Mountain indicates a Des Moines age for the formation. This is the correlation which has been accepted by the Pennsylvanian subcommittee of the National Research Council on Stratigraphy (Moore et al, 1944, p. 701).

Although the type section of the Quadrant formation is described by H. W. Scott (1935) as a series of fine to medium-grained quartzites and limestones, the incomplete exposures of the formation in the McKenzie Canyon area prevented a detailed study of the lithology. Locally, the formation as exposed, is made up entirely of fine to medium-grained quartzites, ranging in color from white at the base, through brown and red, to a reddish purple. The uppermost member, which crops out directly beneath the Madison limestone of the Medicine Lodge thrust sheet, is a finely laminated, light-brown quartzite.

As mentioned previously, the Quadrant formation of south-western Wyoming grades eastward and to the south into the Tensleep formation which is typically a light brown quartzite. H. W. Scott (1935) noted that the calcareous zones found in the upper part of the Tensleep grade westward, through siliceous limestones to the limestones of the upper portions of the Quadrant formation. That the Quadrant formation represents marine sedimentation is evident by the occurrence of marine fossils, marine limestones, and marine crossbedding noted in various localities.

The formation thickens rapidly westward. Approximately 250 feet are reported at the type section at Quadrant mountain (Scott, 1935), while D. D. Condit (1918) reports over 1000 feet in the Quadrant as it is exposed in the Snowcrest Range. Wallace and Krussekopf (1948) measured a thickness of 3319 feet in the area south of McKenzie Canyon. Since much of the formation is covered in the McKenzie Canyon area, and in addition, has been subjected to folding which was later cut by thrusting, no attempt was made to determine its thickness.

## Tertiary system

Red Rock conglomerate: The term Red Rock has been tentatively applied to a series of Tertiary conglomerates, fresh water limestones, and sandstone and shale layers which appear to be restricted to southwest Montana. A conspicuous cliff of the coarse, reddish conglomerate occurs near Dell, on U. S. Highway 91, where it forms part of a low range of hills which are known as the Red Rock Mountains.

Although quite extensive in the areas to the south of McKenzie Canyon, (Cummings, 1948, Wallace, 1948) occurrences of the Red Rock conglomerate are limited locally. The greatest exposure of the formation is in the extreme southeastern corner of the area where it crops out beneath the Medicine Lodge thrust sheet. A small, isolated patch of the formation is found on the eastern slopes of the Tendoy Mountains, and another on the upland portion of the range where it crops out from beneath the Beaverhead thrust sheet.

Both regionally (Eardley, personal communication) and locally, the Red Rock rests in unconformable relationship with the underlying formations. In the extreme southeastern portion of the area, the formation rests unconformably upon the "wavy" facies of the Madison limestone, and is overlain by the Madison formation which makes up the Medicine Lodge thrust sheet. In the area near Bell Canyon (Plate I) the conglomerate occurs as an isolated patch on top of the Quadrant formation, while westward it rests upon the Amsden formation.

The age of the Red Rock conglomerate has not as yet been definitely established for no fossils have been found, and the structural relations of this formation have not been clearly defined. However, on the basis of structural studies, Dr. Eardley (Table I) has tentatively placed its time of deposition as Paleocene. It has been found to lie unconformably beneath the younger Eocene Sage Creek formation, and to overlie upper Cretaceous formations.

The Red Rock conglomerate was involved in at least two phases of the Laramide orogeny. Although post-dating the early-Laramide folding (see Structure), upturning of the formation along the eastern margins of the Snowcrest Range as a result of the mid-Laramide period of folding is noted by Doctor Eardley (personal communication.) Evidence throughout the Tendoy range indicates that the Red Rock conglomerate was overriden by thrusts. This is noted in the McKenzie Canyon area where it is found beneath both the Medicine Lodge and the Beaverhead thrust sheets.

At the present time nothing has been published concerning the lithology of the Red Rock conglomerate, but it is known chiefly for its occurrence near Dell (above) where it appears as a thick conglomerate of rounded pebbles and cobbles in which weathering has produced a striking reddish-orange color. Locally three phases of the formation may be recognized. At all three localities mapped, a conglomeritic phase is present, although lacking the red color which is so typical to the south. Sub-angular to rounded pebbles and cobbles which range in size from a fraction of an inch to more than twelve inches across are cemented by a light brown calcareous and limonitic cement. Fragments of the Madison limestone represent the greatest proportion of material fround in the conglomerate, and makes up more than fifty percent in the Bell Canyon area. The Quadrant formation is represented, as are fragments of the pre-Cambrian granite gneiss, which in the Bell Canyon locale, make up approximately fifteen percent of the total volume. Noted also in the Bell Canyon area is a series of thinly bedded shales ranging from light reddish brown to dark purple, which have been mapped as Red Rock. This is in keeping with the report by Doctor Eardley, (personal communication) of a series of sandstones and shales which occur in the formation as it is traversed to the east.

Although not occurring in the area mapped, mention should be made of a freshwater limestone which is included in the Red Rock. Located in Section 28, T 12 S, R 10 W, it was originally mapped as Madison limestone, (Cummings, 1948) until Doctor Eardley and a group of students made a further study of the outcrop. Varying in color from a creamy white to a light tan, the limestone shows algae structure, as well as local concentrations of oolites. Zones of a fresh water limestone conglomerate were noted which presumably represent local areas of erosion.

Complete sections of the Red Rock conglomerate are not available in the McKenzie Canyon area, and consequently no estimation of thickness can be given.

<u>Basin beds</u>: "Basin beds" has been used as a collective term to indicate a series of Tertiary fresh-water beds and volcanics occurring in the intermontane valleys throughout western Montana. Although originally designated as "Bozeman Lake beds" by A. C. Peale (1893, p. 32-43); W. P. Haynes (1916, p. 270-290) pointed out that these beds represent sub-aerial, fluvial deposits, not lacustrine, and thus the term lake beds is not a proper one. Atwood (1916, pp. 705, 706, and 712) further points out that in many areas the so-called lake beds actually represent glacial outwash deposits. Because of the

lithological similarity and proximity, Doctor Eardley (personal communication) has suggested that the basin beds of the McKenzie Canyon area be correlated with Douglas' Sage Creek formation which crops out near Sage Creek, about seven miles northeast of Lima, Montana.

Regionally the Basin beds are found in the intermontane valleys throughout western Montana. They represent deposition on surfaces which developed during the long period of erosion that followed the end of the Laramide orogeny. (Table I) In the McKenzie Canyon area the most extensive occurrence of these beds is found in the vicinity of Medicine Lodge Creek, a broad shallow valley west of the Tendoy Mountains. None were mapped to the east in Red Rock basin.

Although the thickness of the beds as they occur in the Medicine Lodge valley prevented a detailed study of the relationship of the volcanics to the underlying formations, evidence in the small, narrow connecting valleys seems to indicate that the Basin beds in this area rest unconformably upon a series of volcanic rocks, (see below). J. T. Pardee (1911) points out that a similar relationship exists between the Basin beds and volcanics in the area north of Dillon. He believes that the lowest sequence of basin beds in that area represent sediments derived from the erosion of the volcanics. A detailed petrographic study of the sediments which occur in the McKenzie Canyon area is beyond the scope of this paper, but such an investigation in an attempt to discover their source, suggests a problem for further research.

The age of the basin beds in the McKenzie Canyon area can only be approximated. If the correlation with the Sage Creek occurrence of Tertiary deposits is correct, H. F. Osborn's (1909, p. 98) identification of fossils found by Douglas

(1903, p. 145-149) indicate the beds to be upper Eocene in age. Identification of fossils found by University of Michigan students in the basin beds of Medicine Lodge Creek during the summer of 1948 may prove to date these formations with a greater degree of certainty.

Although studies of the Tertiary deposits throughout Montana indicate a number of lithological units, reconnaissance in the McKenzie canyon indicated only one distinct type. This was a thick sequence of thinly bedded, light yellow to buff shale, which is well compacted, and non-calcareous. Cummings (1948) reports the occurrence of conglomerates, sandstones, fresh-water limestones, and bentonite layers in the area immediately to the south, and coal seams are known in the Medicine Lodge Creek basin. It is interesting to note that J. T. Pardee (1911), in his discussion of the coal formations in the Tertiary basin beds, reports that it is found only in the lowermost series of the deposits.

No estimation of the thickness of the Tertiary beds was possible in the writer's area.

Volcanic rocks: Extensive outcrops of volcanic rocks are found in the western part of the McKenzie Canyon area. Overlain by the basin beds, the volcanics floor the small connecting valleys of Medicine Lodge basin and support the small foothills which border the western part of the Tendoy Mountains. Here, as in many parts of western Montana, the volcanic formations represent a period of extrusive activity which followed the end of the Laramide orogeny, when a thick sequence of rhyolites, basalts, and tuffs were laid down in the great intermontane basins formed as a result of the prolonged period of erosion, and possibly some block faulting.

Within the McKenzie Canyon area, the extrusive rocks appear to rest directly upon the pre-Cambrian granite gneiss which makes up the Beaverhead thrust sheet, and are overlain by the shale members of the basin beds which are found in the Medicine Lodge Creek valley.

Dating of the volcanic rocks can only be approximated until further study is made of the structural relations between them and the underlying formations. Since they appear to lie beneath the upper Eocene Sage Creek series of the basin beds, and as the volcanics include a breccia which contains fragments of the pre-Cambrian granite-gneiss, it seems plausible to consider them as belonging to one of the early periods of volcanic activity. That they correlate with the period of volcanic activity of upper Eocene which centered in Yellowstone National Park and the Absaraka Range, appears probable. (Eardley, Table I)

The base of the volcanic series exposed in the McKenzie Canyon area is represented by a thick volcanic breccia which crops out in numerous small cliffs. On the fresh surface, the cliffs present a distinct reddish-brown color, while the weathered surfaces are light green. Angular to sub-angular fragments of the pre-Cambrian granite-gneiss have been incorporated into the flows. The author believes that these fragments of gneiss represent talus blocks which were present on the eroded surface of the Beaverhead thrust sheet and which were enveloped by the outpouring of lava.

Overlying the volcanic breccia is a series of highly weathered tuffs and rhyolites which can be distinguished from a distance by the alternating series of white and green outcrops. Capping the foothills in the area is a dense, dark brown basalt, which is vesicular in parts, and in some localities contains unidentified phenocrysts.

## Quaternary system

Alluvium: Alluvium occurs in many of the stream valleys throughout the area of McKenzie Canyon. It is particularly prevalent in the Red Rock basin and the valley of Medicine Lodge Creek. In addition, the tributary streams of the latter creek have laid down an extensive blanket of alluvium along the western borders of the Tendoy Mountains. It will be noticed from an examination of Plate I that the alluvium which covers the floor of Deer Canyon terminates rather abruptly along the base of the scarp produced by Tertiary block faulting. (see Structure) Along the fault, the streams which rise on the flanks of the Tendoy Mountains, emerge suddenly from the narrow defile which they have cut through the Madison limestone that forms the upthrown side of the fault, onto the basin floor. Consequently the zone of alluviation is too narrow to map east of the trace of the high angle fault.

The character of the alluvium naturally reflects the composition of the rocks over which the streams pass. Pebbles and cobbles of Madison limestone make up the greater part of the stream deposits in the area. Fragments of quartzite and gneiss are also present.

Landslides: That landsliding has occurred during recent times is readily noted on the western slopes of the Tendoy Mountains, in the south-central portions of the McKenzie Canyon area. The covered slopes in this area present a "textbook" example of landside topography, with its hummocky surface, numerous undrained depressions, and terraces, formed as a result of earth movement.

## STRUCTURE

### Introduction

One of the outstanding problems of the geology of the southwestern part of Montana today is the determination and interpretation of the structural features of the area in an attempt to correlate them with the detailed studies made of the geology of the northern and eastern portions of Idaho and northern Wyoming. The results of careful mapping and interpretation of structures will in turn lead to a more complete understanding of the tectonic history of the region. It is not the purpose of this paper to go beyond the limits of the area studied in the field, but it is hoped that the information about the local structural features will serve as one more link in the determination of the geologic history of the region.

The outstanding structural feature of the area studied, is the zone of thrust faulting which runs generally north-south. V.R.D.Kirkman (1927, p. 26-29) has mapped four major thrust faults to the south in Idaho and, as pointed out by Cummings (1948, p. 34) the Tendoy Mountains form a northward extension of this zone of thrusting. A glance at the Tectonic Map of the United States (1944) shows four great westward dipping thrusts running north-south through Utah and Wyoming. In the northern part of Wyoming and in eastern Idaho the thrusts veer northwestward and disappear under the Snake River lava plain. This trend, projected across the lava flows to the north, appears in the thrusts of southwestern Montana. It is also possible that the thrusts of southwestern Montana continue northward to the Philipsburgh overthrust of western Montana.

## Laramide deformation

<u>Folding</u>: Regional relationships indicate two main periods of folding during the Laramide orogeny. The first resulted in northeast-southwest folds, which are typified by the Snowcrest Range. The first period of folding is classified as early-Laramide. A second period of northeast-southwest folding followed the deposition of the Red Rock conglomerate. Cummings (1948, p. 35) mentions northwest-southeast folds which resulted from mid or late-Laramide orogenic activity, but no evidence is present in the area of McKenzie Canyon to substantiate this.

Extensive folding is not apparent in the area under consideration since most of it is covered by the great sheet of the Beaverhead thrust. The thick, massive limestones of the Madison formation cover considerable area, and local structures within the limestones are difficult to work out. In addition to the thrust faults and massive limestones, several high angle faults have further complicated the structural picture in regard to folding throughout the area.

A major syncline, however, appears to be present on the eastern slopes of the Tendoy Mountains beneath the Medicine Lodge thrust. (Plate I). The fold, involving the Quadrant, Amsden, and Madison formations, has an axis which trends approximately north-south, and can be followed until it disappears beneath the thrust near the head of McKenzie Canyon in Section 31, T 11 S, R 10 W. Folding in this particular area is revealed by the abnormal breadth of outcrop of the Quadrant formation, and the variation in dip of the strata. Moving westward from U. S. Highway 91, the dips along the contact of the Madison, Amsden, and Quadrant formations do not exceed thirty-five degrees. As the Quadrant formation is traversed to the west, the dips increase until directly beneath the thrust they approach seventy-five and eighty degrees to the west.

The conformity of strike of this fold and the trace of the Medicine Lodge thrust indicates the possibility that folding was caused by the compressive forces which resulted in thrusting. Additional evidence must first be obtained, however, before eliminating the chance that the fold represents orogenic activity independent of thrusting. More precise information may be available by a careful study of the outcrops of Madison limestone and the Red Rock conglomerate which are found in sections 20, 21, 22, T 12 S, R 10 W. Here the Red Rock lies beneath the Medicine Lodge thrust and is in contact with the "wavy" member of the Madison formation. A comparison of the strike and dip, and the individual structures of the two formations may yield more clues as to the age of folding in the area.

Thrusting: Two thrust faults were mapped in the area concerned, and although not appearing, a third, the Tendoy thrust, deserves mention. Mapped by Wallace and Krusekopf (1948), the westward dipping Tendoy thrust disappears beneath the alluvium of Red Rock basin, just north of the mouth of Big Sheep Canyon. It is entirely concealed by the alluvium until its' trace again appears southwest of Armstead.

The Medicine Lodge thrust, the trace of which appears on the eastern flank of the Tendoy range, represents a northward continuation of the thrust designated by Smith and Cummings (1948, p. 36) as the Beaverhead thrust. The latter term is now applied to the large thrust on the west. (Plate I.) The thrust, named after Medicine Lodge Creek, was first used by Kirkman (1927).

The Medicine Lodge thrust strkes in a general north-south direction along the eastern flank of the Tendoy Mountains where stratigraphic and structural evidence clearly indicates its' presence. The first indication of the thrust sheet was found in Section 24, T 11 S, R 11 W, where the westward dipping Madison formation overlies the Quadrant quartzite which dips in the same direction. In this locality, the thrust strikes approximately parallel to the strike of the Quadrant, Amsden, and Madison formations, but southward the trace of the fault cuts across the strike of these formations. In Sections 6, 8, and 17, T 12 S, R 10 W, the massive, cliff-forming member of the Madison is found lying upon the younger, "wavy" facies of the Madison. In Section 20, T 12 S, R 10 W, Madison limestone overlies the Red Rock conglomerate of Tertiary age, which is the relationship reported by Cummings (1948, p,36) in the description of the "Beaverhead" thrust, in his area immediately to the south.

Further evidence of thrusting is found in the numerous east-west canyons which cut across the thrust sheet along the eastern margin of the Tendoy Range. Here, in several places, the strata of the thrust sheet are badly crumpled and closely folded as a result of movement. This is particularly noted in the sections exposed in Lilmkiln and Kelmbeck Canyons. The thrust sheet in this locality appears to be made up of the older, thin-bedded Lodgepole member. Here the sharp folds and flexures, some of which have broken, may be traced westward to a distance of one and one half miles from the trace of the thrust with no apparent decrease in intensity.

Since the base of the thrust could not be located in any of the exposures of the thrust sheet in the east-west canyons, it was impossible to determine the dip of the thrust. That shown on the cross-section in Plate I is assumed.

The easternmost trace of the Beaverhead thrust fault is found running generally north-south through Sections 23, 26, and 36 in T 11 S, R 11 W. Here the granite-gneiss is for the most part in contact with the Madison limestone, although small bodies of Amsden formation are found cropping out from beneath the thrust sheet. It is to be emphasized however, that in all probability, this area does not represent the easternmost extension of the thrust sheet, for evidence throughout the region suggests widespread removal of much of the pre-Cambrian that formerly made up the thrust sheet. This is apparent along the western flanks of the Tendoy range, where erosion has cut through the thrust sheet exposing the underlying Amsden and Madison formations. It is on the western flanks of the range that the thrust sheet is cut by a north-south, high-angle fault, which will be described in more detail below. However, it should be mentioned here that movement along this fault elevated the thrust sheet to the east, subjecting it to erosion which has exposed the Mississippian and Pennsylvanian formations below it. To the west of the high-angle fault, the gneiss of the thrust sheet is found again, although the greater part of the area is overlain by the Tertiary basin beds.

The contacts of the thrust sheet as exposed by erosion, and their relation to the topography of the area, indicate the thrust sheet to be gently folded and warped. The axis of the folds trend north-south.

One of the chief difficulties in postulating pre-Cambrian rocks in the area and their exposure by thrust faulting, is the apparent metamorphism of the Madison limestone where the latter formation is in contact with the granite-gneiss. Cummings (1948, p. 30) mentions the alteration in connection with lead mineralization at the Sweeny Mine in the northeast quarter of Section 7, T 13, S, R 11 W, and graphite mineralization at the north end of McBride Creek, Section 22, T 12 S, R 11 W. However, it has been noted by Dr. Heinrich (personal communication) that this mineralization is closely related to high angle faulting in the immediate vicinity. He points out that the apparent contact metamorphism is due to mineralization along high-angle faults where the pre-Cambrian gneiss has been brought into contact with the younger Madison formation. This concept is particularly borne out in Section 20, T 11 S, R 11 W (Plate I) where a small amount of lead mineralization occurs in the Madison limestone where it borders the granite gneiss.

The Beaverhead thrust has been mapped on the south by W. O. Kupsch. (personal communication.)

Tertiary block faulting

The high angle faults have been mapped in the area, at least one of which appears to represent a continuation of a fault mapped to the south by Smith and Cummings. (1948)

Three most important high angle fault trends north-northwest and bounds the western slope of the Tendoy Mountain range. The location of the West Muddy Creek fault as mapped by Smith and Cummings in Townships 12 and 13 S, R 11 W, suggests that it is continuous with the fault of the McKenzie Canyon area. However, lack of field work in the several adjoining sections between the two areas prevents fixing a definite relationship. The fault, which cuts the Beaverhead thrust sheet, is readily recognized in the field by the outcrop of Madison limestone which forms a prominant cliff along the northern part of Medicine Lodge valley. Further evidence of faulting is the cropping out of the pre-Cambrian granite geniss at the base of the cliffs, and the offset of the Madison limestone as noted in Section 28, T 11 S, R 11 W.

The Madison cliffs on the east side of the fault represent the upthrown side of the fault. Here the pre-Cambrian of the Beaverhead thrust sheet has been subjected to erosion and the Paleozoic rocks beneath the thrust have been exposed, which has resulted in the fenester shown in Plate I. The normal faults served in places as channelways for mineralizing solutions as previously described.

Two other, smaller, normal faults were mapped in the field,which trend generally east-west, normal to the fault described above. One fault mapped on the west side of the Tendoy Mountains, cuts the north-south fault. Here the southern block is the upthrown, causing displacement of the Madison formation eastward. Movement along the fault was small, for the north-south fault shows little, if any,displacement.

A second east-west fault was mapped on the eastern side of the range, running through Bell Canyon which has apparently formed along the zone of weakness produced by the faulting. The Red Rock conglomerate is slightly displaced, and the

Paleozoic formations which lie beneath the Medicine Lodge thrust sheet seem cut and also displaced.

## Age relations

General Statement: In discussing the age relationships of the area studied, it is tempting to try to evolve a picture of the tectonic history of the area, but this is only possible where the geology studied covers a larger area, and more precise determinations have been made of the age of the formations involved, and their relations to each other. The age relations of the various structural features of the area are discussed here only in a relative way, since making definite age determinations must await further work in adjoining areas. Based on the present available information obtained in mapping the surrounding areas, Doctor Eardley and students have set up an outline of the Cretaceous and Tertiary history of southwestern Montana, (see table I), upon which the author has depended greatly.

Folding: Evidence throughout southwestern Montana indicates at least two periods of Laramide folding which has resulted in the northwest folded trends as typified by the Snowcrest Range. (Eardley, Table I) Two periods of this northeast folding are indicated (Table I), the first of which is dated as early Laramide. This period was followed by the deposition of the Red Rock conglomerate, after which came a second period of folding designated as mid-Laramide.

The age of the folding present in the McKenzie Canyon area cannot be dated without further study. The major sycline which is found beneath the Medicine Lodge thrust sheet is apparently the result of the orogenic activity that caused the thrusting. The possibility that the folding preceded the thrusting cannot be ignored however, but a greater knowledge of the structures of the Red Rock conglomerate and its relationship to the Madison limestone in this area, is necessary before a definite statement can be made concerning the time of folding.

Red Rock conglomerate: One of the most important studies which needs to be made in the region is that of the Red Rock conglomerate. At the present time little is known as to its age, and the relationship of this formation to the structural features of the area is a problem for further research. A more thorough understanding of its age and structural features will lead to a more definite determination of the relative ages of the periods of orogenic activity which occured throughout southwestern Montana.

It is now thought that the formation was deposited during the Paleocene, following the early Laramide orogeny which resulted in the northeast-southwest folds. That the Red Rock conglomerate has been overriden by thrusting from the west is clearly shown by its relationship to the Medicine Lodge thrust. (Sections 16, 20, T 12 S, R 10 W.) However, the connection between regional folding and folds within the Red Rock is still uncertain, but it appears that a mid-Laramide orogeny is responsible for the upturning of the formation as found along the Snow Crest Range. (Eardley, Table I)

Thrusting: The thrusting in the area has been assigned to the late Laramide. All thrusts in the area cut across the folds and override the Red Rock conglomerate.

In no area are the thrusts found to have cut the Tertiary basin beds, and there is conclusive evidence in the area concerned, as well as in those to the south, that the block faulting post-dates the thrusting.

The age relationships of the thrusts in regard to each other cannot be determined on the basis of the present study.

That an extended period of erosion followed the thrusting is clearly indicated throughout the area. Great windows of the underlying Paleozoic formations are present throughout the thrust sheet of the Beaverhead fault. (Kupsch, personal communication). Although much of this erosion may be attributed to accelerated erosion due to uplift by block faulting, the evidence of an earlier erosion period is inescapable. Included in the series of volcanics making up the Sage Creek formation as it is exposed in the north-south valley immediately to the east of Medicine Lodge Creek, is a volcanic breccia member. (See Stratigraphy) The lava flows which rest directly on the pre-Cambrian of the Beaverhead thrust sheet contain angular to sub-angular fragments of the gneiss.

<u>Block faulting</u>: High angle, normal faulting is prevalent throughout the southwest portion of Montana, and several periods have been recognized, the first of which probably started in middle Oligocene. (Eardley, Table I) The major high angle fault which is traced along the western border of the Tendoy Range apparently cuts the volcanics of the Sage Creek formation, but no evidence is available to further date the faulting except that it is cut by the east-west fault described previously.

Although the faults of this area are dated as post-Sage Creek, it appears that block faulting occured intermittently during much of the upper Cenozoic. The faults of the McKenzie Canyon area do not show the evidence of recent movement as does the Red Rock fault along the eastern border of the Tendoy Mountains which is discussed by Cummings (1948, p. 38) Here, in contrast to the area concerned, the fault cuts the recent alluvium of the Red Rock Basin.

It should be emphasized here, that the identification of the Sage Creek formation in the area is doubtful. If this formation, which is cut by the normal faults is correctly identified, it does not preclude the former presence of younger members of the basin beds, which may or may not have been cut by the fault.

## Unsolved Problems

In summarizing the structural features of the McKenzie Canyon area of southwestern Montana, it might not be amiss to outline briefly the various problems which have arisen and which are in need of further research. Until some of these questions have been answered, a complete picture of the tectonic history cannot be obtained.

One of the primary problems concerning the area is the dating of the Red Rock conglomerate as to the time of deposition, and also to date the formation in regard to the various periods of orogenic activity which have occurred throughout the region. A local problem is one of determining the relationship of the Red Rock and the Paleozoic formations, upon which the former rests unconformably. Fixing the age of folding of the Red Rock and the relations of this folding to the folds found in the Paleozoics should date more precisely the orogenic activity in this locality.

More work needs to be done throughout the area in delimiting the various thrusts. At the present time there is no information concerning the thrusts in their relationships to each other. Another problem is the connection of thrusting to the folding found in the area, particularly that folding which is found in the Paleozoics beneath the Medicine Lodge thrust sheet. How many, if any of the folds are the result of stresses caused by thrusting, and what folds represent orogenic activity independent of thrusting?

Another question which at the present time is unanswered, is that of the age of the basin beds which are found exposed in the vicinity of Medicine Lodge Creek. Not only is the accurate determination of the age of these formations important in outlining the tectonic history of the area, but since they represent deposition of sediments, and volcanic activity during the Tertiary, they should furnish a key to the time of block faulting. The age of these formations also have an important bearing on the study of the old erosion surfaces in the region.

TABLE I - SEQUENCE OF MESOZOIC AND CENOZOIC EVENTS

(after Dr. A. J. Eardley and students)

| | |
|---|---|
| Recent | Continued block faulting. Dissection of present river bottom lands. |
| Pleistocene | Block faulting, alluviation, gentle uplift, dissection of pediments. Two episodes of glaciation in Beaverhead Range. |
| Pliocene | Regional uplift. Block faulting. Erosion |
| Upper Miocene Lower Pliocene | Continued block faulting. Deposition of basin beds to north and east. |
| Miocene | Early period of block faulting. Continued volcanism. Erosion. |
| Mid-Oligocene | Volcanism. Deposition of Cook Ranch formation. |
| Lower Oligocene | Local gentle deformation and erosion. |
| Upper Eocene | Volcanism. Deposition of Sage Creek and equivalent formations. |
| Mid or Upper Eocene | Erosion. Slight crustal movements. Formation of broad intermontane valleys. |
| Upper Paleocene or Lower Eocene | Late-Laramide orogeny thrust faulting. |
| Upper Paleocene | Mid-Laramide orogeny-second period of NE folding. |
| Paleocene | Deposition of Red Rock conglomerate. |
| Upper Cretaceous | Early-Laramide orogenic activity - NE folding. |

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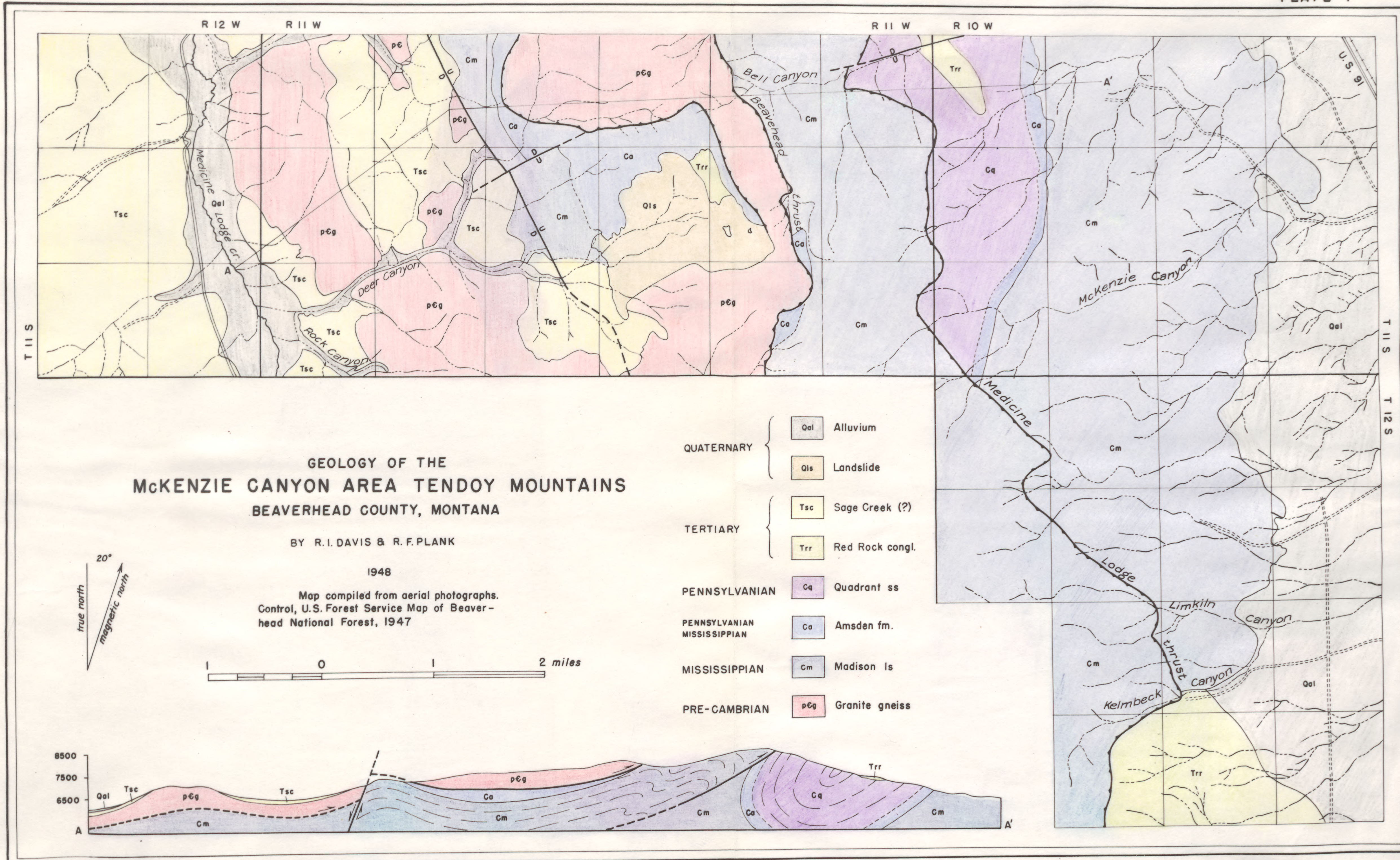
PLATE I


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
true north
magnetic north
20°
1 0 1 2 miles
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
R 12 W
R 11 W
R 11 W
R 10 W
T 11 S
T 11 S
T 12 S
U.S. 91
Medicine Lodge Cr.
Deer Canyon
Rock Canyon
Bell Canyon
Beaverhead thrust
McKenzie Canyon
Medicine Lodge thrust
Limkiln Canyon
Kelmbeck Canyon
A
A'
8500
7500
6500