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GEOLOGY OF THE TENDOY-BEAVERHEAD AREA

BEAVERHEAD COUNTY, MONTANA

by

Walter O. Kupsch

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1950

Committee in charge:

Professor Armand J. Eardley, Chairman
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Professor Lewis B. Kelham
Associate Professor Claude W. Hibbard
Assistant Professor James T. Wilson
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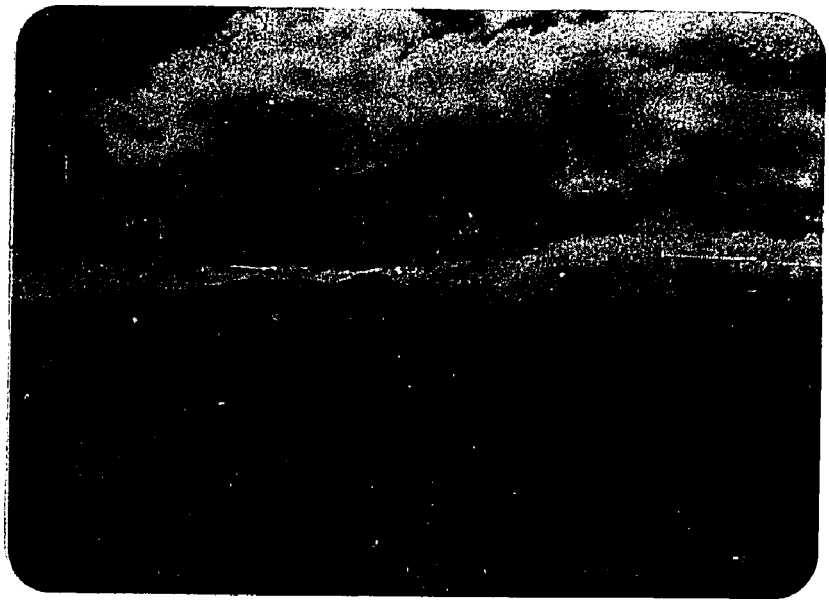
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Walter O. Kupsch

1950

FRONTISPIECE.- Big Sheep Creek Basin and Beaverhead Mountains

Highest peak is Eighteenmile Peak. Mountains consist of granite. Foothills are Tertiary basic volcanic rocks and hummocks of Pleistocene glacial material.



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INTRODUCTION

Scope of investigation

This report is part of a more extensive investigation of the geology of southwestern Montana, conducted by students of the University of Michigan. The geology of the region will be described in at least four doctoral theses, of which this is one. The areas discussed in these reports are shown on the index map of figure 1.

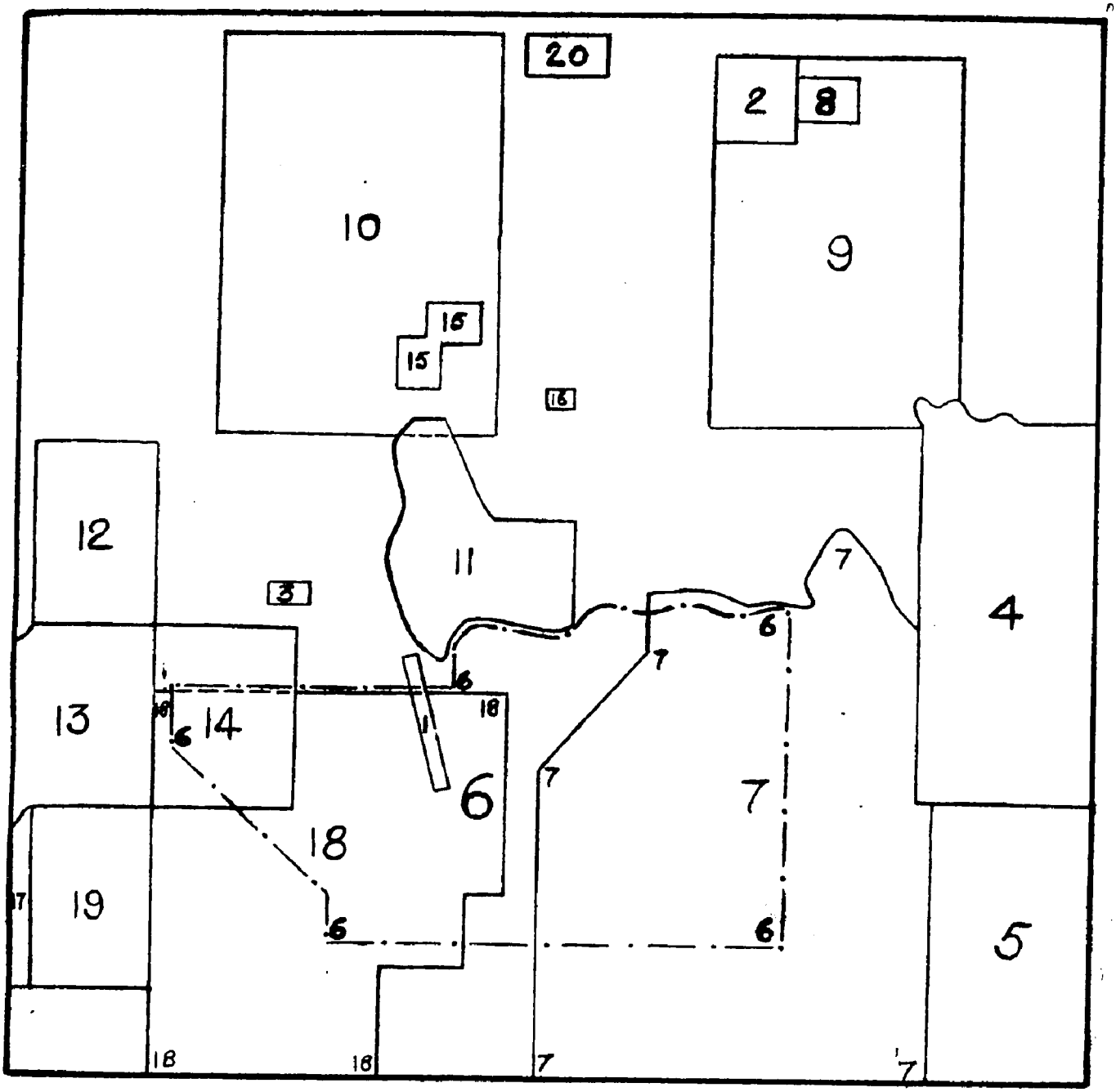
Fieldwork was done by the writer from July 15 until August 23, 1947 and from June 25 until August 18, 1948. Mapping was done on aerial photographs at a scale of approximately 1 : 20,000, and the final map as here presented is on a scale of 1 inch to the mile and is without topographic contours.

Location of area

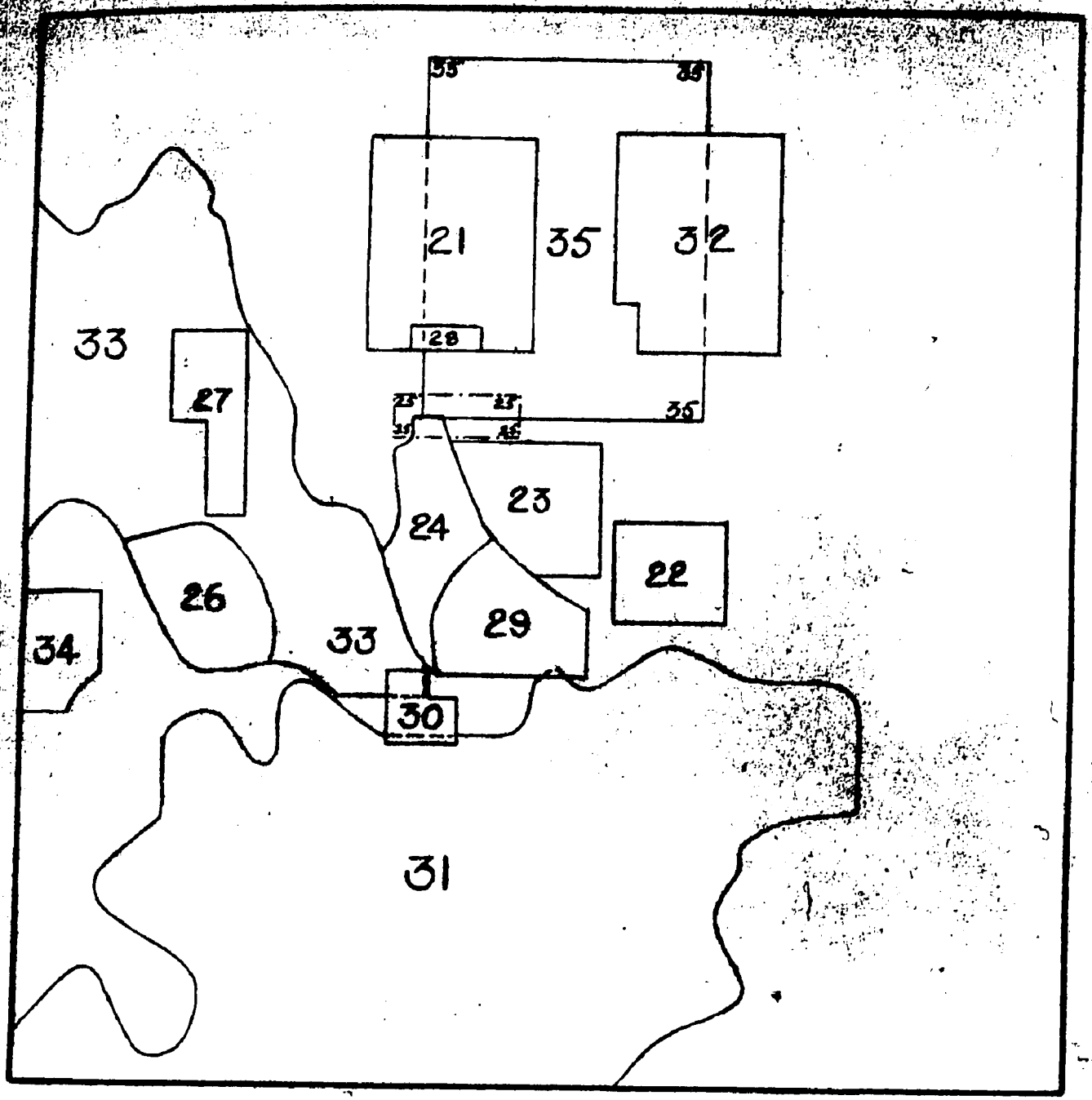
The area described in this report is in Beaverhead County in the extreme southwest corner of Montana and will be referred to as the Tendoy-Beaverhead area. It is located within a quadrangle bounded by parallels 45° 00' and 44° 25' north latitude and meridians 112° 40' and 113° 05' west longitude, and comprises approximately 450 square miles. Large parts of it lie within the boundaries of the Beaverhead National Forest. It is bounded on the west by the Montana-Idaho stateline, Craver Creek and North Medicine Lodge Creek. The north boundary is formed by an arbitrary east-west line four miles north of Armstead. On the east U.S. highway 91 and on the south Big Sheep Creek-Nicholia Creek are the boundaries. See the index map (figure 1).

FIGURE 1.- Indexmap

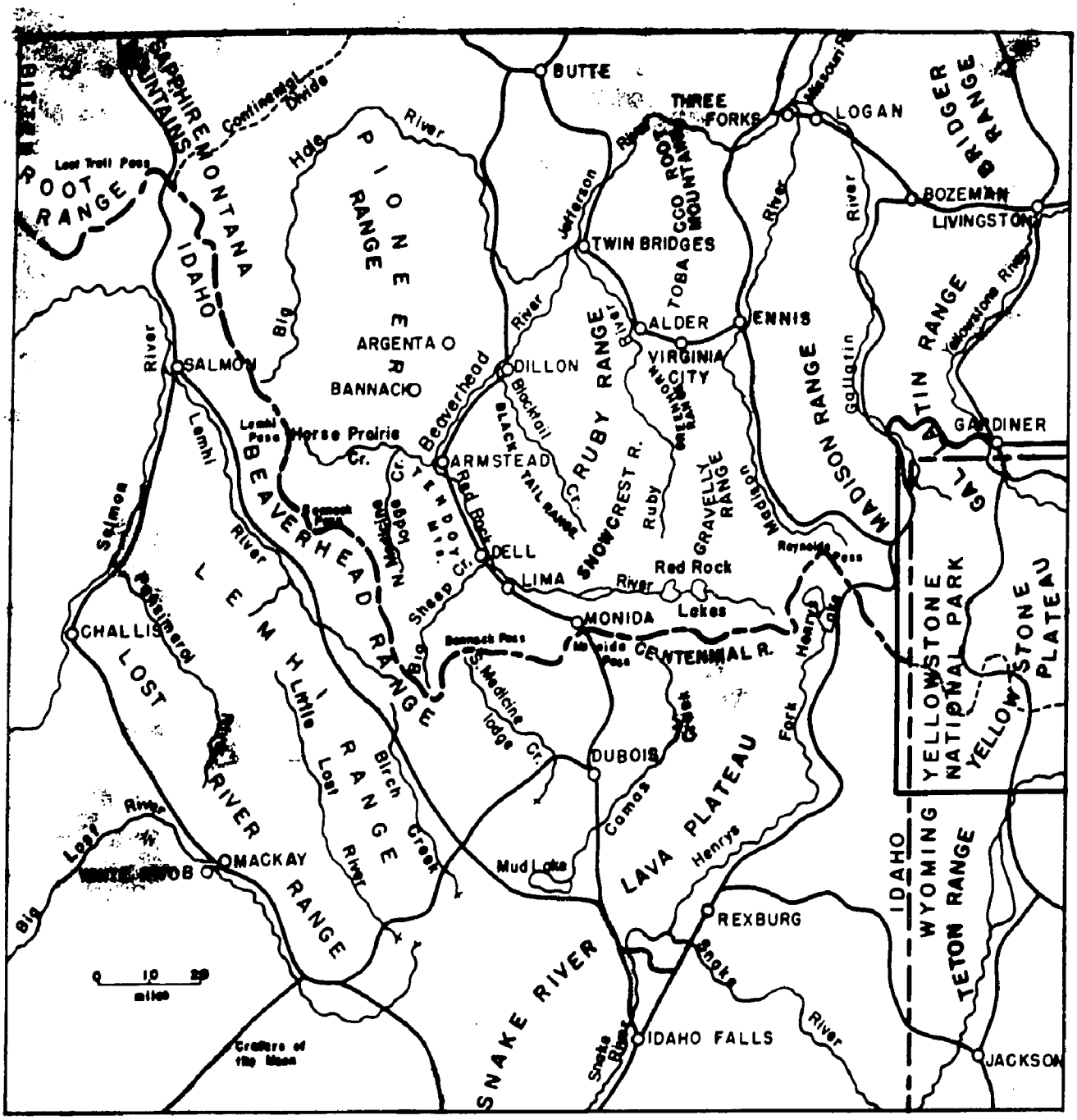
Outline map of the Montana-Idaho-Wyoming region. Overlays show the location of the Tendoy-Beaverhead area and neighboring areas referred to in the text. The titles of the reports are listed in the bibliography under the author's name and year.



1 Anderson and Wagner, 1944
2 Berry, 1943
3 Callaghan and Lemmon, 1941
4 Hague, 1899
5 Horberg, 1938
6 Kirkham, 1927
7 Mansfield, 1920
8 Peale, 1893
9 Peale, 1896
10 Perry, 1934
11 Perry and Sahinen, 1946
12 Ross, 1934[a]
13 Ross, 1937
14 Ross, 1947
15 Shenon, 1931
16 Sinkler, 1942
17 Umpleby, 1915
18 Umpleby, 1917
19 Umpleby and others, 1950
20 Weed, 1912



21 Corry, 1933
22 Honkala, 1949
23 Keenmon, In preparation
24 Kupsch, this report
25 Lowell, 1949?
26 Meinzer, 1924
27 Ross, 1925
28 Sahinen, 1934
29 Scholten, in preparation
30 Shenon, 1928
31 Stearns and others, 1939[b]
32 Tansley and others, 1933
33 Umpleby, 1913[a]
34 Umpleby, 1913[b]
35 Winchell, 1914


BITTERROOT RANGE
SAPPHIRE MOUNTAINS
Continental Divide
Lost Trail Pass
IDAHO
MONTANA
Big Hole River
PIONEER RANGE
BUTTE
THREE FORKS
Missouri River
LOGAN
BRIDGER RANGE
BOZEMAN
LIVINGSTON
Jefferson River
TOBACCO ROOT MOUNTAINS
TWIN BRIDGES
Madison River
Gallatin River
Yellowstone River
ALDER
ENNIS
SALMON
ARGENTA O
BANNACK
DILLON
Beaverhead River
Blacktail Deer Creek
RUBY RANGE
VIRGINIA CITY
MADISON RANGE
GALLATIN RANGE
GARDINER
Lemhi Pass
Horse Prairie Cr.
ARMSTEAD
Red Rock Cr.
Lemhi River
Salmon River
BEAVERHEAD RANGE
Timber Cr.
Sheep Cr.
DELL
LIMA
SNOWCREST R.
Ruby River
GRAVELLY RANGE
Madison River
Reynolds Pass
Red Rock Lakes
MONIDA
CHALLIS
Pahsimeroi River
LOST RIVER RANGE
LEMHI RANGE
Big Lost River
Birch Creek
Bannock Pass
Big Hole Pass
CENTENNIAL R.
Henrys Lake
Fork
Madison Lodge Cr.
DUBOIS
Camas Creek
YELLOWSTONE NATIONAL PARK
YELLOWSTONE PLATEAU
Big Lost River
MACKAY
Mud Lake
LAVA PLATEAU
Henrys
REXBURG
IDAHO
WYOMING
TETON RANGE
Snake River
IDAHO FALLS
JACKSON
Craters of the Moon
0 10 20 miles

Roads. The main roads are shown on the geologic map (plate I). The eastern edge of the area can be reached by car over U.S. highway 91. A gravelled and graded road branches from highway 91 about one mile south of Dell and follows Big Sheep Creek along the southern boundary of the area. In summertime this road is passable by automobile to a point 1 mile south of Tendoy Creek (also called Trail Creek).

To the north an improved road, which branches from the highway at Armstead, affords easy access to Horse Prairie (also called Horse Plain).

From north to south the area can be crossed by car along a road branching from Horse Prairie road at Medicine Lodge, running along North Medicine Lodge Creek, crossing the low divide of Island Butte and descending into Big Sheep Creek Basin (also called Nicholia Basin). In this basin the road partly follows Cabin Creek and connects with Big Sheep Creek road. During the dry season the road can be traversed by car. It is of historic interest because if formed part of the old Corinne stage road from Corinne, Utah to Bannack, Montana, 1862.

The extreme western part of the area can be reached over east-west roads which branch from the Corinne stage road. These roads are usually well maintained in the basin, but end at the mountain fronts. From there only trails follow the main creeks.

A branch of Big Sheep Creek road along Muddy Creek allows easy access to Muddy Creek Basin, which can also be reached over a road that crosses the Tendoy Mountains. It starts at Kidd along U.S. highway 91, follows Little Water Creek and then descends into the basin across the low divide.

---

1) The name Bannack was that of an Indian tribe belonging to the Shoshonean linguistic stock. Bannack is the old spelling, the second a is now often changed to o : Bannock (Wheeler, 1904, II, p. 20).

Numerous trails, many of which are passable by jeep, cross the area in all directions.

Railroads. The railroad nearest to the area is the Oregon Short Line (Union Pacific) which parallels U.S. Highway 91. The Gilmore and Pittsburgh Railroad from Armstead (Montana) to Salmon (Idaho) following Horse Prairie Creek was abandoned in 1939 and the tracks removed in 1940.

Maps and aerial photographs. Available geographic maps are:

1. Map of Beaverhead National Forest prepared by the Forest Service of the U.S. Department of Agriculture. Issued in 1947 on a scale of 1/2 inch to the mile and 1/4 inch to the mile. Best map available.

2. General Highway and Transportation map, Beaverhead county, Montana. Prepared by the Montana State Highway Commission in 1936, revised in 1943 and 1945. Scale 1/2 inch to the mile.

These maps are without contourlines. No topographic maps are available.

Aerial photographs covering the entire area were made in 1942. Contact prints at a scale of 1 : 20,000 can be obtained from the Agricultural Adjustment Agency, Salt Lake City, Utah.

Previous Work

The first scientific explorers to pass through the area were Lewis and Clark and their companions (Wheeler, 1904, II, p. 34-49). In August 1805 they camped close to where Armstead is now. The explorers went up Horse Prairie Creek which they erroneously believed to be the ultimate source

of the Missouri. They crossed the Continental Divide at Lemhi Pass and descended into Lemhi Valley.

The first scientist to publish any geological observations on the area was Hayden (1872, p. 144-146). He noted the anticlinal valley north of Horse Prairie with its Precambrian core. He found fish scales, plants, and lignite in the Tertiary beds along North Medicine Lodge Creek.

The phosphatic oil shales in the Permian near Muddy Creek Basin attracted attention as early as 1917, when they were described by Bowen (1917, p. 315 - 320), who also noted the shales in the Tertiary deposits in the basin.

In a report by Dobbin and others (1932, p. 36) the coals occurring in the Tertiary beds along North Medicine Lodge Creek were analyzed, and a measured stratigraphic section published.

During the summer of 1946 E. S. Perry and U.H. Sahinen (Montana Bureau of Mines and Geology) made a reconnaissance map of southwestern Montana on which the area of this report is included (Perry and Sahinen, 1946). Previous to this map Perry (1933, p. 1) had published some information on the ground-water conditions around Armstead. Perry (1948, p. 18-20) described in detail the graphite deposit along the divide between Kate Creek and McBride Creek. These deposits were mentioned before by Brink (1931, p. 13) in an abstract of a paper read before the Beaverhead Mining Association. Various pre-Beltian rocks, with which the graphite is associated, have been investigated by Heinrich (1949a, p. 10 and 1949b, p. 22).

Lowell (1949) mapped part of the area north of Horse Prairie Creek in detail. The metamorphic rocks in this area have been described by Heinrich (1949b, p. 95). Lowell in collaboration with Klepper has recently studied the Tertiary conglomerate found in the Tendoy Mountains, but the results have not yet appeared in print. The Permian Phosphoria formation in the vicinity of Muddy Creek Basin was also mapped in detail. by Lowell for the U.S. Geological Survey (McKelvey, 1949, p. 273).

Acknowledgments

The writer is indebted to the staffs of the Departments of Geology and Mineralogy of the University of Michigan for various assistance, criticism, and encouragement during his work. Special thanks is due to Dr. A. J. Eardley under whose supervision the fieldwork was done and the writing of this report was undertaken. Dr. L.B. Kellum was kind enough to assist in the identification of the invertebrate fossils. Dr. C. H. Arnold identified the plant remains and Dr. R. R. Miller of the Zoology Museum the fish scales. Dr. E. W. Heinrich and Dr. W. F. Hunt checked the petrographic descriptions of the thin-sections and Mr. M.V. Denny helped in making the photomicrographs and in printing of the other photographic material. Dr. E. W. Walker and Dr. C. W. Hibbard aided in reading the manuscript; Mr. Derwin Bell in making the drawings.

Field conferences and correspondence with Dr. C. P. Ross, Dr. R. W. Imlay, Dr. W. R. Lowell, and Dr. M.R. Klepper of the U.S. Geological Survey, and Dr. L. L. Sloss and Mr. Carl Moritz of the Phillips Oil Co. broadened the writer's view on the geology of this region.

Information on the vegetation and fauna was kindly supplied by Mr. R. H. Mart, District Forest Ranger of Beaverhead National Forest. Mr. J. Colling, ex-president of the Beaverhead Mining Association, provided data on the exploitation of natural resources.

Financial aid was received from the Graduate School of the University of Michigan, and the Montana Bureau of Mines and Geology which employed the writer during the summer of 1946.

The following graduate students in geology at the University of Michigan mapped parts of the area: S.R. Wallace, H.H. Kruseкopf, W.T. Smith, D.L. Cummins, R. F. Flank, R. I. Davis, James Seglund, G. F. Bowers, R. A. Brant, N.C. Elmer, W.A. Gillespie, and J.R. Peterson. Their masters theses, which are listed in the bibliography, helped considerably in the preparation of this report. Students who mapped other parts of southwestern Montana, notably Messrs. Robert Scholten, and K.A. Keenmon contributed to various regional problems.

GEOGRAPHY

Topography

Regional features. Nearly two thirds of the state of Montana lie on the Great Plains. The Rocky Mountains cross the state from northwest to southeast and occupy the remaining one third of Montana in the west and southwest. The northern part of the Rocky Mountains in Montana and Idaho is characterized by a dissected upland country in which the separation of mountains into distinct ranges is indefinite (Fenneman, 1931, p. 153). The southern part of this mountainous province contains the Tendoy-Beaverhead area. This part possesses long, subparallel, linear ranges and broad intermontane basins [2] in southwestern Montana and southeastern Idaho.

Three well-marked ranges having a northwesterly trend are found in this region, one of which is in the area mapped. From west to east these are the Lost River Range, the Lemhi Range, and the Beaverhead Range (see figure 1). The first two are in Idaho, the third one is in Montana. The Lost River Range comprises the highest peak in Idaho (Borah Peak, elevation 12,655 feet). The Lemhi Range is similar in size, shape, and trend to the Lost River Range but is not as high nor as rugged. A broad valley separates the Lemhi Range from the Beaverhead Range, which is somewhat lower than the Lemhi Range but locally reaches altitudes of more than 10,000 feet. The three ranges disappear toward the south under the lavas of the Snake River Plain.

---

[2] Fryxell, (1930, p.1) states: "The term "basin" as commonly used in connection with the Rocky Mountains simply denotes a broad intermontane valley, or lowland; it does not necessarily imply closure so complete as to prevent outward drainage".

East of the Beaverhead Range other mountain ranges occur but no parallelism is evident and several trends are present, as shown by the Blacktail and Snowcrest ranges.

Local features: The most important topographic features of the Tendoy-Beaverhead area are shown in figure 2. Along the west side are the Beaverhead Mountains. This name was given by Umpleby (1913a, p. 23) to about 100 miles of the Continental Divide from Lost Trail Pass to Monida Pass. Because of the parallelism of basins and ranges in this region it seems more appropriate to confine the name Beaverhead to the mountains west of Big Sheep Creek Basin. This would mean termination of the name at Bannock Pass (also called Medicine Lodge Pass) rather than Monida Pass. North of Lost Trail Pass the range splits, and according to Umpleby the eastern part continues as the Continental Divide and the western part as the Bitterroot Mountains. According to the Montana State Highway Map the name Bitterroot Range applies also the mountains south of the Lost Trail Pass and extends to the southwest corner of Montana. In this nomenclature the Beaverhead Mountains would be the southern part of the Bitterroot Range. On some maps the name Beaverhead Range is used to conform with Lemhi Range and Lost River Range.

East of the Beaverhead Mountains lies the intermontane Big Sheep Creek Basin. Its southern part extends into Idaho, merging into the Snake River Plain in the same manner as do Little Lost River and Birch Creek valleys. Similar to these two valleys Big Sheep Creek Basin is also crossed by a divide, which is here part of the Continental Divide. The divide was traversed by the Corinne stage road and is called Bannock

FIGURE 2.- Physiographic diagram

Note- Nicholia Basin is also called Big Sheep Creek Basin



PHYSIOGRAPHIC DIAGRAM [illegible]

TOPOGRAPHIC HIGHS AND [illegible]

IMMEDIATE VICINITY.

Pass or Medicine Lodge Pass to distinguish it from Bannock Pass at the end of Horse Prairie (see figure 1.). Big Sheep Creek Basin is about 7 miles wide and has an average altitude of about 7500 feet. Its trend is northwesterly parallel with the Beaverhead Mountains. The central part is a broad gravel-covered valley with a maximum local relief of about 100 feet. To the north it is bordered by low hills which form another divide across the basin, separating the southward flowing drainage of Cabin Creek from the northward flowing drainage of North Medicine Lodge Creek. The length of Big Sheep Creek Basin between Bannock Pass in the south and Island Butte in the north is about 15 miles.

North of Island Butte the broad valley continues as the North Medicine Lodge Basin. It is here about 4 miles wide and has a surface of low relief. The entire length of North Medicine Lodge Basin to its northern termination is about 6 miles. The creek leaves the broad valley and flows through a narrow constricted gorge into another broad basin, which is also called North Medicine Lodge Basin. It is, however, more an extension of Kate Creek Basin into Horse Prairie, a large east-west trending intermontane valley.

East of Big Sheep Creek Basin and North Medicine Lodge Basin an unnamed ridge rises sharply from the valley floor to an average altitude of 8500 feet, attaining in its northern part an altitude of over 10,000 feet (Ellis peak).

East of this ridge lies Muddy Creek Basin which has a maximum width of 3 miles and a total length of about 12 miles. It has a northwesterly

trend, and is surrounded on all sides by mountains rising at least a 1000 feet above the valley. Generally slopes within the valley are gentle, but locally badlands with steep-walled gullies have been developed, especially in the west central part of the basin.

Northwest of Muddy Creek Basin the much smaller Muddy Hole Basin is found. Its southern termination is formed by high mountains like Grassy Top and Graphite Mountain.[3] It is separated by a relatively low divide on the north from Kate Creek Basin. On the physiographic diagram (figure 2) the two small basins, Muddy Hole and Kate Creek, are treated as one and labeled together as Muddy Hole Basin.

Along the east side of Muddy Creek Basin the northwest trending Tendoy Mountains rise to altitudes close to 9,000 feet. Some peaks, such as Dixon Mountain and Timber Butte, attain even greater heights. These peaks are in the southern part of the range which in general is higher than the northern part. The Tendoy Mountains extend from Horse Prairie southward along the east side of the area. They form a ridge about 4 miles wide with generally a gently rolling summit, especially in the northern part. The eastern front is quite abrupt. The Muddy Creek front exhibits a more gentle approach to the mountains.

East of and parallel with the Tendoy Mountains is the Red Rock Valley. This valley is remarkably straight between Dell and Armstead, a distance

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[3] The name Graphite Mountain is misleading because no graphite is found here. The graphite deposits of Kate Creek and McBride Creek are about 3 miles to the north of this prominent peak consisting in its upper part of the resistant Quadrant quartzite.

of over 20 miles. The altitude at Dell is 6015 feet, that at Armstead 5492 feet. This indicates a gradient of 1 : 200, which means an angle of slope of only 18 minutes imperceptibel to the human eye. The basin has a width of about 5 miles. Along its western margin the Tendoy Mountains rise sharply from the valley floor. Their base is covered with relatively small alluvial fans and other accumulations of debris.

The northern part of the area contains Horse Prairie, an east-west trending intermontane valley. This valley is comparatively narrow in the area investigated but broadens considerably to the west.

The lowest point in the area shown on the Forest Service map is 5439 feet at a point about 3 miles north of Armstead. The highest point probably is Eighteenmile Peak with an altitude of over 10,000 feet. The maximum relief within the area is therefore about 5,000 feet.

Drainage

Regional features. In the part of Idaho adjacent to the area investigated the southward flowing streams are tributary to the Snake River. Some of these streams, such as Lost River and Birch Creek do not actually reach the Snake River but sink into the porous lavas of the plateau before attaining the main channel. The northward flowing streams empty into the Salmon River.

The streams in southwestern Montana are part of the Missouri drainage basin. At Armstead where Horse Prairie Creek joins from the west, the Beaverhead River changes its name to Red Rock River. Formerly this part was known as Red Butte Creek after the red rock southeast of Dell (Brower, 1896, p. 75). The river system of Jefferson, Beaverhead, and Red Rock

rivers constitutes the longesttributary to the Missouri. Hence the remotest source of the Missouri lies at the east end of Centennial Valley where the source of the Red Rock River is (Wheeler, 1904, p. 36).

Large lakes in the region are the Upper and Lower Red Rock Lakes, occupying the eastern half of Centennial Valley. The western part of the same valley is covered by the Lima Reservoir.

Local features. The names of the various creeks in the area are given on the geologic map (plate I). All the creeks are directly or indirectly tributary to the Red Rock River, or in the extreme northern part to the Beaverhead River.

In Big Sheep Creek Basin the major streams are Nicholia Creek and Cabin Creek, which drain to the south. Where Nicholia Creek leaves the basin it is called Big Sheep Creek.

Across the divide at Island Butte the drainage is to the north. The name North Medicine Lodge Creek is used for the main creek in order to distinguish this creek from South Medicine Lodge Creek which heads at the extreme southern end of Big Sheep Creek Basin. On some maps, like the one of Raisz (1941) both creeks are indicated by the name Medicine Lodge Creek, although one drains into the Pacific Ocean and the other into the Atlantic Ocean. Kate Creek is an important tributary to North Medicine Lodge Creek.

The southeastern part of the area is drained by Muddy Creek which flows south and unites with Big Sheep Creek. In the northern part of Muddy Creek Basin the only important permanent stream is Wilson Creek with its tributary McBride Creek.

Lakes are confined to the area west of Big Sheep Creek Basin. They are in glacial cirques or in the morainal material filling the main valleys of the Beaverhead Mountains and forming part of the foothills. The largest and deepest one is Morrison Lake.

Settlements

Concentrations of population are confined to Red Rock Valley. Lima, which lies outside the area and 8 miles south of Dell, is the largest settlement and has about 550 inhabitants. Dell has a population of 45, Armstead has 75. In addition to these villages, ranches are scattered over the valley.

In the other parts of the area only ranches are found. These are confined to the intermontane basins and are commonly located on the alluvial material bordering the major creeks.

The nearest town is Dillon (population 3,000), 22 miles north of Armstead.

Climate

The closest substation of the U.S. Weather Bureau is Lima in the Red Rock Valley. The following data refer to this station and have been taken from "Climate of the States, Montana", Agricultural Yearbook, Separate no. 1844, Washington 1941:

January average temperature	16.3° F.
July " "	62.9° F.
Annual mean	39.3° F.
Annual average precipitation	9.27 inches

Length of growing season between average dates of last killing frost in spring and first in fall: 87 days.

The data represent a continental climate of the arid type.

Although no data are available for either Big Sheep Creek Basin or Horse Prairie the precipitation is about the same as in the wide valley in which Lima is situated.

The more abundant vegetation in the mountainous part is, however, an indication that the precipitation is higher there than in the adjacent basins. The prevailing winds are westerly and much of the moisture precipitates in the Beaverhead Mountains before reaching the more eastern parts of the area. In winter snow accumulates to considerable depth in the mountains and provides water for the creeks in summertime.

Freezing temperatures and snowfall may occur late in May, or even in June, and as early as September in the fall. In the summer nights are cool in the mountains. Strong winds occur in the afternoon, but usually diminish at sunset. Thunderstorms and light showers are frequent. Even in mid-summer hail can be expected.

Vegetation

Distribution factors. The almost complete absence of trees in the basins and the prevalence of conifers among the trees, which cover some of the mountain slopes, is characteristic of the region. The difference in vegetation of the basins from that of the mountains is due to various factors of environment and climate. Such as: altitudinal differences, humidity, exposure, slope, the depth of soil cover, and its moisture holding capacity.

Vegetation of the mountains. A difference in tree coverage between slopes with a southern exposure and those with a northern exposure can be noted.

The names of the trees most commonly found on slopes facing a northern direction are: Douglas fir, lodgepole pine, limber pine, white bark pine, white balsam fir, Engelman spruce, and quaking aspen.

The names of the common shrubs and trees on slopes with a southern exposure are : sagebrush, mountain mahogany, and Rocky Mountain juniper.

Vegetation of the basins. The basins are covered mainly with sagebrush and bunchgrasses. Sagebrush and grasses intermingle in habitat, but ordinarily the grasses will use a soil too shallow or stony for the sagebrush. On some alkaline soils which occur in the basins sagebrush can survive, whereas grasses are limited by species adaptability.

Vegetation along creeks. The vegetation along most creeks is dominated by the mountain willow. The meadowlands along the major creeks in the basin commonly possess a greater moisture than sagebrush can tolerate and only grasses, weeds, and herbs are found.

Fauna

Also the animal life of the basins is different from that in the mountains. Animals typical of the mountains are : tree squirrel, pine grouse, porcupine, marten, bear, elk, mule deer, and moose.

More confined to the basins are: ground squirrel, sage chicken, jack rabbit, antelope, and coyote.

GENERAL STRATIGRAPHY

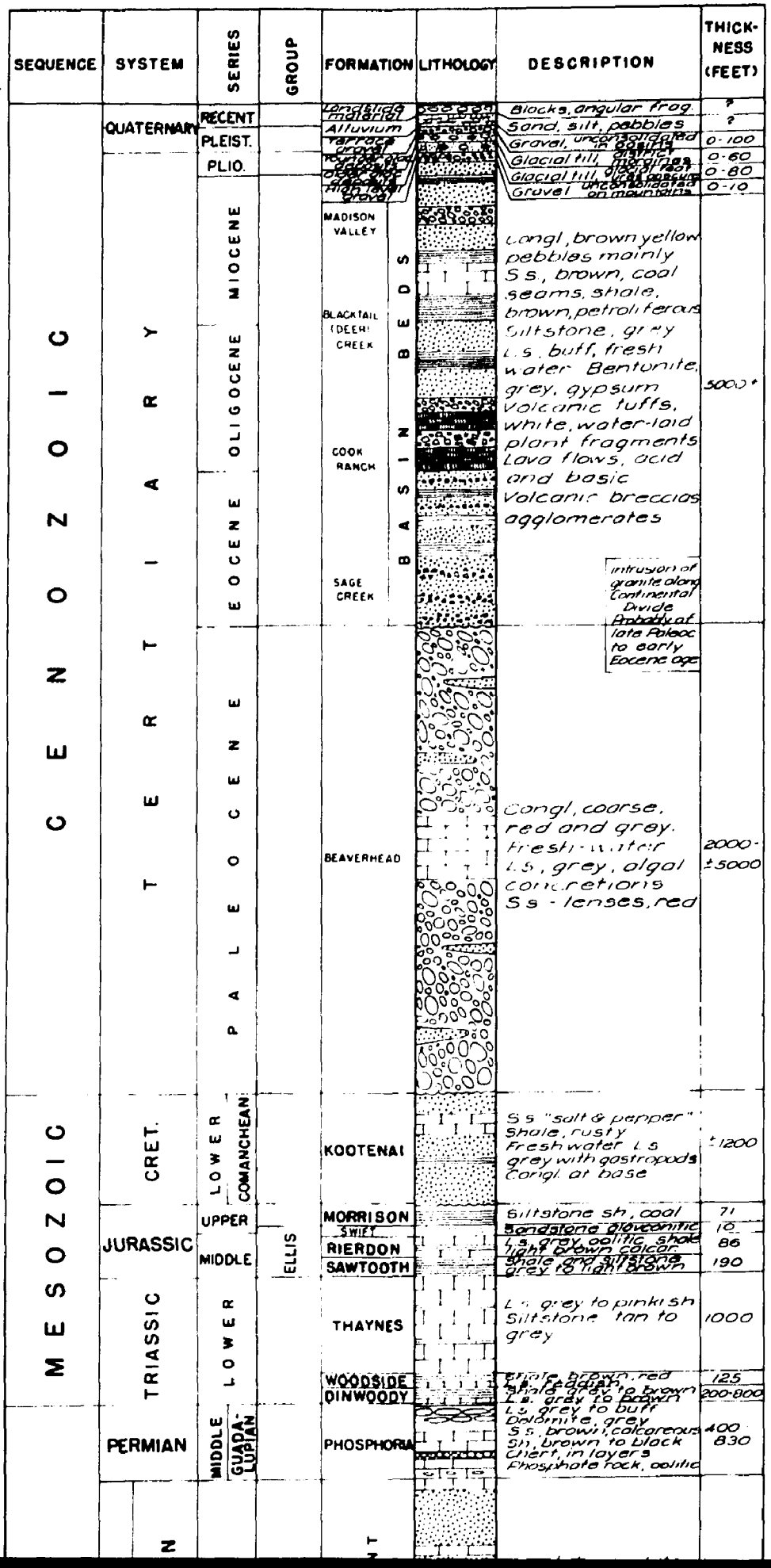
Table 1 shows the stratigraphic column of the area. The rocks range in age from Precambrian to Recent. All systems except the Silurian seem to be present, but the presence of the Ordovician is doubtful.

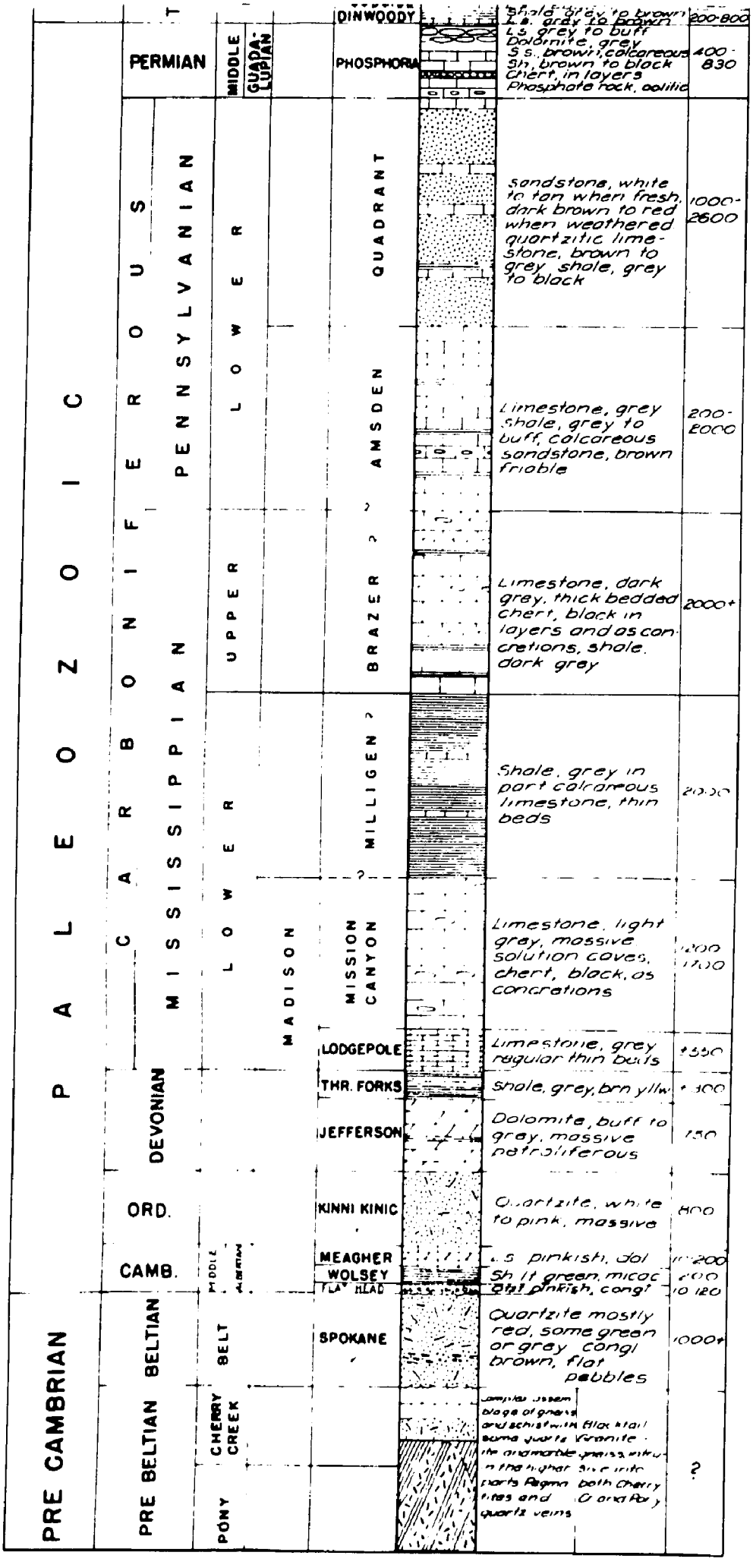
Precambrian rocks are confined to the western half of the area where they are abundant. Paleozoic and Cenozoic rocks are of much greater areal extent than Mesozoic strata. Cenozoic sediments are largely confined to the intermontane basins. Mesozoic rocks are present only in the Tendoy Mountains. They are found in the northern part of this range and west of Muddy Creek Basin. Ross (1947, p. 1126) notes that the western border of present exposures of Mesozoic rocks in Montana and Idaho extends approximately along 113° west longitude. The thickness of Mesozoic rocks seems first to increase to the east of the area and then to decrease again. The Paleozoic rocks on the other hand increase in thickness to the west where they attain an aggregate thickness of 20,000 feet in Idaho (Ross, 1947, p. 1126).

Most of the older Precambrian rocks are of igneous origin, the younger Belt rocks are undoubtedly sedimentary. All the Paleozoic and most of the Mesozoic rocks represent marine sedimentation. Clastic sediments such as sandstones and shales, and chemical sediments such as limestones and dolomites make up most of the stratigraphic column. Continental deposits form the upper part of the Mesozoic and the whole of the Cenozoic part of the section.

In the Precambrian rocks no unconformities are exposed, but probably at least two are present in nearby areas. An unconformity probably occurs

TABLE I.- Generalized stratigraphic column


SEQUENCE
SYSTEM
SERIES
GROUP
FORMATION
LITHOLOGY
DESCRIPTION
THICKNESS (FEET)
CENOZOIC
MESOZOIC
QUATERNARY
RECENT
PLEIST.
PLIO.
TERTIARY
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRET.
LOWER
COMANCHEAN
UPPER
JURASSIC
MIDDLE
ELLIS
TRIASSIC
LOWER
PERMIAN
MIDDLE
GUADALUPIAN
Undistinguished material
Alluvium
Terrace gravel
Gravel
Glacial till
Glacial till
Gravel
Blocks, angular frag.
Sand, silt, pebbles
Gravel, unconsolidated to cemented in places
Glacial till, gravelly
Glacial till, gravelly
Gravel unconsolidated on mountains
0-100
0-60
0-80
0-10
MADISON VALLEY
BLACKTAIL (DEER) CREEK
COOK RANCH
SAGE CREEK
BASIN BEDS
Congl, brown yellow pebbles mainly Ss, brown, coal seams, shale, brown, petroliferous Siltstone, grey Ls, buff, fresh water Bentonite, grey, gypsum Volcanic tuffs, white, water-laid plant fragments Lava flows, acid and basic Volcanic breccias agglomerates
intrusion of granite along Continental Divide Probably of late Paleoc to early Eocene age
5000+
BEAVERHEAD
Congl, coarse, red and grey. fresh-water Ls, grey, algal concretions Ss - lenses, red
2000-±5000
KOOTENAI
Ss "salt & pepper" Shale, rusty Freshwater Ls grey with gastropods Congl at base
±1200
MORRISON
SWIFT
RIERDON
SAWTOOTH
Siltstone sh, coal
Sandstone glauconitic
Ls, grey, oolitic, shale light brown colour
Shale and siltstone grey to light brown
71
10
86
190
THAYNES
Ls, grey to pinkish Siltstone tan to grey
1000
WOODSIDE
DINWOODY
Shale brown, red Ls reddish Shale grey to brown Ls, grey to brown
125
200-800
PHOSPHORIA
Ls, grey to buff Dolomite, grey Ss, brown, calcareous Sh, brown to black Chert, in layers Phosphate rock, oolitic
400
830


PALEOZOIC
PERMIAN
MIDDLE
GUADALUPIAN
DINWOODY
PHOSPHORIA
Shale, grey to brown
L.S. grey to buff
Dolomite grey
S.S. brown, calcareous
Sh. brown to black
Chert, in layers
Phosphate rock, oolitic
200-800
400-830
MISSISSIPPIAN
CARBONIFEROUS
PENNSYLVANIAN
LOWER
UPPER
QUADRANT
AMSDEN
BRAZER ?
Sandstone, white to tan when fresh, dark brown to red when weathered quartzitic limestone, brown to grey, shale, grey to black
1000-2600
Limestone, grey shale, grey to buff, calcareous sandstone, brown friable
200-2000
Limestone, dark grey, thick bedded chert, black in layers and as concretions, shale, dark grey
2000+
MILLIGEN ?
Shale, grey in part calcareous limestone, thin beds
2000
MADISON
LOWER
MISSION CANYON
Limestone, light grey, massive solution caves, chert, black, as concretions
1200-1700
DEVONIAN
LODGEPOLE
Limestone, grey regular thin beds
350
THR. FORKS
Shale, grey, brn yllw
300
JEFFERSON
Dolomite, buff to grey, massive petroliferous
150
ORD.
KINNI KINIC
Quartzite, white to pink, massive
400
CAMB.
MEAGHER
Ls pinkish, dol
100-200
WOLSEY
Sh lt green, micac
200
FLATHEAD
Qtzt pinkish, congl
10-120
PRE CAMBRIAN
PRE BELTIAN
BELTIAN
SPOKANE
Quartzite mostly red, some green or grey congl brown, flat pebbles
1000+
CHERRY CREEK
PONY
Complex assemblage of gneiss and schist with thick basal sedimentary quartz Granite pegmatite and aplite dikes in the higher grade parts Both Cherry Creek and Pony quartz veins
?

at the base of the Cambrian. An angular unconformity is clearly indicated at the base of the Tertiary deposits. The writer agrees with Perry (1945, p. 2), who writes: "Remarkable is the nearly complete parallelism of all Paleozoic and Mesozoic strata, even in areas where strata of two or even three geologic periods are missing. Angular unconformity is generally slight and seldom evident.

In describing the various formations the author has tried to pursue the following scheme as much as possible:

1. Definition
2. Distribution and thickness
3. Lithologic and stratigraphic features
4. Correlation
5. Origin

PRE-BELTIAN SYSTEM

General remarks

Three main units can be distinguished in the pre-Beltian rocks of southwestern Montana. These units from oldest to youngest are: Pony series, Cherry Creek series, Blacktail granite gneiss. The distinction between Pony and Cherry Creek is not easy to make, especially if only a small area is examined (Heinrich, 1949b, p. 16). The Pony series contains sedimentary and igneous rocks and has been considered to be of Archeozoic age. The Cherry Creek series contains chiefly rocks of sedimentary origin and was believed to be of Proterozoic age. According to Tansley and others (1933, p. 8) such an age division of Pony and Cherry Creek rocks is not justified. They state that both series may belong either to the Archeozoic or Proterozoic age. These writers prefer to call the metamorphic rocks pre-Beltian as they are definitely older than the Belt series, because in several places in western Montana the Belt rests on schists and gneisses. The term Archeozoic has been rejected by the U. S. Geological Survey, which now classifies all pre-Paleozoic rocks as Precambrian. The time covered by these rocks is called Proterozoic era (Wilmarth, 1938, p. 67 and 1737). The addition of a third unit to the pre-Beltian rocks of southwestern Montana is relatively new as the term Blacktail granite gneiss was proposed by Heinrich (1948, p. 1329) only about a year ago.

Commonly the metamorphic character of the pre-Beltian rocks is evident. This is especially true for the Blacktail granite gneiss which is the most widespread of the three units in the Tendoy-Beaverhead area.

The presence of the Pony is uncertain and rocks undoubtedly belong-

ing to the Cherry Creek occur only in one locality. On the geologic map (plate I) the pre-Beltian rocks are mapped as a single unit and no differentiation is attempted, with the exception of one large area underlain by typical Cherry Creek. The Belt rocks are clearly of sedimentary origin and exhibit no apparent metamorphism in hand specimen, but a low degree of metamorphism is evident in thin-section.

Pony series

Definition. The name Pony series was given by Tansley and others (1933, p. 8) to a complex assemblage of metamorphic rocks in the Tobacco Root Mountains. The series is older than the Cherry Creek and is of sedimentary and igneous origin. The assemblage was named for exposures at and in the vicinity of the town of Pony.

Heinrich (1949b, p. 17) recognized the Pony in the Dillon region and states that the absence of marbles, quartzites, and other well defined meta-sedimentary units is characteristic.

Distribution and thickness. The Pony series has been recognized only in southwestern Montana in Madison and Beaverhead Counties.

In the Tendoy-Beaverhead area the presence of the Pony is not certain but some rocks in the pre-Beltian are assigned to this series. The distribution of the entire pre-Beltian complex in the Tendoy-Beaverhead area will be discussed under the heading Blacktail granite gneiss. No thickness of the Pony series was given by Tansley and others in the Tobacco Root Mountains, as no older rocks are known and because most of the series is probably of igneous origin.

Lithologic features. In the Tendoy-Beaverhead area the rocks assigned to the Pony series are hornblende gneisses and amphibolites.

At least two types of hornblende gneisses seem to be present: 1. Those containing a moderate amount of feldspar; 2. Those containing little or no feldspar. The first type commonly exhibits gneissic banding in hand specimen, although the banding is not as conspicuous as in the acidic gneisses of the Blacktail granite. A thin-section of a specimen (1548) from the Kate Creek area shows a granoblastic texture with little or no alignment of minerals. Quartz is absent except in veinlets along which it was introduced later. The amount of dark minerals about equals that of feldspar. Green hornblende is the most prominent constituent. The feldspar is plagioclase of the composition andesine. Pyroxene (hypersthene) is also present but is greatly altered. Some of the hypersthene shows nearly complete alteration to serpentine (bastite). Other individuals are changed to chlorite, iron oxides, zoisite, epidote, and carbonates. The feldspar also is much altered and commonly completely changed into very small flakes of sericite. In other instances the sericite alteration is concentrated mainly along cracks. Accessory minerals include apatite, magnetite, and zircon. The rock is the metamorphic equivalent of a diorite. Similar hornblende-plagioclase gneisses are in the northern part of the Armstead anticline. Here the gneisses seem to contain more pyroxene, which is present as augite, diopside, and hypersthene. The rock is not so much altered. The plagioclase is more basic and falls in the labradorite range, (Brant and others, 1949, p. 95). Some of the hornblende gneisses are cut by thin stringers of acid plagioclase or potash feldspar with or without quartz, commonly parallel to the more or less dis-

tinct lineation. Rocks containing these stringers are believed to represent hybrids due to the later intrusion of granitic material of the Blacktail pluton into the older hornblende gneisses (Heinrich, personal communication).

A specimen of hornblende gneiss belonging to the second group which has little or no feldspar was collected in N. E. ¼ sec. 4, T. 14 S., R. 11 W. In hand specimen no banding is evident in the dark, coarse-grained rock in which the amphibole is readily recognizable. Examination of a thin-section (4148) shows a very pronounced alignment of the elongated hornblende crystals. The little feldspar present is largely altered almost beyond recognition. The amount of quartz is insignificant and as it occurs mainly in veinlets it is probably all secondary. Epidote and smaller amounts of zoisite are prominent constituents and together with chlorite they represent alteration products of hornblende. The pyroxene is diallage, which is the characteristic pyroxene of gabbro and related rocks. The mineral has a fine lamellar structure and distinct parting. In general the rock is greatly altered and minerals such as calcite, sericite, and iron oxides are abundant.

The hornblende gneisses grade into rocks that are properly termed amphibolites. A specimen (1448) of this type was collected in the Kate Creek area. The color is nearly black and well-developed crystals of amphibole in random orientation can be recognized megascopically. A thin-section (specimen 1448) shows that the rock consists nearly entirely of green hornblende blades in a granoblastic arrangement. Although no great alteration has taken place, some blebs of chlorite are found in the hornblende. This chlorite which is mostly pennine also occurs in

cracks and between the amphibole crystals. Some veins filled with calcite are present. Other alteration products include sericite and iron oxide. Small grains of magnetite are scattered through the amphibole. Other accessory minerals are apatite, titanite, and pyrite.

Correlation. The stratigraphic relations between the Pony and the younger Cherry Creek are not clearly exhibited in the Tendoy-Beaverhead area.

Tansley and others (1933, p. 10) report that no unconformity was found between the two Precambrian series, but they believe that a stratigraphic break is present because of unoriented boulders of Pony gneiss in a schist at the base of the Cherry Creek. This relationship suggests two periods of pre-Beltian metamorphism: one of which predates the Cherry Creek and another which postdates it and which is responsible for the metamorphism of the Cherry Creek rocks.

Origin. It is uncertain if the rock types described above belong to the Pony. They are also common in many parts of the Cherry Creek and probably represent metamorphosed sills and lenses of igneous rock intrusive into the Pony as well as the Cherry Creek (Heinrich, 1949b, p. 23 and p. 33). The composition of the hornblende gneisses shows that the original intrusions were of a dioritic to gabbroic character. The hornblende gneisses are also in places completely enclosed in the Blacktail granite gneiss and there represent roof pendants and xenoliths of this later intrusion (Heinrich, personal communication).

Cherry Creek Series

Definition. The name Cherry Creek was already employed by Peale (1896). He used the term to designate an assemblage of interlayered gneisses, mica schists, marbles, crystalline limestones, and quartzites resting unconformably on older gneisses and schists. The series was named after Cherry Creek, about 16 miles southeast of Virginia City.

Distribution and thickness. The Cherry Creek series has been reported from central southern Montana (Three Forks Quadrangle) and southwestern Montana (Wilmarth, 1938, p. 416).

It crops out in the northern part of the Armstead anticline outside the Tendoy-Beaverhead area (Heinrich, 1949b, p. 95). Rocks which clearly belong to the Cherry Creek are on the northside of the headwaters to Kate Creek.

The thickness of the series in the southern end of the Ruby Range has been estimated at 30,000 feet (Heinrich, 1949b, p. 16). In the Tobacco Root Range 8,000 feet are believed to be present (Tansley and others, 1933, p. 8). At the type locality more than 7,000 feet were found (Peale, 1896).

No attempt was made to measure the thickness in the Kate Creek area as the lower contact is undertain and the upper contact is a high angle fault, but at least 1,000 feet are present.

Lithologic and stratigraphic features. In the Kate Creek area gneisses, schists, marbles, and quartzites make up the Cherry Creek series.

One type of gneiss assigned to the Cherry Creek is a biotite-

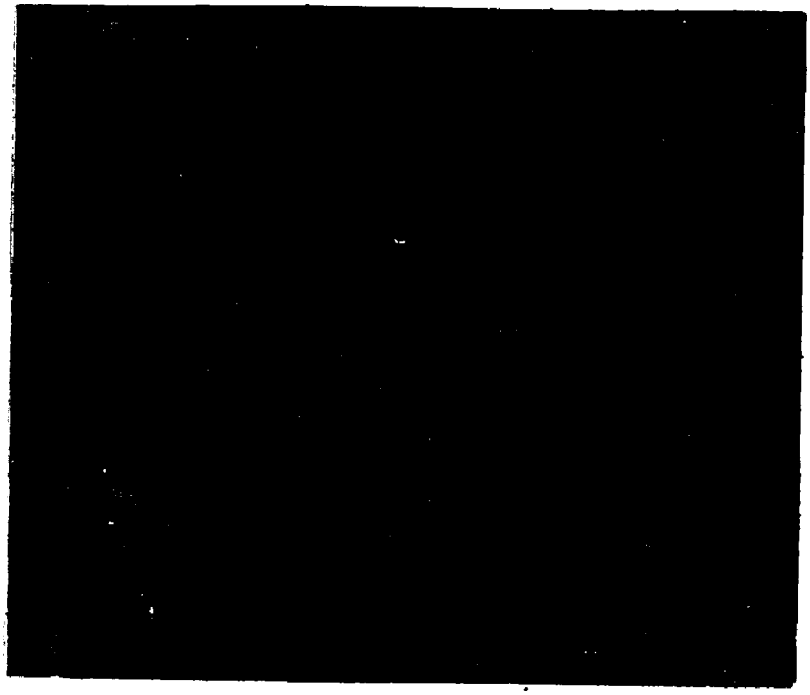
garnet gneiss near the base of the series. The rock is light reddish-brown. Gneissic banding is not pronounced. Large feldspar crystals are numerous, almost black dots of garnet crystals are easily recognized. Some parts exhibit a certain fissility and the gneiss seems to grade into schist. Microscopic investigation shows a rock made up mainly of quartz, feldspar, garnet, and biotite (specimen 5048). Accessory minerals are apatite, zircon, magnetite, and ilmenite. The feldspar is orthoclase and is considerably less abundant than quartz. The garnet is of the variety almandite and has a poikiloblastic texture and it commonly contains numerous inclusions of rounded quartz grains. The largest garnet noticed attained a diameter of 8 mm. Green and brown biotite are present, in some places altered to chlorite and magnetite. It is not certain that this rock belongs to the Cherry Creek. It has been assigned to that series mainly because of the numerous garnets it contains. Tansley and others (1933, p. 9) state that the Cherry Creek rocks include members with very high garnet content and that this mineral is comparatively rare in the Pony rocks. The biotite-garnet gneiss probably represents the metamorphosed equivalent of an impure sandstone with calcareous and argillaceous admixtures.

An important type of schist in the Cherry Creek along Kate Creek is a graphite schist, which is in the lower part of the series. The rock has a gray color due to small crystals of white-weathered feldspar and flakes of black graphite. The presence of the soft graphite is easily detected, as it soils the fingers when the rock is rubbed. Schistosity is commonly well developed. A thin-section of this rock (specimen 1948) shows quartz, feldspar, graphite, rutile, and sericite.

The feldspar is possibly orthoclase, but is so much altered that a closer identification is not possible. Quartz about equals feldspar in amount. The graphite is in slender needles, which form bundles and long streaky masses. The individual needles are as much as 1.5 millimeters long but the composit masses attain dimensions of one to two centimeters. The needles lie in all directions, but more abundantly in one direction parallel with each other and causing the distinct schistosity of the rock. Some of the needles are bent. Others show parallel growths with colorless mica flakes. The edges of the graphite needles and bundles are commonly ragged (figure 3). The rock contains a significant number of small rutile crystals, some with a partial coating of leucoxene. According to Chudoba (1932, p. 195) rutile is a characteristic associate mineral of graphite in metamorphic sediments of partly organic origin. The original deposit which gave rise to the graphite schist was probably an argillaceous sediment containing abundant carbonaceous matter. However, the fact that the graphite schist is confined to the proximity of a Laramide fault and is not continuous along strike but grades into schists without graphite suggests that the carbon content of the schists is secondary (Heinrich, personal communication). In the Kate Creek area graphite also occurs in fault gouges, fault breccias, and crushed gneiss (Perry, 1948, p. 18). This graphite was deposited there by later hydrothermal solutions after the intensive Laramide faulting. If the graphite in the Cherry Creek is of primary origin then it was probably the source for the secondary graphite in the fault breccias etc. The economic aspects of the graphite deposits along Kate Creek will be discussed in the chapter on Economic

FIGURE 3.- Cherry Creek

Photomicrograph of specimen 1948 (Cherry Creek; graphite-schist). Crossed nicols, 85x .
G- Graphite
R- Rutile



Geology.

The upper part of the Cherry Creek in the Kate Creek area consists mainly of marbles and quartzites. The marble is white on a fresh surface and forms a conspicuous cliff north of the creek. Some of the ma bles are silicified and contain impurities of iron oxides. The quartzites occur in lesser amount than the marbles. Heinrich (1949b, p. 22) reports a pale to vivid emerald-green quartzite from the Cherry Creek in the Kate Creek area. The color seems to be due to the presence of a green mica. Heinrich believes that this green quartzite is diagnostic of Cherry Creek rocks.

Correlation. The general sequence of the Cherry Creek in the Kate Creek area seems to be: biotite-garnet schists and gneisses, graphite schists, marbles, and quartzites.

A similar sequence is reported by Tansley and others (1933, p. 10) from the Tobacco Root Mountains where the following units were recognized: a lower division made up largely of garnetiferous schists and gneisses; a middle division of dominantly limestone with varying amounts of quartzite and mica schist; and an upper division, composed chiefly of feldspar-quartz gneiss and quartz-mica schists. This upper division seems to be absent on Kate Creek, where the series is cut off by a fault which brings the Cherry Creek in contact with Devonian and Mississippian rocks.

In the Tendoy-Beaverhead area no normal contact betweenCherry Creek rocks and Belt or Paleozoic rocks was observed. Hornblende-rich rocks of the type as described under the heading Pony series are also in the Cherry Creek, where they transect the marble (Heinrich, 1948, p. 1329).

Origin. The marbles and quartzites of the Cherry Creek are of sedimentary origin. The graphite schist possibly represents a metamorphosed black shale. From other localities great thicknesses of black shales and slates are known from Proterozoic formations, containing large quantities of carbon disseminated through the rock (Hussey, 1947,p. 84). The carbonaceous material is most likely due to simple vegetable organisms. The origin of the biotite-garnet schists and gneisses is even less certain, but they too possibly represent sediments. The hornblende-rich rocks are metamorphosed dikes and sills intruded into the Pony and Cherry Creek before the intrusion of the Blacktail granite gneiss.

The whole assemblage of Cherry Creek rocks was metamorphosed before the deposition of the Belt. Heinrich (personal communication) assumes that most of this metamorphism took place before and during the intrusion of the Blacktail granite which is syntectonic with the second pre-Beltian disturbance.

Blacktail granite gneiss

Definition. The name Blacktail granite gneiss was first used by Heinrich (1948, p. 1329) to designate a batholithic intrusion of red granite gneiss cutting both Pony and Cherry Creek. The gneiss was named after the Blacktail Range where it is well exposed. The type locality is on the summit of this range south and southeast of Jake Canyon (Heinrich, 1949b, p. 29).

As the name Blacktail is already in use for a Beltian formation in northern Idaho (Wilmarth, 1938, p. 208), the granite gneiss will probably be called Dillon granite gneiss in future (Heinrich, personal

communication).

Distribution. The Blacktail granite gneiss has been recognized only in southwestern Montana in the Blacktail and Ruby Ranges around Dillon and in the Tendoy-Beaverhead area.

In the writer's area it is the most widespread of the pre-Beltian rocks, and found everywhere where large areas of these rocks are exposed. It is along the eastern side of Big Sheep Creek Basin and North Medicine Lodge Basin in the continuous outcrop. North of Kate Creek it is together with exposures of the Cherry Creek series. It is also found along Rock Canyon, Deer Canyon, Johnson Gulch, and Kissick Canyon, all tributaries to North Medicine Lodge Creek. Here it forms the eastern termination of the intermontane basin and is partly covered by "Basin Beds." The core of the Armstead anticline is made up of pre-Beltian rocks, which in the southern part consist of the Blacktail granite gneiss. The northern part of this core contains some rocks that probably belong to the Pony, whereas still more to the north outside the Tendoy-Beaverhead area Cherry Creek rocks are present. No pre-Beltian was found in the investigated part of the Beaverhead Range, or in the eastern part of the Tendoy Mountains.

Lithologic features. The Blacktail metamorphic complex in the Tendoy-Beaverhead area comprises several different kinds of acid gneisses, pegmatite, aplite, and quartz veins, epidote-rich gneisses, and some amphibole-quartz-feldspar gneisses.

Outcrops of the pre-Beltian rocks are characterized by rounded grass covered hills. Only in exceptional places does this complex seem to produce a soil favorable for trees. Weathering of the Blacktail

granite gneiss gives a reddish hue to the hills. Hand specimens of the typical granite gneiss are reddish-brown and exhibit a distinct gneissic banding with pink bands consisting of feldspar and quartz and dark bands of mafic minerals. The amount of dark minerals varies. In some specimens the dark bands are much thinner than the quartz-feldspar bands, in others the dark bands are as wide or even wider (figure 4 and figure 5).

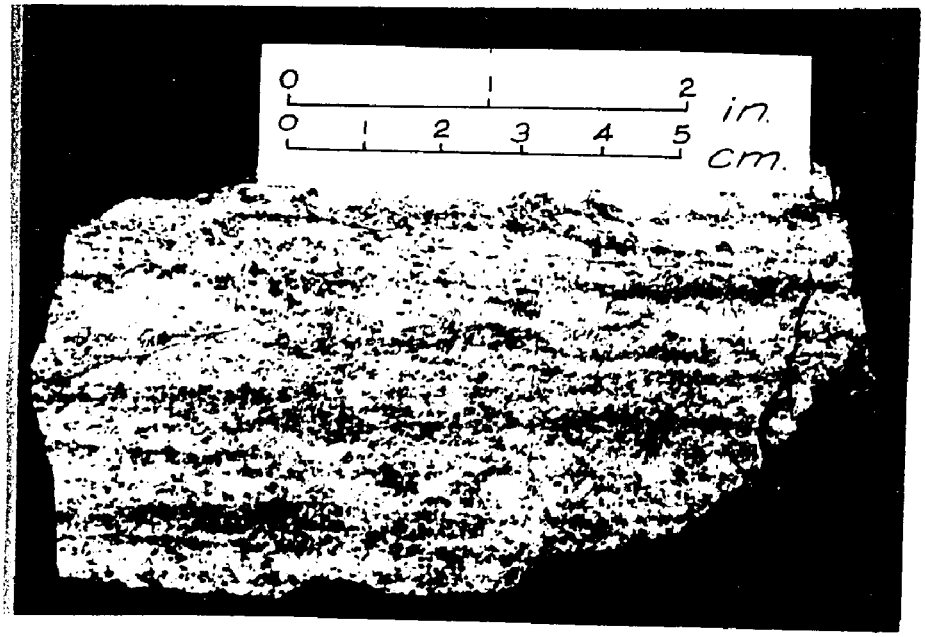
Microscopical examination of several acid gneissic rocks of the Blacktail complex reveals a feldspar quartz gneiss with considerable variation in texture and mineral compostion (specimens 8547, 148, 2048, 4048). Quartz is universally present and commonly shows strain-shadows. Several types of feldspar are found. Orthoclase seems to be the most abundant in the thin-sections from exposures east of Big Sheep Creek Basin and North Medicine Lodge Basin. Microcline is present too, but is more common in the coarse-grained pegmatitic parts. In the Blacktail rocks of the Armstead anticline, microcline seems to be the only potash feldspar to the exclusion of orthoclase. Plagioclase is in all slides but the amount varies greatly. The composition of the plagioclase ranges from albite to oligoclase. Locally the feldspars are greatly altered, the plagioclase replaced by sericite flakes, the orthoclase clouded by kaolinite. The dark mineral commonly present is biotite, but in specimens of the coarser-grained parts of the granite gneiss dark minerals are nearly entirely absent. In the finer-grained rocks both the green and brown variety of biotite can be observed. In the brown variety pleochroic halos occur in a few flakes around small grains of probably zircon. The biotite is in some places greatly

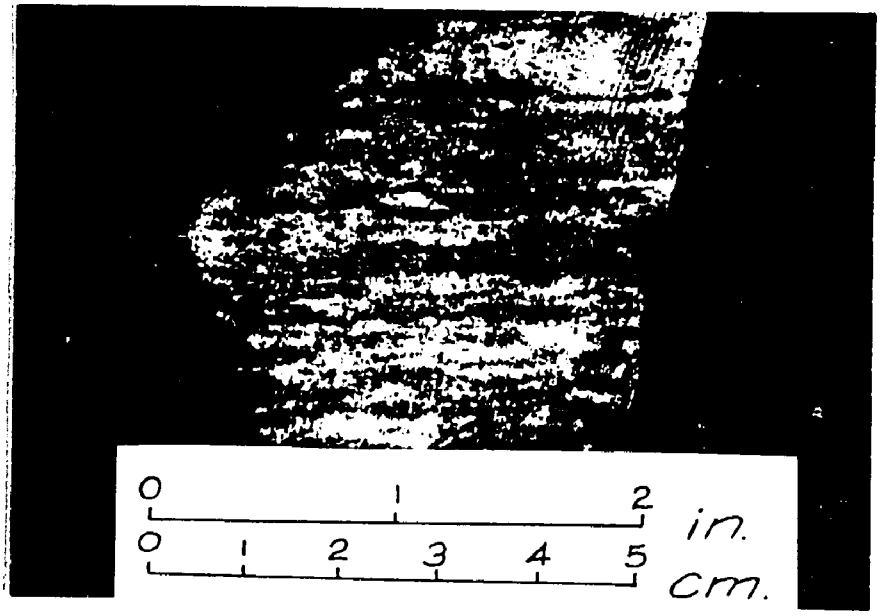
FIGURE 4.- Blacktail granite gneiss

Gneissic banding with small bands of dark minerals.

FIGURE 5.- Blacktail granite gneiss

Gneissic banding with wide bands of dark minerals.
Augen of feldspar - quartz.


0 1 2 in.
0 1 2 3 4 5 cm.


0 1 2 in.
0 1 2 3 4 5 cm.

altered to chlorite, carbonate, and magnetite. Green hornblende is rare, but one or two small grains of this mineral are in most of the thin-sections. Garnet is localized and seems to be abundant in parts of the Armstead anticline, but in other outcrops of the Blacktail granite gneiss it is less common. Zircon is an important accessory mineral and is present in all thin-sections examined, often in large rounded grains. Other accessory minerals are apatite, magnetite, ilmenite and sphene. The last two minerals are covered with leucoxene in some slides.

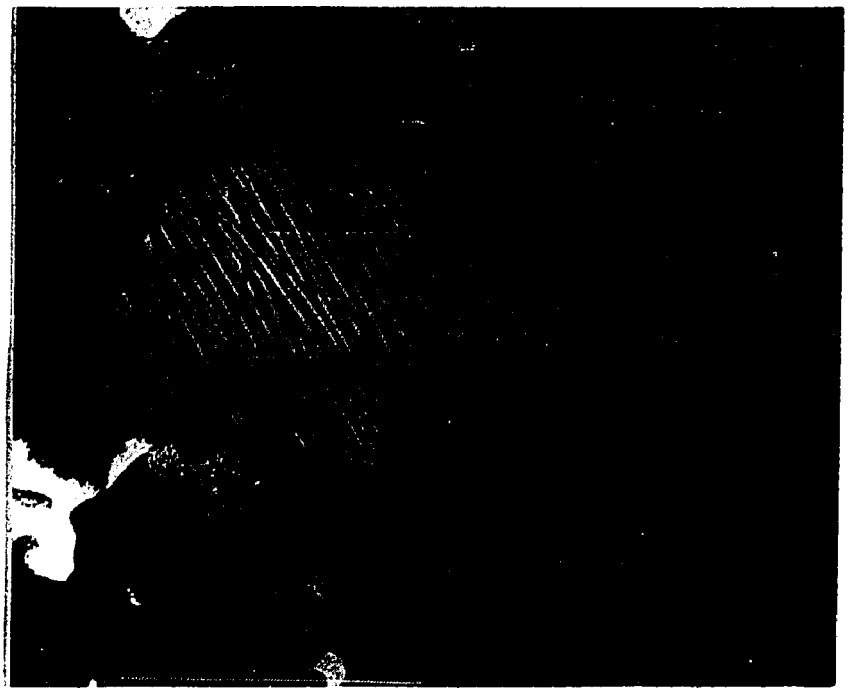
The most conspicuous microscopic feature in almost all parts of the Blacktail granite gneiss are perthitic and to a lesser degree micropegmatitic and myrmekitic intergrowths. The perthitic intergrowth is between orthoclase or microcline and an acid plagioclase which is prob bly albite. The plagioclase occurs in small oriented blebs in the potash feldspars. Figure 6 depicts this kind of intergrowth, which is very common and characteristic of the Blacktail granite gneiss. The micropegmatitic intergrowth is less common in the finer-grained portions of the granite gneiss, but occurs more in the pegmatitic parts. Myrmekitic intergrowths of worm-like masses of quartz in plagioclase are rather rare compared with other types of intergrowths. In some thin-sections the feldspars show a poikiloblastic structure enclosing a number of rounded quartz grains. This kind of structure may be combined with the perthitic intergrowth (figure 7). Characteristic features are the reaction rims found around potash feldspar and plagioclase, where in contact with each other. These reaction rims are especially well developed in the granite gneiss

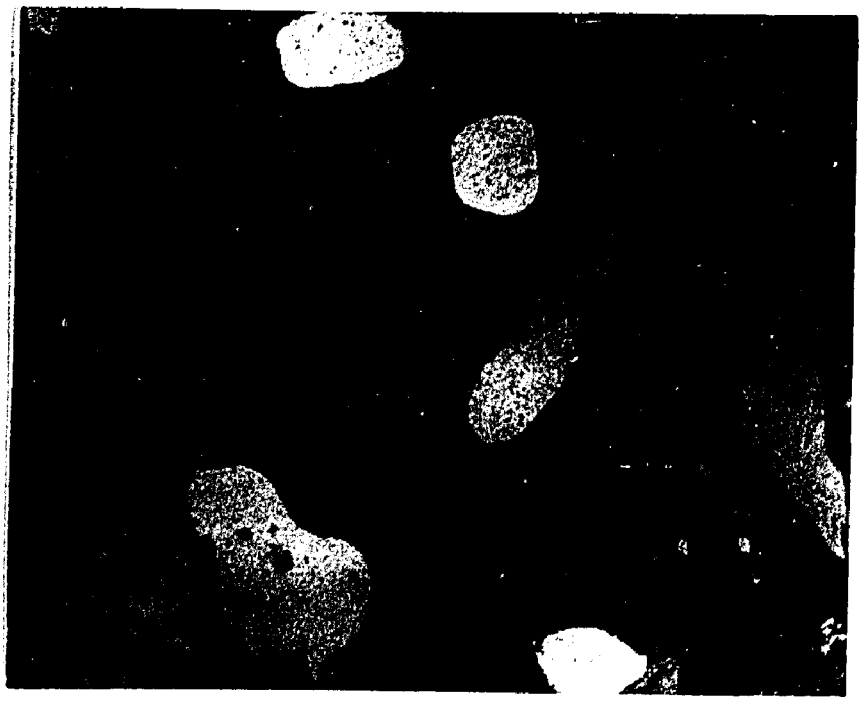
FIGURE 6.- Blacktail granite gneiss.

Perthite. Photomicrograph of specimen 1648. (Blacktail granite gneiss; meta-aplite). Crossed nicols, 85x .

FIGURE 7.- Blacktail granite gneiss.

Plagioclase with poikiloblastic enclosures of quartz grains. Photomicrograph of specimen 2048 (Blacktail granite gneiss; biotite granite gneiss). Crossed nicols, 85x .





of the Armstead anticline. They are also found in some of the specimens from other localities. They are often more difficult to recognize. (see figure 8).

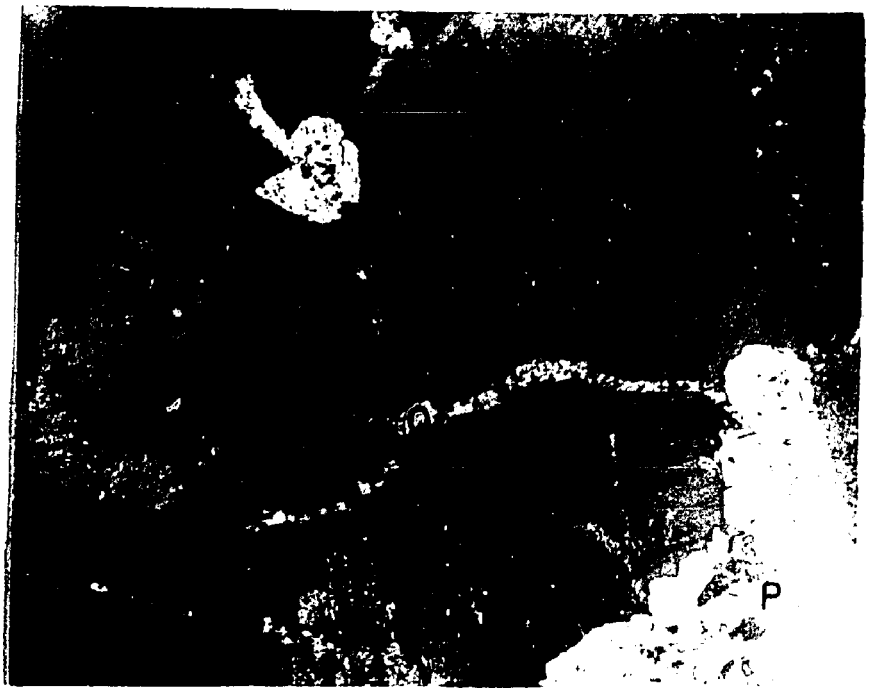
In the Blacktail granite gneiss occur coarse-grained rocks that represent pegmatitic dikes. In places a transitional zone exists between fine-grained and the coarse-grained parts. Because of this zone, the similar mineralogical composition, and the fact that the coarse-grained parts also show the effects of metamorphism, the writer believes that most of the pegmatitic intrusives are of Precambrian age. But pegmatites of Laramide age may be present also. The pegmatitic parts of the Blacktail granite gneiss commonly possess a graphic intergrowth of quartz and potash feldspar clearly visible in hand specimen. Microscopic investigation (specimens 1848, 3748, 3848, 4248) shows quartz, microcline(in some cases orthoclase), and a few accessory minerals. Specimens containing significant amounts of plagioclase (albite-oligoclase) may represent a different zone of the pegmatite. Perthitic intergrowths are common in these coarse-grained rocks especially orthoclase perthite. Reaction rims of secondary quartz are visible around some of the quartz bodies where in contact with the microcline (figure 9). Chlorite and biotite are found locally and follow veins that were probably introduced later by hydrothermal action. Quartz also occurs in veins, so that two generations of quartz, one primary and the other secondary, are present. Chlorite develops in patches on the feldspar and perthite as an alteration product together with sericite and kaolinite. That these pegmatitic rocks were subjected to metamorphism is evident from the various cataclastic structures.

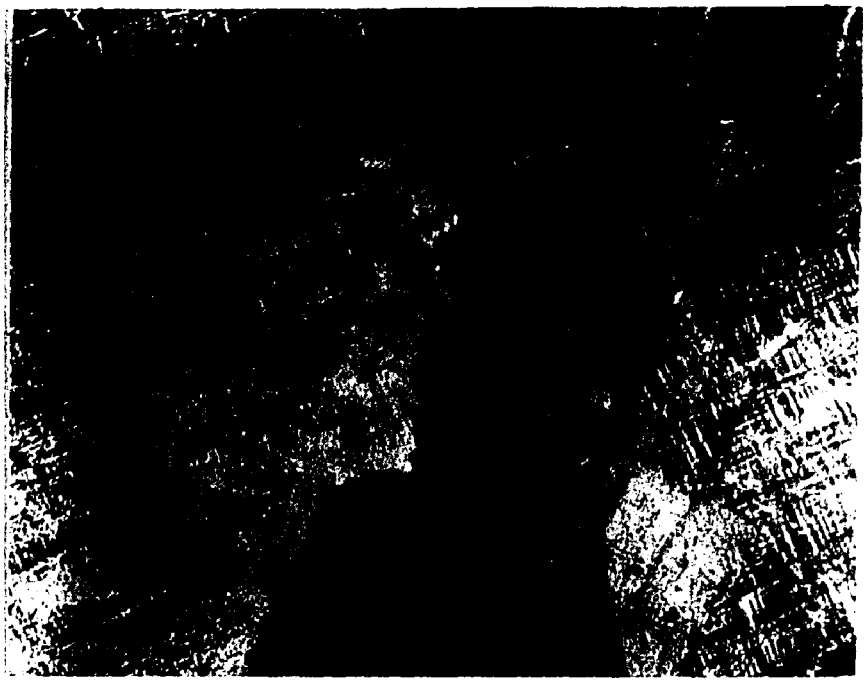
FIGURE 8.- Blacktail granite gneiss.

Reaction rim of quartz between two microcline individuals. Plagioclase with large flakes of colorless mica. Photomicrograph of specimen 348 (Blacktail granite gneiss; biotite-epidote gneiss). Crossed nicols, 85x .
M - Microcline
Q - Quartz reaction rim
P - Plagioclase

FIGURE 9.- Blacktail granite gneiss.

Reaction rim of quartz around quartz pod in microcline (graphic granite). Photomicrograph of specimen 3848 (Pegmatite of Blacktail granite gneiss).
Crossed nicols, 85x .


P



The feldspar lamellae of the plagioclases are commonly bent or broken by small-scale faults (figure 10). Quartz nearly always has a wavy extinction and is badly shattered.

One thin-section (specimen 1648) of a meta-aplite reveals a fine-grained uniform texture with anhedral crystals. Quartz and feldspar are the main minerals. The feldspars are orthoclase and oligoclase. The development of perthitic intergrowth is particularly conspicuous. Quartz is commonly shattered. A small amount of dark minerals is present including grains of green hornblende and a brown mineral that may be allanite. Apatite is abundant. Other accessory minerals include zircon, rutile, and magnetite. Secondary minerals are chlorite, sericite, iron oxide, carbonate, and kaolinite.

Quartz veins are found in several places in the Blacktail granite gneiss. Some of these are clearly younger than the Precambrian rocks and will be discussed under the heading Igneous rocks. It is not known if there are any quartz veins of Precambrian age in the area.

Epidote-rich gneisses are found at several places in the Blacktail metamorphic complex. Microscopically they show many of the characteristic features of the Blacktail granite gneiss, but are distinguished by the abundance of epidote and zoisite (specimens 248, 348). As in the granite gneisses quartz is universally present. Different kinds of feldspar such as orthoclase, microcline, and plagioclase (albite-oligoclase) can be observed. Perthitic intergrowths and reaction rims around the feldspar are distinct in places. Some of the plagioclase twin-lamellae are bent. Accessory minerals are zircon, apatite, magnetite, and sphene.

FIGURE 10.- Blacktail granite gneiss

Small faults displacing twin lamellae of plagioclase. Photomicrograph of specimen 4248 (Pegmatite in Blacktail granite gneiss). Crossed nicols, 85x .



The rocks have varying quantities of biotite, either green or brown. These minerals and textures resemble those in the ordinary Blacktail granite gneiss. The difference lies in the conspicuous development of epidote, and zoisite, which occur in numerous, medium sized, individual crystals. Epidote is in the plagioclase mostly together with flakes of white mica, which are commonly oriented. In some rocks the minerals of the epidote-zoisite group also occur in veinlets. The potash feldspars do not have the mica flakes and epidote-zoisite crystals. This saussuritization of the plagioclase is an indication of retrogressive metamorphic changes in an ordinary Blacktail quartz-feldspar gneiss. The changes are similar to those in plutonic rocks unaffected by metamorphism. Because the decline in temperature during regional metamorphism is much slower than the cooling of a pluton, the resulting minerals are much better developed. This alteration of plagioclase yields an obscure cloudiness in the case of a non-metamorphosed igneous rock, but gives rise to distinct crystals of zoisite-epidote and mica where retrogressive metamorphism has taken place (Harker, 1939, p. 352).

Other types of epidote-rich gneisses (specimen 4348) do not have epidote confined to the feldspar, but the mineral occurs in veinlets and large patches that consist of a dense aggregate of small grains. Here too the abundance of quartz, the presence of microcline, orthoclase, and oligoclase, and the occurrence of perthitic intergrowths suggests close connection to the ordinary Blacktail granite gneiss. Still the origin of this epidote-rich rock is not entirely clear. It is possible that this rock originated by the interaction of th· Blacktail granite gneiss and the older more basic gneisses assigned to the Pony.

Another rock of probable hybrid origin is a plagioclase-actinolite gneiss (specimen 3948) found in N.E. 1/4 sec. 11, T. 14 S., R. 11 W. Study of a thin-section shows the rock to be composed of quartz, plagioclase, (oligoclase) and amphibole (actinolite). Under the microscope the actinolite is pale in color and apparently some iron has been leached out during the alteration process. The plagioclase has been again greatly altered into large crystals mainly of zoisite and smaller amounts of epidote and flakes of mica, all due to later retrogressive changes.

Correlation. The core of the Armstead anticline was assigned to the Precambrian as early as 1872 by Hayden (p. 145). Lowell (1949) on his preliminary map covering part of the Armstead anticline mapped the core as "Intrusive-metamorphic complex" and states that the intrusive rock may be late Cretaceous or early Tertiary and that the metamorphic rock may be lower Paleozoic or Precambrian. On his final map the whole unit will be assigned to the Precambrian as the nature of the rocks in that area has become better known (Heinrich, personal communication).

The Tertiary intrusive occurring n the western part of the Tendoy-Beaverhead area is quite distinct from the Blacktail granite gneiss. The differences between these two rock types will be enumerated under the heading Igneous rocks.

In the Kate Creek area the contact between the Blacktail granite gneiss and the Cherry Creek series is not well exposed and no definite indication of its intrusive nature was noticed. In other areas these relationships seem to be better developed and the Blacktail granite gneiss was found to be intrusive into both the Pony and Cherry Creek series (Heinrich, 1948, p. 1329).

Origin. The magma of the Blacktail intrusive probably was rich in water as suggested by the many pegmatitic parts. The low viscosity of the magma is also shown by the many stringers of pegmatitic material which were intruded in a lit-par-lit fashion into the older hornblende-gneisses. This relationship is found in the southern part of the Armstead anticline (Brant and others, 1949, p. 92). Some hybrid rocks such as the plagioclase-actinolite gneiss resulted from this intrusion.

B E L T I A N S Y S T E M

Belt series

Definition. The term Belt was first used by Peale (1893, pp. 15-20) for rocks in the Big Belt and Little Belt Mountains in central Montana. No type section was given.

The U.S. Geological Survey classifies the Belt as a provincial series consisting of late Precambrian slightly metamorphosed rocks, for the greater part of definite sedimentary origin.

The Belt series consists mainly of clastic strata with subordinate non-clastics and minor amounts of lavas and intrusive rocks (Fenton and Fenton, 1937, p. 1875).

In early reports the Belt series was also called "Belt formation", "Belt terrane", "Belt beds", and "Belt group" (Wilmarth, 1938, p. 157). The writer follows Tansley and others (1933, p. 8) who use the term Beltian for the system (period) and Belt for the series (epoch).

Distribution and thickness. The Belt series has a wide regional distribtuion and is found in Montana, Idaho, Alberta, British Columbia, northern Arizona, south central Arizona, and southeastern California (Fenton and Fenton, 1937, p. 1875). Large areas of Belt rocks are found in the Argenta quadrangle north of Armstead.

In the Tendoy-Beaverhead area Belt rocks are confined to the western part. They are very well exposed on Island Butte and on the divide between Big Sheep Creek Basin and North Medicine Lodge Basin. Here they occur along the road, but they are in part covered by Tertiary volcanic rocks. The

Belt has its greatest areal extent along and north of Indian Creek in sections 1, 2, 3, 10, 11, 12, 13, 14, and 24, of T. 14 S., R. 12 W. It also occurs in a small outcrop at the foot of the Beaverhead Mountains along Tex Creek. A good exposure is found in Trail Creek Canyon and along the west side of Nicholia Creek Canyon. A more doubtful occurrence is in the northern part of the area in sections 4 and 5 of T. 12 S., R. 11 W. The quartzites which are exposed here were mapped by Perry and Sahinen as belonging to the Belt series (1946) but may be part of the pre-Beltian system.

Emmons and Calkins (1913, pp. 32-43) report in the Phillipsburg quadrangle a thickness of 5,000 feet of the Spokane formation with which the Belt rocks in the writer's area probably can be correlated.

The total thickness of Belt rocks in the Tendoy-Beaverhead area is unknown as the base of the series is nowhere exposed. The thickest section is present along Trail Creek and was estimated to be more than 900 feet. The total thickness is probably much more.

Lithologic and stratigraphic features. The Belt series as exposed in the area is very uniform throughout and consists of red, green and light gray quartzites and minor amounts of conglomerate. In one place a lens of brown chert was observed. This is exposed on the north bank of Indian Creek in SW 1/4 sec. 13, T. 14 S., R. 12 W.

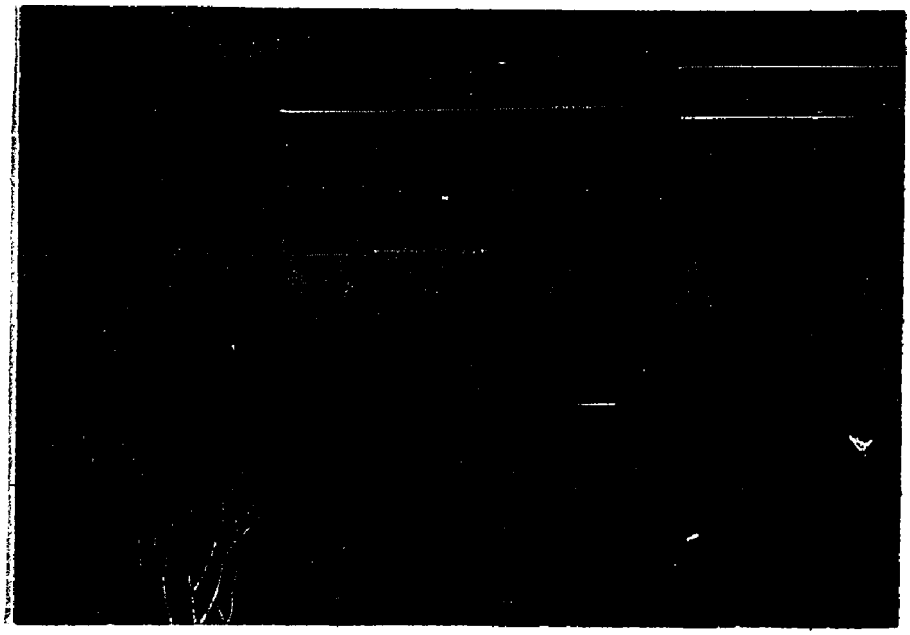
The formation is very resistant and forms cliffs and steep slopes, in most places with considerable talus at the base. Figure 11 shows a typical exposure along Trail Creek. The Belt strata are preserved where other less resistant rocks have probably been removed by erosion, as at

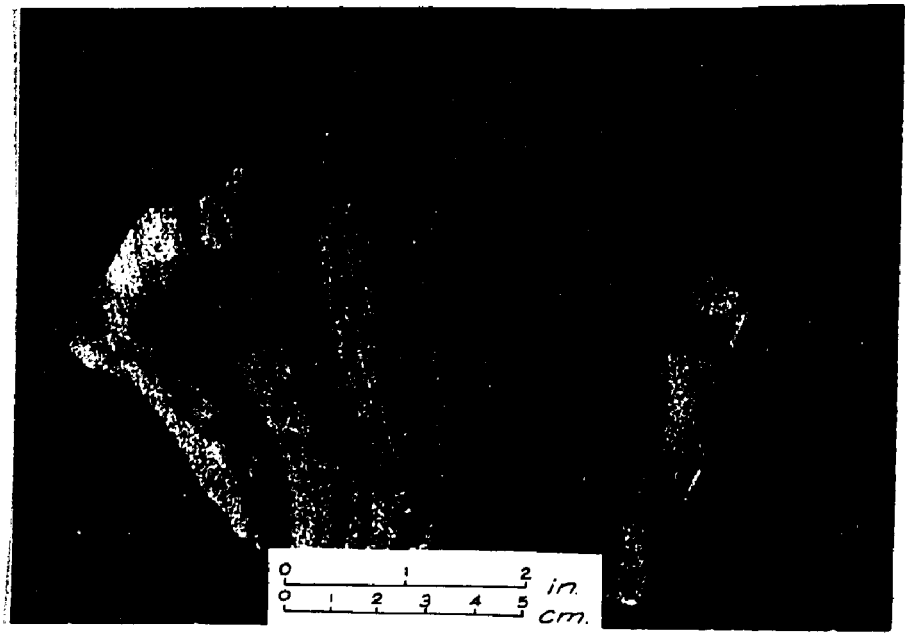
FIGURE 11.- Belt series

Exposure of maroon Belt quartzite on east side of Trail Creek. Extensive talus covers the base of the cliff.

FIGURE 12.- Belt series

Penecontemporaneous folding in green mica-rich Belt quartzite.




0 1 2 in.
0 1 2 3 4 5 cm.

the divide between Big Sheep Creek Basin and North Medicine Lodge Basin. The quartzites are thickbedded and due to the extensive jointing they are blocky in appearance. Many quartzites show a well developed banding of darker and lighter material, a few millimeters in thickness. Cross-bedding is common in the red quartzites. Local minor folding is characteristic of the greyish-green beds (see figure 12). As the red quartzites do not show any folding at all, it is concluded that the small-scale folding in the green beds took place in the unconsolidated sediment. Flowage was more likely to occur in the clayey material, which later formed the green quartzites, than in the more sandy sediment which formed the red quartzites. The few conglomeratic beds which were observed along Nicholia Creek show stretched pebbles as much as one inch in length.

The prevailing color of the quartzites is deep red, but minor amounts of greyish-green beds are present. The red color is due to disseminated flakes and blebs of hematite embedded in the cementing material. Microscopic investigation shows that the grayish-green color is due to a larger amount of very fine-grained colorless mica.

A Rosiwal analysis (specimens 2347, 447, 6348) of the quartzites from different parts of the area shows a rock composed of about 41 percent quartz, 32 percent feldspar, 23 percent micaceous material, and 4 percent other minerals like zircon, magnetite, titanite, apatite, biotite, chlorite, limonite, and hematite. Figure 13 is a photomicrograph of a specimen (2347) of the red quartzite from Trail Creek. The quartz grains attain a maximum diameter of about 0.3 millimeters, are poorly sorted and subangular to angular. Wavy extinction in the quartz grains is common. The large amount of feldspar, commonly altered to sericite and kaolinite, is a distinctive feature.

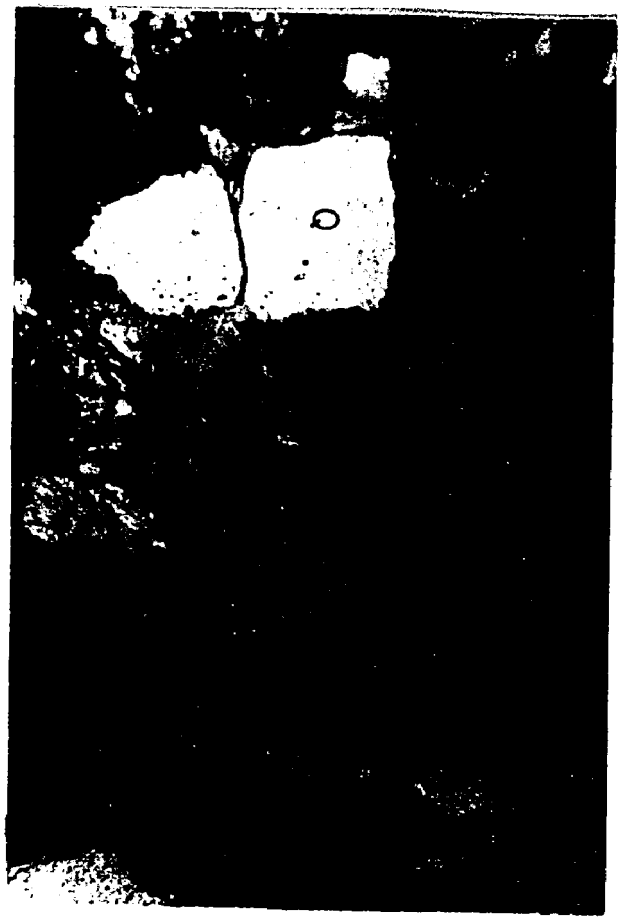
FIGURE 13.- Belt series

Maroon Belt quartzite. Coarse grained. Traces of sericite. Photomicrograph of specimen 2347. Crossed nicols, 100x .
Q - Quartz
M - Microcline .

FIGURE 14.- Belt series

Green Belt quartzite. Large patches of sericite material. Photomicrograph of specimen 6247. Crossed nicols, 100x .





Orthoclase, microcline, and plagioclase are present. The plagioclase has the composition of oligoclase-andesine. The mica is sericite which in thin-section is colorless but in great concentration is greenish. It is found as an alteration-product of the plagioclase and also between quartz and feldspar grains as a cement where it represents recrystallized argillaceous material. In the grayish-green quartzites a much greater amount of sericite is present forming streaks and blebs, large and abundant enough to give a megascopic green color to the rock. Figure 14 shows a photomicrograph of a representative specimen (6248) of the green quartzite from Trail Creek.

The Belt quartzites show only a slight degree of metamorphism and could better be called feldspathic sandstones. Also Douglas (1905, p.411) mentions that the Belt rocks in southwestern Montana do not have a very ancient appearance, are not highly metamorphosed, and are not greatly disturbed.

Correlation. The base of the Belt is not exposed in the area. The red quartzites are overlain, with apparent conformity, by white quartzites tentatively assigned to the Ordovician. No Cambrian strata were found overlying the Belt. According to Deiss (1935, pp. 95-96) regional investigations prove the existence of an unconformity between the Belt and the basal Cambrian.

Red quartzites similar to the Belt rocks and also overlain by white quartzites have been described from Lemhi County, Idaho (Shenon, 1928, p. 7). Shenon correlated the red and the white quartzites with the lower and upper quartzites of Umpleby (1917, p. 23). Umpleby assigned a Cambrian age to both these quartzites and to two lower members, which are apparently absent in the Beaverhead Mountains. Anderson and Wagner (1944, p. 6) who

reworked the Birch Creek district, earlier mapped by Shenon, thought both quartzites to be of Ordovician age. The writer in an earlier report (Kupsch, 1948, p. 14) correlated the dark red quartzite tentatively with the Cambrian Flathead, and the white quartzite with the Ordovician Kinnikinic. This correlation was suggested by Dr. Ross on a fieldtrip with the author. However, subsequent fieldwork and microscopic studies make this correlation doubtful. The greater thickness of the red quartzite (at least 900 feet) contrasts with the rather small thickness (average 108 feet) of the Flathead over an area of 35,000 square miles (Deiss, 1935, p. 123). South of the Armstead area the Flathead thins rapidly and around Kate Creek only about 15 feet are found. It is difficult to conceive that the thickness would reach 900 feet again farther south within the distance of a few miles. Furthermore, if the red quartzite is equivalent to the Flathead then the apparent absence of Cambrian limestones which elsewhere overlie the Flathead is somewhat surprising (Ross, personal communication). Also the lithological character of the red quartzite differs considerably from that of recognized Flathead in the northern part of the area where the Cambrian limestones are present (table 2). These considerations lead the writer to assign the red quartzites to the Beltian period (late Precambrian).

No fossils have been found, nor have they been reported from other localities in this region. The age assignment therefore must be regarded as tentative. If the red quartzite belongs to the Belt series, it probably is part of the Spokane formation. In the Philipsburg quadrangle (Emmons and Calkins, 1913, pp. 32-34) this formation forms the upper part of the Belt. It consists of deep red shales which are dominant in the lower part, and red sandstones which are dominant in the upper part. Also Wilson and others (1924, p. 92) speak of the "red rocks" of the Spokane formation in

TABLE 2.- Comparison between Belt and Flathead quartzites

TABLE 2. Macroscopic and microscopic differences between Belt and Flathead quartzites.

Characteristics	Belt quartzite	Flathead quartzite
Composition	Quartz 41% Feldspar 32% Sericite 23% Other minerals 4%	Almost pure quartz, few rounded grains of zircon, few small flakes of mica
Rounding of quartz grains	Poorly rounded	Well rounded
Cementing material	Micaceous	Siliceous
Size of quartz grains	Maximum observed in thin-section about 0.3 mm.	Size over 0.3 mm. common and maximum observed about 1.5 mm.
Strainshadows in quartz	Abundant	Exceptional
Secondary addition of quartz around quartz grains	Not significant	Common feature. Dust particles show outline of original grain.
Presence of feldspar.	Significant. Orthoclase, plagioclase, and microcline	Only one grain of plagioclase noted
Amount of hematite visible in reflected light	Commonly flakes and large blebs in the cementing material	Thin film surrounding quartz grains
Macroscopic differences	Dark red, fine grained, feldspathic sandstone	Pinkish, medium grained sandstone

southwestern Montana. Shenon (1931, p. 45) describes the Spokane formation from the Bannack-Argenta area and remarks that it is difficult to distinguish from the lower beds of the Flathead quartzite. More to the west Belt rocks similar to those in the writer's area have been described by Callaghan and Lemmon (1941, p. 7).

Origin. Emmons and Calkins (1913, pp. 32-34) believed that the Spokane formation represents floodplain deposits. Wilson and others (1924, p. 92) report predominantly terrestrial sediments in the upper Belt of the 49th parallel and correlate these with the Spokane group in southwestern Montana. Beiss (1935, p. 97) thought that deposition of the Belt sediments had taken place in a sea.

Although the area investigated does not give any clues about the origin of the Beltian rocks, the writer is inclined to believe that they were deposited in a marine environment. The fairly regular bedding at some horizons, the cross-bedding and pebble-conglomerates at others suggest a shallow sea. In other areas to the north well-preserved ripple marks and mud cracks are common (Shenon,1931, p. 41). Fenton and Fenton (1937, p. 1938) who studied similar features in Glacier National Park state that the Belt sea was long and narrow, and through most of its history more shallow than any existing sea.

The poor rounding of the grains composing the feldspathic sandstones of the Belt in the area indicates a nearby source of the sediments. The abundance of microcline, a mineral conspicuous in the Precambrian Blacktail granite gneiss, confirms the conclusion that the Belt sediments were derived from the pre-Beltian complex of gneisses, schists, and other metamorphic rocks. The nearest source was probably to the east where according

to Deiss (1935, p. 104) an archipelago of islands composed of pre-Beltian rocks stretched from Yellowstone Park in the south to beyond the Highwood Mountains in the north.

CAMBRIAN SYSTEM

General remarks

Peale (1893, pp. 20-25) divided the Cambrian section of the Three-forks area into two formations. The lower one he called the Flathead formation and the upper one the Gallatin formation. Weed (1899) recognized only one formation (Barker formation) with seven subdivisions in the Cambrian of the Fort Benton quadrangle. In 1900, however, Weed (1900, p. 285) presented the following division, raising his subdivisions to the rank of formations:

Yogo
Dry Creek
Pilgrim
Park
Meagher
Wolsey
Flathead

For the first time these formations were defined, sections of each given, and the names established as standard names for central Montana. Since then these names have come to general use in all of Montana. Deiss (1936, p. 1326) in his revision of the Cambrian in Montana retains the names given by Weed. The U.S. Geological Survey also discards the inclusive Barker formation and treats the subdivisions as formations (Wilmarth, 1938, p. 112). According to Deiss (1936, p. 1326) the formational names were correctly taken from geographic features which, however, were far distant from the type localities. Deiss therefore gives the exact type locality of each of the above named formations.

In the Tendoy-Beaverhead area only the Flathead, Wolsey, and Meagher formations are present. They are all considered to be of Middle Cambrian age, the Lower Cambrian strata being absent in Montana (Perry, 1945, p.3).

In Montana conditions in the early Albertan were similar to those in the Waucobian in areas to the north and south which were flooded earlier by the transgressing seas (Deiss, 1941, p. 1091).

Flathead formation

Definition. The name Flathead formation was first used by Peale (1893, pp. 20-21) in the Three Forks area, but no type section was given. The formation was named for exposures in Flathead Pass near Three Forks. According to Deiss (1936, p. 1328) the emended type section is on Belt Creek in the Little Belt Mountains, but the formation is better exposed, more complete, and less metamorphosed on Crowfoot Ridge in Yellowstone Park.

In Peale's original description the Flathead formation was subdivided into the Flathead quartzite and the Flathead shales, both of Middle Cambrian age. After the adoption of Weed's classification (1900), the term Flathead formation is restricted to the quartzite, the shales now belong to the Wolsey formation.

Distribution and thickness. The Flathead formation has been recognized in the western part of Montana and in northwestern Wyoming.

In the Tendoy-Beaverhead area it is present north of Horse Prairie Creek in what has been called the Armstead anticline. It occurs mainly on the east side of the anticlinal axis and to a lesser extent on the west side where it is partly cut out by a fault. Flathead quartzite also was found at the head of Kate Creek, on the divide between Kate Creek and McBride Creek (sec. 27, T. 12 S., R. 11 W.). Boulders of it occur in high-level gravels on the ridge east of Big Sheep Creek Basin.

Deiss (1936, p. 1328) who measured the Flathead over extensive parts of Montana reports an average thickness of 180 feet, with a maximum of 276 feet, and a minimum of 90 feet. Shenon (1931, p. 47), however, claims a maximum thickness of about 500 feet in the Argenta area. He remarks that the bottom limit of the Flathead could not everywhere be accurately located because of the resemblance of some of the lower beds to some of the upper beds of the Spokane formation. Honkala (1949, p. 15) reports 77 feet of Flathead in the Gravelly Range. Emmons and Calkins (1913, pp. 32-34) found a thickness varying from 5 to 250 feet in the Philipsburg quadrangle.

Merits (personal communication) estimated a thickness of about 120 feet in the Armstead area. Only 10-20 feet seem to be present in the Kate Creek area (Hardley, personal communication).

Lithologic and stratigraphic features. The Flathead formation in the Armstead area consists of a rather pure quartzite with some conglomerate parts, especially at its base. It is very resistant and because of its steep dip erodes to wall-like outcrops. The bedding is distinct, commonly several feet in thickness. Cross-bedding is locally well developed.

The color ranges from moderate pink to moderate red and is due to hematite dust which occurs in thin films around the quartz grains, as can be observed in reflected light under the microscope. Quartz pebbles up to 2 centimeters in diameter are found scattered through the quartzite. Also pebbles of granite gneiss were noticed. Deiss (1935, pp. 122-123) remarks that the occurrence of rounded white quartz pebbles is characteristic for the Flathead all over western Montana. Banding of light and dark red material is conspicuous in some places. Joints are not very regular and spaced far apart.

Microscopic investigation of two rock specimens revealed a rather pure non-metamorphic quartzite. In addition to quartz which is rounded to subangular, very few grains of other minerals were noticed. Plagioclase was observed once. Well-rounded grains of zircon and small individual flakes of white mica are found more often. The quartz is not clear but contains numerous small inclusions. A characteristic feature is the addition of secondary quartz around the original grains in optical continuity with them. A narrow zone of dust inclusions marks the boundary between the well-rounded allothigenic quartz and the later interstitial authigenic quartz (figure 15). Under the microscope the Flathead quartzite shows enough distinctive differences from the Belt quartzites to be readily recognized. These differences are listed in table 2.

Correlation. An angular unconformity is assumed to exist between the pre-Beltian complex and the overlying Flathead quartzite in the Armstead area, although the contact is nowhere well exposed. No Flathead was observed in contact with Belt quartzites, but north of the Armstead area the Flathead seems to overlie Belt rocks (Winchell, 1914, p. 23). The existence of an unconformity at the base of the Cambrian in western Montana has been doubted by some investigators (Deiss, 1935, pp. 95-96). The Wolsey shales are in conformable contact with the top of the Flathead quartzite in the Armstead anticline.

No fossils are present in the Flathead formation in the area. According to Deiss (1936, p. 1328) they are unknown from this formation, except on Crowfoot Ridge in Yellowstone Park where some unidentified calcareous brachiopods were found.

FIGURE 15.- Flathead formation

Addition of secondary quartz around original grains and in optical continuity with them. Dark rim of dust inclusions marks boundary between authigenetic and allothigenetic quartz. Photomicrograph of specimen 7AE48 (Flathead quartzite). Crossed nicols, 100x .



The formation is at present assigned to the Middle Cambrian (Albertan) according to Perry (1945, p. 2). Deiss (1938, p. 1161) remarks that the correlation of Middle Cambrian formations over widely separated sections is doubtful, mainly because the character of sedimentation was not uniform in all parts of the Cordilleran trough. He believes that the basal sandy member of the Depass formation in the Wind River Canyon (Wyoming) represents the southern phase of the Flathead formation. Also the Brigham quartzite in Blacksmith Fork (Utah) is correlated with the Flathead. These correlations are, however, uncertain, because they are based only on similar lithology and stratigraphic position.

Origin. Like the Belt the Flathead probably represents sediments laid down in a shallow sea. The floor on which the Cambrian was deposited appears to have been remarkably uniform and level (Perry, 1945, p. 2). According to Deiss (1941, p. 1112) the Flathead sea transgressed across Montana from the south toward the northeast and the sediments were derived mainly from Belt rocks.

Wolsey formation

Definition. The Wolsey shales were first named by Weed (1899) and he included the shales in the Barker formation. In 1900 he mentioned the Wolsey again and treated it as a formation, but gave no type section (Weed, 1900, p. 285). Deiss (1936, p. 1329) emended the Wolsey formation and established a type section on the southern end of South Hill in Belt Park. He remarked, however, that the best exposures are found on Crowfoot Hill in Yellowstone Park.

The formation consists of green to grayish-green shales, is transitional between the Flathead quartzite and the Meagher limestone, and is of Middle Cambrian age (Deiss, 1936, p. 1329).

Distribution and thickness. The Wolsey formation is found in central northern Montana (Fort Benton quadrangle), central western Montana (Helena-Big Belt Mountain region), and central southern Montana (Little Belt Mountains quadrangle and to the southeast), according to Wilmarth (1938, p. 2362).

In the Tendoy-Beaverhead area it occurs only in the Armstead anticline. It seems to be absent in the Kate Creek area where other Cambrian strata are found. The best exposures are found east of the axis of the Armstead anticline, but even these are rather poor because of minor faults, slumping, and vegetation. On the west side of the anticline the Wolsey formation is nearly absent due to faulting.

Deiss (1936, p. 1329) who measured several sections of well-exposed Wolsey shales mentions an average thickness of 240 feet, with a maximum of 363 feet, and a minimum of 150 feet. North of the Armstead anticline in the Bannack-Argenta area the Wolsey shales are absent (Shenon, 1931, p. 46). He states : "The absence of shales at the top of the Flathead quartzite is in marked contrast with the Three Forks and Philipsburg regions where shales make up a considerable part of the Cambrian system". Peale (1896, p. 21) reported 290 feet of shale on top of the Flathead quartzite in the Three Forks area, and Emmons and Calkins (1913, pp. 32-34) 120 feet in the Philipsburg quadrangle.

In the Armstead anticline Moritz (personal communication) estimated a thickness of 200 feet of shales.

Lithologic and stratigraphic features. The Wolsey formation consists of grayish-green shales which are fissile and fine grained.

The shales are easily attacked by erosion and are found in topographic depressions. Weathering produces a green clay which forms a rather thick soil. Vegetation commonly obscures the presence of the shales. The best exposures are found at the undercut side on the bottom of the creek along the outcrop.

The shales are micaceous. Some mica occurs in flakes large enough to be seen with the naked eye. The bedding averages a few inches in thickness and is commonly crenulated. Thin lenses of sandstone as well as calcareous nodules are found.

Correlation. The Wolsey shale rests conformably on the Flathead. The Meagher formation overlies the Wolsey shale and also shows a conformable contact.

According to Moritz (personal communication) trilobite fragments have been found in the Armstead anticline in the calcareous nodules of the shale. These fossils could not be identified. In other areas, however, diagnostic fossils have been identified which indicate the Middle Cambrian (Albertan) age of the Wolsey shales.

The Gros Ventre formation, as exposed in the Wind River Canyon (Wyoming), contains trilobites similar to those in the Wolsey, and on this basis is correlated with that formation (Deiss, 1938, p. 1161). Deiss specifically stated that none of the genera or species of the Meagher limestone could be found in the Gros Ventre formation, but later Perry (1945, chart) correlated the Gros Ventre formation with the Wolsey and Meagher formations, probably on the basis of new evidence.

Origin. The fossils clearly indicate the marine origin of the Wolsey formation. The water was probably deeper and less agitated than in Flathead time.

Meagher formation

Definition. The Meagher limestone of Middle Cambrian age was first treated as a formation by Weed (1900, p. 285) and described as a thinly and irregularly bedded, pure, gray limestone, mottled with patches of buff-colored, arenaceous clayey matter. The derivation of the name for the formation is not stated by Weed, but it is probably derived from Meagher county, Montana. Deiss (1936, pp. 133-1331) considered the original definition inadequate. He emended this definition and established a type section on the south side and top of South Hill, Belt Park. The best exposed, most completely developed, and most fossiliferous section is however found in Nixon Gulch near Manhattan, Montana (Deiss, 1936, p. 1332).

Distribution and thickness. The formation has been reported from central Montana (Wilmarth, 1938, p. 1332) and lately also from southwestern Montana (Honkala, 1949, p. 16).

In the area of this report it is found in the Armstead anticline. It is better exposed on the east side of the axis than on the west side. It is also probably present in the Kate Creek-McBride Creek area.

In southern Montana the Meagher limestone seems to vary greatly in thickness, averaging 258 feet, with a maximum of 416 feet, and a minimum of 50 feet (Deiss, 1936, p. 1331). In the region east of the Tendoy-

Beaverhead area 585 feet and 637 feet have been reported from two localities in the Centennial Mountains (Honkala. 1949, p. 16) where they were measured by Kennedy. Honkala measured the great thickness of 1007 feet in the Gravelly Range.

In the Armstead area 200 feet of Meagher limestone are exposed according to Brant and others (1949, figure 1). In the area of the headwaters of Kate Creek 10-20 feet are found (Hardley, personal communication).

Lithologic and stratigraphic features. The Meagher formation in the Armstead area is a pinkish to light brown, magnesian limestone. It is resistant to erosion and crops out as a prominent cliff. The fine-textured limestone occurs in irregular beds that range from one to eighteen inches in thickness. Dark spots of a green material, which may be glauconite, are conspicuous especially in the upper part. Weed (1900, p. 285) in his original description of the Meagher limestone mentions the occurrence of glauconite as a characteristic feature. On the other hand, Deiss (1936, p. 1330) states that the formation contains very few glauconite grains in most of the sections measured by him. In the Armstead area the green spots can hardly be overlooked, but it is uncertain whether they are due to the mineral glauconite. The weathered rock is commonly darker and buff in color with irregular markings. Determination in the field showed some parts of the formation to be dolomitic.

Study of a thin-section showed a very pure carbonate rock. The carbonate crystals form a mozaic which is generally very fine grained, the crystals being under 0.1 millimeters in diameter. In a few spots a coarser mozaic was observed, where the grains attained a size of 0.4 millimeters

and over. These larger crystals probably developed later in solution cavities or veins. Some secondary quartz was found associated with the carbonate.

Brant and others (1949, p. 67) report 1.5 percent insoluble material and no heavy minerals in a sample of the limestone. No shale beds as described by Deiss (1936, p. 1331) from the type section were noticed. Some siliceous impurities were found.

Correlation. The Meagher limestone conformably overlies the Wolsey shale. In the Armstead area the Park, Dry Creek and Yogo formations are absent. The erosional or non-depositinnal interval between the Cambrian Meagher formation and the overlying Jefferson formation of Devonian age did not leave any noticeable traces in the rock sequence, as the Jefferson lies with apparent conformity on top of the Meagher.

A few fossils were found in the Armstead area, but these were fragmental and could not be identified. Honkala (1949, p. 19) also notes the absence of fossils. A varied trilobite fauna has been found by Deiss (1936, p. 1314) at Nixon Gulch. Weed (1900, p. 285) states that faunal remains are confined to the upper part of the formation, whereas Deiss (1936, p. 1331) mentions that the basal beds carry the majority of fossils.

On the basis of the identification of the trilobites the age of the Meagher formation has been established as Middle Cambrian (Albertan). According to Deiss (1938, p. 1163) the Pentagon shale in the Lewis and Clark Range (Montana) and the Wheeler shale plus the Marjum limestone in the House Range (Utah) are equivalent in time to the Meagher limestone of Montana. Perry (1945, chart) correlates the Meagher with part of the Gros Ventre formation in central southern Montana.

Origin. The fauna which has been found in the Meagher formation clearly indicates its marine origin. The sea was probably deeper than during Welsey time, but became shallower toward the end of Meagher time as indicated by the greater abundance of glauconite (?). The sediments contain hardly any clastics which is an indication that the lands from which they were derived, and which supposedly stood to the east, had a low relief.

Kinnikinic (?) formation

Definition. The Kinnikinic formation was named by Ross (1934, b, p. 947) for exposures along Kinnikinic Creek, at Clayton, Custer County, Idaho. It is described as a massive light-colored quartzite with local lenses of dolomite, dolomitic shale, and some conglomerate. The age of the Kinnikinic formation has been established recently as early Upper Ordovician, (Ross, 1947, p. 1104).

Distribution and thickness. The Kinnikinic quartzite is known only from southern central Idaho (Custer County) and the name is now introduced into the adjacent part of Montana.

In the area mapped by the writer the quartzite is exposed at several places west of Nicholia Creek above the basin. It oberlies the Belt on top of the ridge immediately west of the creek. A very good exposure is found in section 15, T. 16 S., R. 11 W. Along the Continental Divide the quartzite is present south of the intrusive mass of Eighteen Mile Peak. It is found here in two isolated outcrops. One of these is an overthrust mass. In other the quartzite has come to a higher position along high-angle faults and is in immediate contact with Mississippian limestone. A small outcrop is amidst Tertiary volcanic material along Meadow Creek. The most northerly exposure is in section 1, T. 15 S., R. 12 W.

The thickness as estimated by Ross (1947, p. 1095) for exposures in the Lemhi Range is about 3000 feet. Anderson and Wagner (1944, p. 7) mention only 200 feet in the area adjacent to the Tendoy-Beaverhead area.

Umpleby (1917, p. 23) states that the upper quartzite is at least 800 feet thick in the Mackay region. For the Nicholia Creek area an estimated 800 feet are present.

Lithologic and stratigraphic features. In the writer's area the Kinnikinic (?) formation is exposed as a white to light gray quartzite. The rock is resistant to erosion and forms conspicuous ledges (see figure 16). Weathering produces iron oxide stains which give the rock a pale-yellow to light-pink color in irregular spots. The quartzite is rather thick-bedded and much fractured. The color and the absence of the fine banding and crossbedding make it easy to distinguish from the underlying Belt. At the base of the Kinnikinic (?) a conglomeratic layer has been found in some places.

Study of a thin-section (specimen 547) shows a very pure quartzite with detrital grains averaging 0.1 millimeters and ranging up to 0.5 millimeters in diameter. In some parts of the thin-section the grains are well rounded, in other parts they are more irregular, but not interlocking. Characteristic is the well-fitted mozaic pattern formed by the quartz grains with no interstitial material and no secondary quartz additions as in the Flathead quartzite.

The photomicrograph of figure 17 shows a representative part of the rock. The quartz is relatively free from inclusions. No feldspar and only a few small grains of biotite are noticeable. Zircon, chlorite, and iron oxide are present in very small amounts. The rock has been subjected to very little metamorphism. Strain shadows in quartz are exceptional and no shearing is visible.

FIGURE 16.- Kinnikinic (?) quartzite

Ledge of white Kinnikinic (?) quartzite at headwaters of Trail Creek.

FIGURE 17.- Kinnikinic (?) quartzite

Pure quartzite. Photomicrograph of specimen 547. Crossed nicols, 85x .





Correlation. The contact between the Kinnikinic (?) quartzite and the underlying Belt rocks is rather poorly exposed west of Nicholia Creek. No unconformity is indicated. Shales which have been assigned to the Devonian Three Forks formation overlie the Kinnikinic (?) formation with apparent conformity.

In the type locality no diagnostic fossils were found and the formation is probably of Lower or Middle Ordovician age. This is based on its relations to fossiliferous formations above and below (Ross, 1937, p. 18). Well-preserved fossils have been obtained from the Kinnikinic formation in the vicinity of Gilmore on the east flank of the Lemhi Range. These faunal remains have been identified as early Upper Ordovician in age, approximately the age of the Fernvale formation of the Mississippi Valley (Ross, 1947, p. 1104). No fossils were found in the writer's area. The fucoidcasts mentioned by Ross (1947, p. 1103) were also absent.

The white quartzite was identified as Kinnikinic by Dr. Ross, who visited the writer during the summer of 1947, and the only basis for correlation was the similar lithology. In a letter to the writer (September 7, 1947) Dr. Ross states: ". . I am personally convinced that the white crystalline quartzite I told you looked like Kinnikinic does belong to that formation and is hence of Ordovician age". At that time it was believed that the underlying red quartzite belonged to the Flathead. But later investigations by the writer (see under Flathead formation) revealed that the red quartzite is strikingly different from the Flathead in the Armstead area which is clearly part of a whole Cambrian sequence. The red quartzites have therefore been assigned to the Belt series.

However, the possibility exists that the white quartzite also belongs to the Belt as it is similar in many respects to some of the Beltian quartzites as exposed in west central Montana (Sloss, personal communication). At the present the writer does not have enough evidence to either support or disprove the correlation made by Dr. Ross and the white quartzite is therefore tentatively assigned to the Ordovician (?) Kinnikinic (?) formation.

On the correlation chart of the Paleozoic sequence in south central Idaho (Ross, 1934, b, p. 940) the Kinnikinic formation of the Lemhi and Lost River Ranges is correlated with part of the Swan Peak quartzite in southeastern Idaho.

Origin. As long as the correlation of the white quartzite is uncertain nothing specific can be told about the origin, as the position of the area itself does not afford any specific clues to this problem.

DEVONIAN SYSTEM

General remarks

Devonian strata are present in all of Montana, except the southeastern corner. The Devonian system in Montana is divided into tw units: the lower one is called the Jefferson formation and the upper one the Threeforks formation. Both are of Upper Devonian age and are present in the area of this report.

The total thickness of Devonian strata in Montana is rather persistently about 1000 feet, but thicknesses become less to the south and east. Southwestward in Idaho the strata are over 3000 feet thick (Perry, 1945, p. 5). The Tendoy-Beaverhead area was part of the shelf sea east of the Devonian basin in which more than 4000 feet of Devonian sediments accumulated (Eardley, 1947. p. 311).

Jefferson formation

Definition. The name Jefferson formation was first employed by Peale (1893, p. 27) and derived from the Jefferson river in the Three Forks quadrangle. The Jefferson was described by Peale as a brown and black crystalline limestone underlying the Threeforks shales and overlying the Cambrian formations.

The Jefferson formation was originally assigned to the Middle Devonian, but it is now considered to be of Upper Devonian age. Berry (1943, p. 10) states: "Stratigraphic position, a distinctive composition (dolomite), color, and petroliferous odor have been the basis for identification of the Jefferson formation, because fossils are notably scarce and generally poorly preserved."

Distribution and thickness. The Jefferson formation has been recognized in central and southern Montana, in western Wyoming, southeastern and south central Idaho, northern Idaho, and northern Utah (Wilmarth, 1938, p. 1041).

In the writer's area Jefferson strata have been found on the east side of the Armstead anticline. They are probably present in the Kate Creek - McBride Creek area, but were mapped together with the Threeforks as Devonian undifferentiated.

Peale, (1893, pl. IV) in his original description of the Jefferson formation, mentions a thickness of 640 feet. Sloss and Laird (1947, p. 1412) who redefined the formation measured 715 feet of Jefferson at the type section near Logan. The much greater thickness of 1500 feet is recorded by Shenon (1931, p. 47) in the Argenta area.

In the Armstead area 758 feet were measured by Brant and others (1949, p. 19).

Lithologic and stratigraphic features. In the Armstead area the Jefferson consists of a dolomitic limestone with shaly partings between the limestone beds and one two foot shale zone near the middle of the formation.

Most of the Jefferson strata are resistant to erosion and form a cliff. The beds are massive, range from a few inches to well over a foot in thickness and do not exhibit any obvious lithologic changes along strike. The color is pinkish-gray in a fresh specimen, but more

characteristic is the color of the weathered rock, which is pale-brown to dusky-brown. Weathering had produced a typical mottled appearance. When broken the rock emits a rather strong petroliferous odor. Calcite stringers are quite common all through the formation. In most places the rock is dense and has a finely crystalline texture.

The limestone is rather impure as indicated by an insoluble residue of 15.9 percent (Brant and others, 1949, p. 70). The impurities do not contain any heavy minerals and seem to be made up mainly of clayey material.

Correlation. The Jefferson dolomite lies with apparent conformity on the Meagher formation in the Armstead anticline. The Three Forks formation conformably overlies the Meagher formation.

In the Armstead area the dolomite seems to be unfossiliferous. This does not seem to be uncommon (Berry, 1943, p. 11). Ross (1937, p.25) writing about the Bayhorse region, Custer County, Idaho, states that the formation is distinguished in most outcrops by a digitate form of Favosites. In the Threeforks area, where the Jefferson can be divided into three units, stromatoporoids are the most frequent fossils in the middle limestone member, according to Sloss and Laird (1947, p.109).

Since the Jefferson was originally described uncertainty has existed regarding its age and it has been variously assigned to the Silurian-Devonian, Devonian, Lower and Middle Devonian, and Middle Devonian plus lower Upper Devonian (Berry, 1943, p. 10). Berry brings forth evidence to prove that the Jefferson formation can be correlated with the Devils Gate formation of Nevada which is partly Middle Devonian and partly

lower Upper Devonian. More recently Sloss and Laird (1947, p. 1427) report the Devonian strata of Montana to be of Upper Devonian age. According to these investigators the Jefferson is partly of Senecan age and partly of Chautauquan age. The Ermont formation, which has been described from several places north of the Armstead area, can be correlated with the Jefferson formation (Shenon, 1931, p. 47). Perry (1945, p. 4) correlates the Jefferson with part of the Minnewanka formation of British Columbia.

Origin. The Jefferson formation is doubtless of marine origin.

Threeforks formation

Definition. The name Threeforks was given by Peale (1893, p.29) to a formation of Upper Devonian age exposed at the junction of the three forks of the Missouri River, near Three Forks, Montana. The type section has been restudied recently by Sloss and Laird (1947, p.1411) who describe the formation as follows: " ... composed of dark brown dolomitic shale and shaly dolomite at the base, green plastic (probably in part bentonitic) shale interbedded with fossiliferous black limestone in the middle and yellow-weathering sandy limestone and calcareous sandstone at the top." Hence the formation is mostly shaly in the Three Forks area, but in some other areas the formation becomes so calcareous that it is called Threeforks limestone (Wilmarth, 1938, p. 2145).

Distribution and thickness. The Threeforks formation is widespread in Montana and is also found in western Wyoming, southeastern Idaho, and northern Utah (Wilmarth, 1938, p. 2145).

In the area of this report the Threeforks is present above the Jefferson formation in the Armstead anticline. It was also found in the Kate Creek-McBride Creek area, but as the boundary between the Jefferson and Threeforks could not be located both formations were mapped together as Devonian undifferentiated. Beds which presumably belong to the Threeforks formation were found in a belt extending through sections 16, 21, 22, 27, 28 of T. 16 S., R. 11 W. Here these beds overlie the white quartzite assigned to the Ordovician (?) Kinnikinic (?) formation and are overlain by the Mississippian Madison group. They form part of the major anticline along Trail Creek.

A total thickness of 150 feet of Threeforks shales has been reported from the type locality (Sloss and Laird, 1947, p. 1411). In the Argenta area, where the Jefferson formation is present, the Threeforks shales seem to be absent (Shenon, 1931, p. 47). Honkala (1949, p.22) measured 238 feet of Threeforks strata in the Centennial region.

In the Armstead area about 300 feet are found. In the Trail Creek area about 600 feet of shales occur below the Madison limestone, but these may belong partly or not at all to the Threeforks formation. In general it has been noted, that the thickness of the Threeforks formation varies considerably within short distances (Ross, 1947, p. 1112). Ross believes that this is due to differences in amount of material originally deposited.

Lithologic and stratigraphic features. The Threeforks formation as it occurs in the Tendoy-Beaverhead area probably consists exclusively

of soft shales with no or very subordinate amounts of limestone.

The formation is poorly exposed and is commonly covered with a rather thick soil layer. It is slope forming and occurs between cliff-forming formations. This is true for both the Armstead and Trail Creek areas.

In the debris which covers the slope, pieces of yellow and gray to black, calcareous, fissile shale with lumpy brown masses are found. Also thin plates of red and yellow calcareous siltstone occur. In the Trail Creek area some purplish, cherty shale is present, especially in the lower part of the formation. Cubes of limonite pseudomorphous after pyrite and calcite veins are common in section 22 of T. 16 S., R. 11 W. The upper beds become progressively more limy and contain thin-bedded, grayish-blue limestones with chert layers. The most characteristic feature of the Threeforks formation is the yellowish-gray soil covering the outcrops.

Correlation. In the Armstead anticline the Threeforks formation lies conformably on top of the Jefferson limestone. In the Trail Creek area, where the Jefferson is absent, the contact between the Kinnikinic (?) and the Threeforks is not exposed, but it is probably unconformable. The shales assigned to the Threeforks in this area grade into the typical Madison and no unconformity is present between the Devonian and the Mississippian.

No fossils have been found in the shales of the float. Winchell (1914, p. 27) mentions the absence of fossils in the Threeforks shales of the Dillon quadrangle.

Sloss and Laird (1947, p. 1427) state that the Threeforks formation is of late Upper Devonian (Chautauquan) age. The Threeforks shales correlate with part of the Minnewanka formation in British Columbia. The Potlatch anhydrite beds, found east of Glacier National Park and in Alberta, are approximately equivalent in age to the Threeforks formation (Perry, 1945, p. 5).

Origin. The Threeforks shales were deposited in a sea which was somewhat shallower than the one during Jefferson time. Probably the water of this sea was foul at the bottom and contained a high percentage of hydrogen sulfide. The sulfur combined with iron during diagenesis to form pyrite, which later was oxidized to form limonite.

MISSISSIPPIAN SYSTEM

General remarks

The Lower Mississippian of southwestern Montana is represented by the Madison group. The name Madison formation was first employed by Peale (1893, p. 33) who subdivided the formation into three members. Later Weed (1900, p. 290) used the term Madison group, embracing the Woodhurst and Castle limestones, and Paine shales. But the first discussion of Madison rocks as a true group, divided into separate formations, was by Collier and Cathcart (1922, p. 173). More recently Sloss and Hamblin (1942) reworked the Madison. The terminology used by these various writers has been summarized and compared in table 3. In this report the classification as given by Collier and Cathcart will be used, and the Madison group will be discussed under the headings Lodgepole formation and Mission Canyon formation. Remarks and data pertaining to the Madison group as a whole are given under the heading Mission Canyon formation.

Beds in south-central Idaho that are more or less equivalent in age to the Madison group are known under the name Milligen formation. Strata of this formation are probably present in the southwestern part of the area described in this report and will be discussed under the heading Milligen (?) formation.

The Brazer formation of Upper Mississippian age has been widely recognized in south central Idaho where it overlies the Milligen formation. The writer believes that most of the Mississippian limestones of the Beaverhead Range belong to this formation, which will be treated under the heading Brazer (?) formation.

TABLE 3.- Nomenclature of Madison group

Peale 1893	Weed 1900	Collier & Cathcart 1922	Sloss & Hamblin 1942
Jaspery limestone Massive limestone Laminated limestone } Madison formation	Castle limestone Woodhurst limestone Paine shale } Madison group	Mission Canyon formation Lodgepole formation } Madison group	Mission Canyon formation Woodhurst member Lodgepole formation Paine member } Madison group

On the geologic map (plate I) the writer has attempted to differentiate the Mississippian strata into the Madison group, the Milligen (?) formation, and the Brazer (?) formation. This differentiation should be regarded as tentative as there is no sufficient fossil evidence to substantiate the writer's opinion. There are, however, enough lithologic differences between these three units to warrant their distinction.

The Amsden formation includes strata of both Pennsylvanian and Mississippian age, but because latest investigations (Scott, 1945, a, p. 1195) seems to indicate that the greater part of the Amsden is of Pennsylvanian age, the formation will be discussed under the heading Pennsylvanian system.

The age relationship between the various Mississippian formations has been summarized in table 4 after Perry (1945, chart) and Ross (1933, figure 2).

Lodgepole formation

Definition. The Lodgepole formation of Lower Mississippian age was named for exposures in Lodgepole Canyon in the Little Rocky Mountain region. The name was first used by Collier and Cathcart (1922, p. 173), who described the formation as a thin-bedded limestone and shale.

Sloss and Hamblin (1942, p. 315-318) proposed to divide the Lodgepole into two members, using names given by Weed (1900, p. 289-294). At first these investigators believed the two units could be given formational rank, but later work showed that they are not persistent

TABLE 4.- Correlation of Mississippian formations

TABLE 4. CORRELATION OF MISSISSIPPIAN FORMATIONS OF south central Idaho and southwestern Montana .

PERIOD	EPOCH	S-C IDAHO	S-W MONTANA
MISSISSIPPIAN	CHESTER	BRAZER	LOWER AMSDEN / BRAZER
	MERAMEC		
	OSAGE	MILLIGEN	MISSION CANYON) MADISON GROUP
	KINDERHOOK		LODGEPOLE)

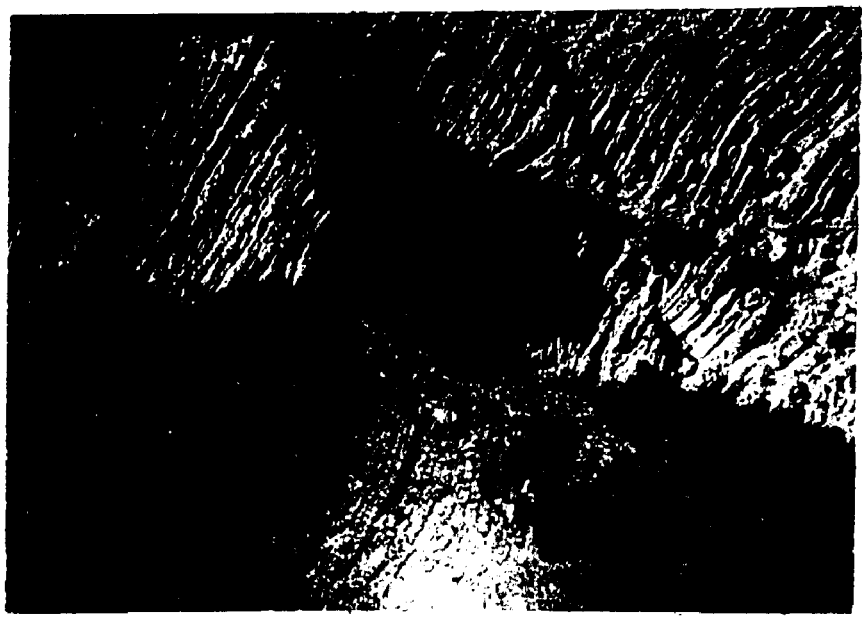
enough. The lower member is called the Paine member and characterized by thin-bedded, dense limestones in units averaging 5 inches thick, separated by almost equal amounts of calcareous shale and shaly limestone. The upper member is called the Woodhurst member and consists largely of alternating massive and thin-bedded limestones with thin shale partings which upon weathering give a characteristic yellow or light orange color to the rocks. The division of the Lodgepole into its members is not clear in the type section of the Madison group and will not be attempted in this paper.

Distribution and thickness. The Lodgepole formation of the Madison group has been recognized in central northern Montana (Little Rocky Mountain region), southeastern Alberta, southern Saskatchewan, western North Dakota, northern Wyoming, and several places in southern and western Montana (Sloss and Hamblin, 1942, fig. 2).

In the Tendoy-Beaverhead area the Lodgepole formation is found in the Tendoy Mountains, the area north of Armstead, and the Trail Creek anticline. In the Tendoy Mountains it was observed along Big Sheep Creek in sec. 15, T. 14 S., R. 10 W., near Shearing Pen Gulch. Farther north the Lodgepole formation is found in McKenzie Canyon and North Limekiln Canyon where a partial section was measured. A very good and easily accessible exposure is along U.S. highway 91, about 3 miles north of Armstead. A photograph of this Lodgepole outcrop was used by Sloss and Hamblin (1942, fig.5) to show the characteristic thin and even bedded limestones with intercalated calcareous shales. The same outcrop is shown in figure 18.

FIGURE 18.- Madison group

Lodgepole formation. Thin limestone beds separated by shales. Outcrop along U.S. highway 91, 3 miles north of Armstead. (Photo by N. C. Elmer)



In the Little Rocky Mountains the thickness of the Lodgepole as given by Collier and Cathcart (1922, p. 173) is 800 feet. Sloss and Hamblin measured 531 feet at the type section near Logan.

Nowhere in the Tendoy-Beaverhead area the top and the bottom of the Lodgepole formation is exposed in one outcrop. And because correlation between the various outcrops is not feasible in view of the great similarity of the individual limestone beds, only a minimum thickness can be given. This has been estimated at 550 feet, a figure based on exposures in the Armstead area.

Lithologic and stratigraphic features. The Lodgepole formation as exposed in the area of this report is a dense, finely crystalline and laminated limestone.

The limestone is fairly resistant to erosion and is commonly well exposed. An important feature is the bedding, which is thin, ranging from four to eight inches in thickness, and which is very persistent. The distinction between the Mission Canyon formation and the Lodgepole formation is based largely on lithological characteristics and especially on difference in bedding. The thin limestone beds of the Lodgepole are separated by calcareous shales, which in the Armstead area are less thick than the limestones and range from 1 to 2 inches in thickness.

The limestone is medium bluish-gray, but weathering causes a noticeable darkening, producing a dark gray and finely-pitted surface. In the weathered state the Lodgepole limestone is darker than the Mission Canyon. Chert is common in some of the limestone beds. The lower strata are slightly arenaceous.

In North Limekiln Canyon a partial but representative section of the Lodgepole was measured by the writer's associates G.F. Bowers and J.A. Seglund.

Partial section of Lodgepole formation as exposed in North Limekiln Canyon, section 6, T. 11 S., R. 10 W.

		Thickness (feet)
5.	Limestone, slabby, dark gray, weathering chocolate brown	33
4.	Same as unit 2	5
3.	Limestone, slabby, dark gray, thin-bedded, very fine grained, weathers to a dark gray-brown	12
2.	Limestone, greenish-gray, weathers to a tan color, almost lithographic	51
1.	Limestone, light gray, spotted with green, weathers to an orange-yellow, thin-bedded, almost lithographic	124
	Total thickness of measured part of section	195

Correlation. The base of the Lodgepole formation is exposed in the Armstead and Trail Creek areas, where the Lodgepole overlies the Devonian Threeforks shales conformably. The exact boundary between the Threeforks formation and the Lodgepole formation has not been determined. The basal shale of the Lodgepole, which is characterized by a conodont fauna (Sloss and Hamblin, 1942, p. 315), was not noticed. The contact between the Lodgepole formation and the overlying Mission Canyon formation is very well exposed near Shearing Pen Gulch, along Big Sheep Creek road. The Mission Canyon apparently overlies the Lodgepole conformably, although the absence of bedding in the massive Mission Canyon obscures the relationships between the two formations.

Fossils were collected from the Lodgepole formation at several places in the area. But the brachiopods and the crinoidal fragments (almost exclusively columnals) were in such a poor state of preservation that no identification was attempted. In other places, however, better preserved fossils are found. A faunal list of the "laminated limestones" is given by Peale (1893, p. 34).

Sloss and Hamblin (1942, p. 311) believe that the base of the Lodgepole may be dated rather accurately by the conodont fauna in the basal shale. This fauna indicates that the shales are correlative with the Chattanooga and Woodford shales of the Mississippi Valley and the Mid-Continent areas, and are hence of Lower Mississippian age. Perry (1945, chart) correlates the Lodgepole formation with the Englewood formation of South Dakota and with the Banff formation of British Columbia.

Origin. The origin of the Lodgepole formation has been depicted by Sloss and Hamblin (1942, pp. 324-325) as follows. The basal shale of the Lodgepole formation was deposited in shallow isolated basins, after local withdrawal of the Devonian sea. The invasion of the Lodgepole sea started from the west into a shallow east-west trough extending through central Montana. In the western part of this trough periodic influxes of clastic material took place forming the shaly partings between the limestone beds. Later this clastic material diminished and a further spread of the sea to the north and south took place.

Mission Canyon formation

Definition.

The name Mission Canyon formation was given by Collier and Cathcart (1922, p. 173) to the upper unit of the Lower Mississippian Madison

group in the Little Rocky Mountain region. The formation was named for exposures in Mission Canyon and was described as a massive white limestone of marine origin.

Previously the same unit had been described by Peale (1893, pp. 36-39) under the name "Jaspery limestones" and by Weed (1900, pp. 289-294) under the name "Castle limestone". Peale (1893, p.33) was the first to apply the name "Madison" to the whole Lower Mississippian sequence in the Three Forks area. He derived the name from the Madison River, but did not locate his type section, which Sloss and Hamblin (1942, p. 313) believe is on the Gallatin River at Logan. Sloss and Hamblin (1942, p. 321 and p. 322) and also Berry (1943, p. 16) remeasured Peale's sections and came to some different results regarding the thickness of the Madison.

Distribution and thickness. The Madison is present in southern Alberta and Saskatchewan, all over Montana, in western North and South Dakota, in southeastern Idaho, and is rather widespread in Wyoming. The equivalents of the Madison group extend as far as southern California and Mexico (Weller and others, 1948, p. 111).

In the Tendoy-Beaverhead area the Madison is of greater areal extent than any of the other Paleozoic and Mesozoic formations. It is found in the Tendoy Mountains and forms the greater part of the mountains between Big Sheep Creek and North Medicine Lodge Basins in the west and Muddy Creek Basin in the east. It is present in the Beaverhead Mountains, although here most of the Mississippian strata belong to the Brazer (?) formation. The Mission Canyon formation has been recognized wherever the Madison group was found.

The thickness of the Madison group in the Three Forks area has been measured by Peale (1893, plate 4) who reports 1250 feet of which 575 feet belong to the "Jaspery Limestones" (Mission Canyon formation). At the type section Sloss and Hamblin (1942, p. 321-322) report 1443 feet of which 912 feet are Mission Canyon. Barry (1943, p. 16) believes that the two lower members of Peale are much thicker (1200 feet) and arrives at a figure of 1800 feet in total and 600 feet for the Mission Canyon formation. As far as the writer was able to find out these measurements all represent the same section, or at least sections very close to each other.

In the Armstead area, where the Mission Canyon formation was divided into two units, the total thickness is 1700 feet, the lower unit being 1250 feet and the upper one 450 feet.

Lithologic and stratigraphic features. In the Tendoy-Beaverhead area the Mission Canyon formation is exposed as a massive limestone, which is very resistant to erosion and forms prominent cliffs. In places it stands up as a vertical wall as shown in Big Sheep Creek Canyon. Isolated masses often show rounded pinnacles and ridges (see figure 19) and do not have much talus at their bases. This relatively small amount of talus may be due to the massive character of the limestone, which does not show any apparent bedding. Cross bedding can be noticed at several places in the cliffs of Big Sheep Creek. Characteristic are the many caves, holes, and a few natural bridges which occur in the Mission Canyon. Figure 19 and figure 20 show two typical outcrops. According to Sloss and Hamblin (1942, p. 318) the Mission Canyon has been subjected to intense solution action, partly Paleozoic in age. Most

FIGURE 19.- Madison group

Rounded pinnacles and ridges of Mission Canyon formation exposed on west side of Muddy Hole Basin.

FIGURE 20.- Madison group

Vertical wall and solution caves of Mission Canyon formation along Big Sheep Creek.





of this solution action occurred prior to the deposition of the overlying formation. In places the caverns are filled with reddish to yellow material from the overlying Amsden formation. This can be observed very well along Cabin Creek road, about 1 mile north of Big Sheep Creek road. It is also possible that this soil material in the caves is residual limestone soil which is commonly red or orange. Accumulations of it may be seen in nearly all caves according to Lobeck (1939, p. 136). Sloss and Hamblin (1942, p. 318) mention the occurrence of a coarse "solution breccia" in some of the caves, formed by the collapse of cavern roofs. A brecciated part of the Mission Canyon was noticed along McBride Creek close to its source, in sec. 34, T. 12 S., R. 11 W. Whether this breccia, which is also colored yellow and reddish and contains abundant arenaceous material, is comparable to the "solution breccia" as described by Sloss and Hamblin is uncertain. It does not occur in a cave, but it might be that it was a cave-filling originally and that the surrounding Mission Canyon was removed and the filling preserved.

The Mission Canyon limestone is dark to blue-gray on a fresh surface and becomes lighter when weathered. Outcrops are light colored, have a dusty appearance and show slight color variations. Calcite veins are common and some beds contain numerous chert nodules. Fossils are strongly silicified. The rock yields a fetid odor on a freshly broken surface. The limestone effervesces freely with cold, dilute HCl and apparently no great amount of dolomite is present. Brant and others (1949, p. 72) tested two samples from the Armstead area insoluble residues. The first sample contained 9.1%, the second 11.2% insoluble material.

In the northern part of the Tendoy Mountains the Mission Canyon formation can be divided into two members. The lower one is the typical Mission Canyon as described above. The upper unit is a "wavy" limestone exhibiting small, tight folds which seem to be present all through the member. The beds of this unit range in thickness from 8 to 12 inches and consist of coarsely crystalline limestone with calcite stringers. The color is gray and does not differ greatly from the lower unit. The limestone contains chert nodules. This unit is in normal contact with the overlying Amsden formation on the west side of the Armstead anticline.

Correlation. The lower contact of the Mission Canyon formation is well exposed at several places in Big Sheep Creek Canyon where it overlies the Lodgepole formation conformably. The Amsden formation probably overlies the Mission Canyon conformably, but the contact is nowhere so well exposed that the relationship is clearly shown.

Fossils are common in the Mission Canyon formation, but they are so poorly preserved and intensely silicified as to make them unfit for identification. Sloss and Hamblin (1942, p. 305) also state that: " ... there are too many localities which yield no fossils or where the fossils are so tightly bound in the matrix as to make recognition impossible". According to these investigators fossils cannot be relied on to identify units of the group, and they propose to use insoluble residues instead. Fossils in the Tendoy-Beaverhead area include cup corals, crinoid columnals, bryozoa, and brachiopods. Bowen (1917, p. 316) found some fossils in the Muddy Creek area which were identified by G. H. Girty as being of Mississippian age. No names of the fossils were listed by Bowen.

There is little doubt that the Madison sediments are of Lower Mississippian age and join on the East with Kinderhook and Osage sediments of the Mississippi Valley (Sloss and Hamblin, 1942, p. 308). On the other hand Weller and others (1948, p. 137) state that precise correlation of the Madison formations with the standard sections in the Mississippi Valley is somewhat uncertain and that the limits of the western formations are generally defined lithologically. According to Perry (1945, chart) the Pahasapa formation of the Dakotas is of the same age as the Mission Canyon formation of the Madison group.

Origin. The Mission Canyon formation was deposited in marine water as indicated by the fossils. Apparently the sea was deeper than during Lodgepole time, because there is no clastic material between the limestone beds. The great abundance of cup corals and the numerous crinoid fragments indicate warm, clear, and quiet waters. Direct marine connections between the Madison basin and the sea covering the Mississippi valley region existed by the way of Kansas, Oklahoma, Texas, and New Mexico (Weller and others, 1948, p. 111). The Madison sea probably reached its greatest extent in Mission Canyon time and everywhere almost pure lime stone was deposited under stable conditions (Sloss and Hamblin, 1942, p. 325). The Madison in this area is of geosynclinal thickness.

Milligen (?) formation

Definition. The name Milligen formation was first used by Umpleby, Westgate and Ross (1930, p. 10) and derived from Milligen Creek near Ketchum (Blaine County, Idaho). Most of the formation consists of black

carbonaceous argillite, although it varies considerably in lithologic character. The exact age of the Milligen is unknown and the formation might include strata ranging from Devonian to Pennsylvanian in age.

Distribution and thickness. The Milligen formation has been reported only from south central Idaho, mainly from Custer County and Lemhi County.

In the Tendoy-Beaverhead area shales assigned to the Milligen (?) occur exclusively in the extreme southwestern part, along the Continental Divide west of the upper course of Nicholia Creek.

The thickness of the formation at the type section is at least 3000 feet. More to the east in the Borah Peak quadrangle Ross (1947, p. 1113) estimated the thickness at 1000 feet. The formation has not been described from areas in Montana and consequently no thicknesses can be given.

In the author's area the thickness of the Milligen (?) was measured to be 2019 feet.

Lithologic and stratigraphic features. The Milligen (?) formation as exposed along Nicholia Creek consists of a monotonous series of black shales with a few limestone beds. The formation is not well exposed except on the Continental Divide.

The color of the shales ranges from gray to black, the weathered shale being lighter colored than the fresh rock. Locally distinct slaty cleavage has been developed, as in SW. 1/4, sec. 6, T. 17 S., R. 10 W. White calcite veins are common and some shales contain a considerable amount of calcium carbonate.

The following representative section of the Milligen (?) formation was measured by Carl Moritz, Robert Scholten, and the writer.

Section of the Milligen (?) formation west of Nicholia Creek and up to the Continental Divide in sec. 6, T. 17 S., R. 10 W.

		Thickness (feet)
9.	Same as unit 7	537
8.	Calcareous shales, dark, cliff former	135
7.	Shale, gray, weathers brown and gray, thin, calcite veins, partially covered at base but cliff forming in upper part	187
6.	Partially covered interval, shale fragments on slope, dark gray	80
5.	Covered interval. Few benches indicate harder, probably more calcareous beds	810
4.	Shale, dark gray, weathering light gray and thinly interbedded shaly limestone	57
3.	Partially covered interval, shaly float.	160
2.	Shale gray, weathering gray, paper-thin, slope forming typical mottling due to organic remains, very much shattered	28
1.	Shale gray, weathering bluish-grey with few limestone banks which are gray, weather brown and contain some fossiliferous remains, mainly crinoid stems. Forms cliff at base . . .	25
	Total measured	2019 ft.

Correlation. The base of the Milligen (?) formation is not well exposed in the Nicholia Creek area. In the Borah Peak quadrangle the

Milligen is in direct conformable contact with the underlying Threeforks shale (Ross, 1947, p. 1113). The Brazer (?) limestone overlies the Milligen (?) formation conformably as is clearly shown at the head of Nicholia Creek.

The Milligen beds have yielded no diagnostic fossils in any one of the areas from which they have been described (Ross, 1947, p. 1113). Also the Nicholia Creek area is almost barren. Only some carbonaceous material has been found which probably represents macerated plant fragments. From many other places plant fragments have been described from the Milligen formation, but no identifications have been given.

The age of the typical Milligen is uncertain and the formation probably ranges from Upper Devonian to Upper Mississippian (Weller and others, 1948, p. 139). The strata in the Nicholia Creek area were assigned to the Milligen (?) on lithologic and stratigraphic grounds. They are very similar to strata of the recognized Milligen in adjacent parts of Idaho according to Sloss (personal communication). Some authors correlate the Milligen with the Madison formation and regard both formations as more or less equivalent in age (Ross, 1947, p. 1113).

Origin. The Milligen (?) formation was deposited in a rather shallow sea, as suggested by the type of sediment prevailing and the plant fragments found. Its comparatively great thickness indicates that it belongs to the geosynclinal facies of the Mississippian (Weller and others, 1948, p. 139).

Brazer (?) formation

Definition. The Brazer formation was named by Richardson (1913, p. 407) for exposures in Brazer Canyon, Rich County in northeastern Utah. The formation was described as consisting of massive to thin-bedded, light-gray siliceous limestone and sandstone. The Brazer is considered to be of Upper Mississippian age.

Distribution and thickness. Besides in northeastern Utah the Brazer has been recognized in eastern and southern Idaho, southwestern Wyoming and southwestern Montana.

In the Tendoy-Beaverhead area the thick-bedded gray limestones of the Beaverhead Range belong for the greater part to the Brazer (?) formation. Good exposures are found at several places along the Continental Divide, notably at the head of Simpson Creek, Tex Creek, and Nicholia Creek.

The thickness of the Brazer in northern Utah ranges from 800 to 1400 feet (Wilmarth, 1938, p. 256). In Idaho, Ross (1947, p. 1116) reports thicknesses from 2000 to 4000 feet in the Borah Peak quadrangle. He stresses the fact that the thickness is everywhere great. Much thinner sections were measured by Honkala and Kennedy in the Centennial region, where they found 772 and 406 feet (Honkala, 1949, p. 29).

The writer measured part of the Brazer along Simpson Creek, where 1677 feet are exposed. At this section both top and bottom are not exposed and the total thickness is well over 2000 feet.

Lithologic and stratigraphic features. The Brazer (?) formation consists mainly of limestones with a minor amount of shale.

The beds are very resistant and form ridges and good exposures. The base of the ridges is commonly covered with extensive talus material for the well-bedded limestones break up in blocks due to intense physical weathering. The Brazer beds are conspicuously folded in several places along the Continental Divide.

The limestones are gray to bluish-gray and characteristically darker colored than the Mission Canyon. The bedding is nearly always distinct. This is different from the Mission Canyon formation, in which no bedding is noticeable. A few thinner-bedded limestone members occur, but commonly the limestones are thick bedded, the bedding averaging several feet. The general appearance of the formation is illustrated in figure 21. The limestones effervesce very rapidly with cold dilute hydrochloric acid and the magnesium content is probably low. Silica is concentrated in nodules and streaks of chert. In the gray weathered limestones chert nodules weather out in relief. See figure 22. The chert is black on fresh surface, but where weathered it is covered with a thin coating of brown iron oxide. The chert occurs commonly in irregular lenses and nodules, all of which have their longest dimension parallel to the bedding. On a freshly broken surface the rocks yield a distinctly fetid odor. Calcite veins are common and penetrate the rock in all directions.

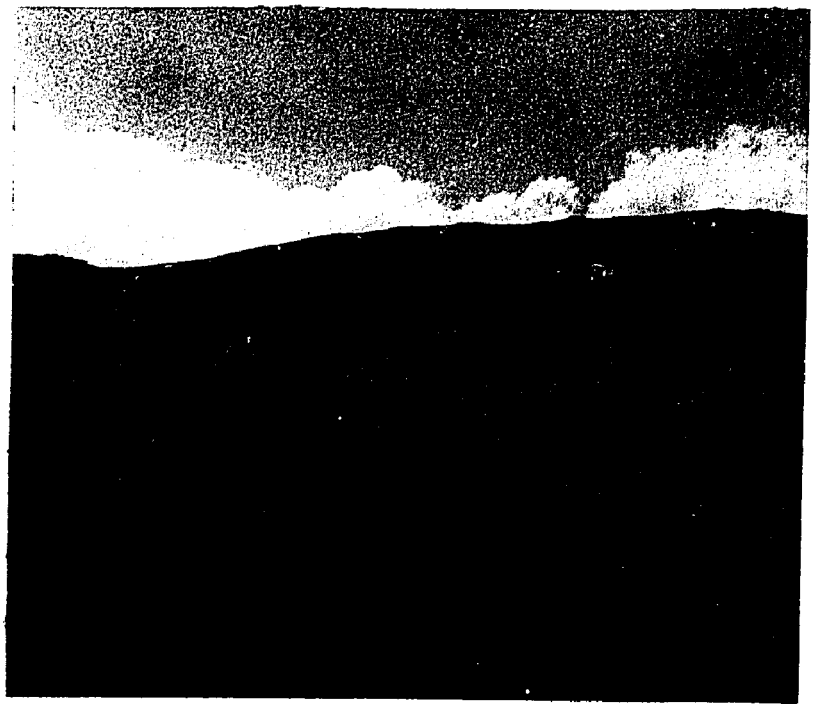
In one unit (10) of the Simpson Creek section a rock similar to the "zebra rock" as mentioned by Ross (1947, p. 1114) is present. The

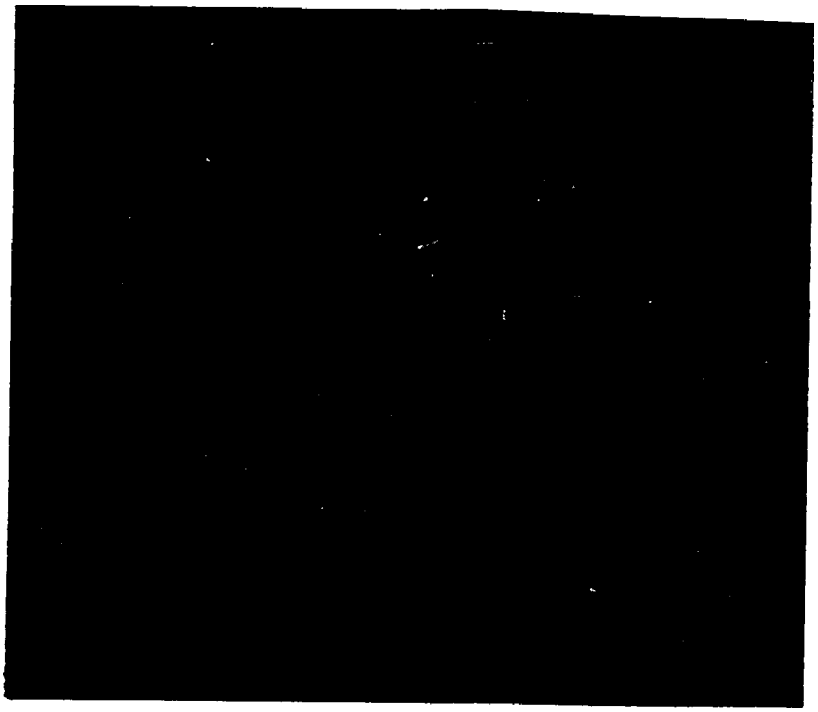
FIGURE 21.- Brazer (?) formation

Well-bedded, thick limestones of Brazer (?) formation with extensive talus. Headwaters of Tex Creek.

FIGURE 22.- Brazer (?) formation

Chert nodules weathered out in relief and small scale folding in Brazer (?) limestone.





rock contains closely spaced white subparallel bands of calcite, which are not so sharply separated from the gray limestone as the calcite of ordinary veins. This rock type presumably results from recrystallization of calcite along roughly parallel shear planes.

The following partial, but representative, section of the Brazer (?) formation was measured by the writer in cooperation with Mr. Carl Moritz (now at Dartmouth College).

Partial section of the Brazer (?) formation as exposed on the south side of Simpson Creek in sec. 34, T. 14 S., R. 12 W.

		Thickness (feet)
15.	Limestone, black, with much black chert, which in spots weathers brown. Some zones very fossiliferous	140
14.	Limestone, gray, weathering red to pinkish, very fossiliferous. Contains crinoid columnals, bryozoa, brachiopods, corals. Thin bedded, some places shaly . . .	260
13.	Partly covered interval, some exposures showing shale, brown to black, weathering red to brown. Some slabs full of crinoid stems	87
12.	Limestone, light and dark gray, slopeforming and grading into shale	98
11.	Limestone, light gray, slope forming, strongly weathered, thin bedded, very few fossils, only crinoid fragments	270
10.	Limestone, gray, massive, blocky appearance, cliff forming, has few shaly layers between beds and a few conformable chert layers. Small calcite veins make typical "zebra rock". Few poorly preserved fossils, mainly cup corals. Near top characteristic mottled limestone, with dark streaks weathering out of a gray groundmass	443
9.	Limestone, light gray when fresh, brownish when weathered, more sugary than underlying limestones. Some interbedded dark shales. Some poorly preserved brachiopods and many crinoid remains. Limy nodules with chert cores common in the lower part	118

8. Partially covered interval. Few exposures of limestone, gray, much shattered. Poorly preserved brachiopods, especially at the base. Some shale beds are intercalated 69

7. Limestone, gray, non fossiliferous, no chert. Some shale interbedded, reddish to brown, rather thickbedded, indeterminable organic remains, petroliferous odor 45

6. Partially covered interval. Slope covered with shale, dark gray to black, weathers brown, calcareous. Thick conformable veins of crystallized calcite 34

5. Limestone, gray, no chert layers, crinoid columnals, At top of shale partings. 34

4. Covered interval 23

3. Limestone, bluish, chert layers at base, crinoid stems and bryozoa 12

2. Shale, dark gray, grading into unit 3 1

1. Limestone, blue-gray, crinoid stems, calcite veins, few bryozoa 48

Total measured . . . . . 1677 feet

The following section was measured by the writer in cooperation with Mr. Robert Scholten.

Partial section of the Brazer (?) formation as exposed at the head of Nicholia Creek, in sec. 7, 8, 9, 17, T. 17 S., R. 10 W.

		Thickness (feet)
12.	Limestone, medium to dark gray, thinbedded, bands of dark chert, cliff forming . . .	350
11.	Limestone, dark gray, weathers differentially in light gray and tan, laminated in gray colors, bedding of intermediate thickness, scattered chert nodules, crinoid stems and large cup corals, bryozoa, gastropods. Crinoids decrease, corals increase in quantity in higher parts of unit	200

10. Limestone, light to medium gray, massive, strongly jointed, almost entirely built up of fossils, mainly crinoids, calcite veins, chert layers 200

9. Limestone, medium gray, weathers tan and light gray to white, bedding of intermediate thickness, strongly jointed, calcite veins, chert layers, few fossils . 60

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

7. Limestone, light gray, laminations in gray color, cliff forming, calcite veins, chert, very fossiliferous, crinoid stems, corals, bryozoa, brachiopods . 50

6. Limestone, gray, thin bedded, slope forming, chert nodules, calcite veins 15

5. Limestone, dark gray to black, fan-like laminations, breccia layers, regular chert beds, calcite veins, fossiliferous 100

4. Limestone, gray, weathering pink, laminations in brown and red colors, massive, chert nodules, calcite veins, corals 30

3. Limestone, dark gray, thin bedded, chert and calcite, fossiliferous 25

2. Shale, brown and sandstone, light red 30

1. Limestone, dark gray, breccia with sandstone fragments, rusty brown, few fossils, some lenses of recrystallized crinoid stems 60

Total thickness 980

Correlation. The Brazer (?) formation is in conformable contact with the underlying Milligen (?) formation at the head of Nicholia Creek. The same relationship has been described from the Borah Peak quadrangle by Ross (1947, p. 1114). The top of the Brazer (?) formation is nowhere exposed and the relationship with the Pennsylvanian strata could not be determined. In the Centennial Region the Amsden

formation is in conformable contact with the Brazer limestone (Honkala, 1949, p. 36).

In the writer's area the Brazer (?) is locally very fossiliferous. Most common are the crinoid columnals, next in abundance are cup corals, bryozoa, and brachiopods. The specimens were so much silicified as to make a more precise determination impossible (personal communication, Dr. Ehlers). The rocks under discussion were classified as belonging to the Brazer (?) formation on the basis of their lithology. The strata show many similarities with the Mission Canyon, but there are enough differences to recongize the two units in the field. Strata similar to the Brazer (?) as described in this report have been mapped by Shenon (1928, pp. 7-8) in the Birch Creek district, a few miles outside the Tendoy-Beaverhead area. Shenon assigned the strata to the Upper Mississippian mainly on the basis of cup corals, which were identified as Zaphrentis stansburyi (?). Also Scholten (1948, p. 22) mentions the presence of a fossil (no identification given) with Brazer affinities from the southern part of the Beaverhead Range, although most of the fossils from same strata seem to be Madison in age. Apparent incompatibilities among the fossils from the Brazer formation have also been reported by Ross (1947, p. 1117) from the Borah Peak quadrangle and by Honkala (1949, p. 34) from the Centennial Region.

In general the Brazer formation is regarded as being of Upper Mississippian (Meramec and Chester) age. According to Perry and Sloss (1943, p. 1288) the Brazer formation is essentially of the same age as the Big Snowy group in central and eastern Montana. It can also be correlated with the Hannan in northwestern Montana and the

Rundle in British Columbia and Alberta.

Origin. The Brazer formation is a marine deposit as evidenced by the great number of exclusively marine fossils. The water was probably warm and clear. The sediments were derived from low adjacent lands to the east which supplied mainly chemical sediments with minor amounts of clastic material.

PENNSYLVANIAN SYSTEM

General remarks

Pennsylvanian strata are present only in the southern half of Montana and can be divided into the Amsden and Quadrant (Tensleep) formations. (Perry, 1945, p. 7).

The Pennsylvanian system in the Tendoy-Beaverhead area comprises both the Amsden and the Quadrant. Although the Amsden contains some beds which are probably Mississippian in age, it will be discussed here, because the greater part of the formation seems to be of Pennsylvanian age (Scott, 1945, a p. 1195).

Amsden formation

Definition. The name Amsden was given by Darton (1904, p. 386) to a series of red shales, white limestones, and cherty and sandy limestones as exposed ih the Bighorn Mountains. The name is derived from the Amsden Branch of the Tongue River, west of Dayton (Wyoming).

Branson (1937, p. 650) proposed to establisha new formation, which he named Sacajawea and which includes all the Mississippian strata of the Amsden. The writer has used the name Amsden and no attempt was made to divide the formation into a Mississippian and a Pennsylvanian part. On a purely lithologic basis the Amsden can be divided into three units.

Distribution and thickness. The Amsden formation has been recognized in Wyoming, where it is rather widespread, and in Montana, where it is found in the southern half of the state.

In the Tendoy-Beaverhead area the Amsden occurs in the Tendoy Mountains. A good exposure is along Big Sheep Creek in sec. 36, T. 13 S., R. 10 W. The Amsden is also found in the northern part of the ridge between Big Sheep Creek Basin and Muddy Creek Basin. In the Beaverhead Mountains a small exposure is at the head of Indian Creek.

In Wyoming near the type locality the thickness of the Amsden varies between 150 and 350 feet. Honkala (1949, p. 36) reports a thin unit of 73 feet.

In the Big Sheep Creek area the Amsden is exceptionally thick as more than 2000 feet were measured. Several parts of the section are covered or poorly exposed so that a repetition of strata due to faulting might have remained unnoticed. This consideration should carry special weight as repetition of strata has been proved in the overlying Quadrant. Only 30 miles to the north in the Armstead area where no local faulting occurs in the underlying or overlying beds, the total thickness is 208 feet. In the McKenzie Canyon area the thickness was estimated to be 300 feet. In other parts of the Tendoy Mountains the estimated thickness does not exceed 400 feet.

Lithologic and stratigraphic features. In the Tendoy-Beaverhead area the Amsden formation consists of a series of gray limestones with interbedded calcareous gray and buff shales and a few beds of argillaceous sandstone.

At the type locality the Amsden formation is commonly covered by talus from the overlying Quadrant (Scott, 1935, p. 1021). The same was noticed in the writer's area. This condition makes it very difficult to establish the true contacts of the Amsden. The Amsden is slope forming and is commonly covered by a relatively thick layer of yellow-brown soil with fragments of gray limestone and buff-colored sandstone.

Most of the limestones are thin bedded and dark gray when fresh, but weather light gray. The characteristic buff, red and brown colors of the Amsden slope are apparently due mainly to the shales and sandstones, which display these colors. The shales are often banded, the darker bands being red or purple, the lighter ones buff.

Gypsum is present in some of the beds, but it does not occur in

commercial quantities as in other regions. Some beds in the Amsden are conglomeratic, as in the Kissick Canyon area where the following units are present (Seglund, 1949, p. 12):

4. Conglomerate, yellow-brown. Quartzite pebbles, light gray, angular and up to three inches in diameter.

3. Limestone, gray, slope forming.

2. Limestone, dark gray, arenaceous with some chert.

1. Sandstone, conglomeratic, buff, pebbles rounded and smooth.

The total thickness of these four units was estimated to be 400 feet. Honkala (1949, p. 35) also mentions a conglomerate in the Amsden in the Centennial area.

Wallace and Krusekopf (1949, p. 10 and p. 13) measured a section of the Amsden along Big Sheep Creek and report a total of 2022 feet of limestones with minor quantities of shale and sandstone. Although the writer believes that too great a thickness was measured, probably due to minor faulting, this section will be given here because it is fairly representative of the formation in this area. Dillon (1949, p. 20) amended it by dividing the Amsden into three units.

Section of the Amsden formation as exposed along Big Sheep Creek, in NW 1/4, sec. 36, T. 13 S., R. 10. W.

	Upper Amsden	Thickness (feet)
29.	Same as unit 27	2
28.	Sandstone, light tan, friable	6
27.	Limestone, dark gray, weathering light gray, fine grained	8
26.	Covered interval	58
25.	Limestone, dark gray, weathering light gray, massive, dense	10
24.	Covered interval	139
23.	Limestone, gray, weathering buff, crystalline, well bedded, numerous bands of dark chert	43

22. Shales, gray, grading upward into brown shales. Upper part of bed covered 398

Darwin (?) member

21. Sandstone, light brown, thin bedded, calcareous. Bedding planes very well developed, some of the beds considerably thicker than others. Weathers in places reddish-purple color 120

20. Sandstone, tan, weathering rusty brown, massive, friable. 24

Lower Amsden

19. Covered interval, mainly Quadrant talus 269

18. Limestone, dark gray, weathering buff, argillaceous, thin bedded, some interbedded chert 12

17. Limestone, dark gray, weathering buff, finely crystalline fossiliferous 38

16. Limestone, gray-brown, weathering buff, finely crystalline fossiliferous. 62

15. Shale, gray, calcareous, numerous pelecypods 80

14. Sandstone, light tan, weathering orange-buff, hard quartzitic 3

13. Shales, gray, calcareous, thin bedded 29

12. Limestone, dark gray, weathering buff, crystalline, productids 21

11. Shales and limestones, gray, alternating, grading upwards into brownish and buff beds 106

10. Limestones and shales, dark gray, weathering light gray, alternating. Limestones, thin bedded and shales, calcareous. Some darker shale members with fragments of gypsum . 245

9. Limestone, medium gray, medium grained, highly fractured . 29

8. Same as unit 6 67

7. Limestone, light to medium gray, weathering buff, finely crystalline, highly fractured, fractures filled with secondary calcite 14

6. Shale, dark gray, weathering light gray, calcareous, some interbedded argillaceous limestones 43

5. Limestone, gray, thin bedded 67

4. Limestone, buff, thin bedded, silty 10

3. Limestone, dark gray, fine grained, petroliferous odor . . 4

2. Shale, gray, weathering lighter gray, thin bedded, calcareous, pelecypods 86

1. Limestones, dark gray, weathering buff, dense, compact . . . 48

Total thickness 2022 feet

Correlation. The contact between the Mission Canyon and the overlying Amsden in the Sheep Creek area seems to be conformable and more or less gradational. A sharp lithologic break exists between the Amsden and the overlying Quadrant formation but the contact is commonly covered by redundant talus. The Quadrant seems to overlie the Amsden formation conformably.

Some of the beds of the Amsden are very fossiliferous and especially pelecypods and brachiopods (Productus sp.) are quite abundant. Also bryozoa and crinoid fragments are present locally, but in most places the beds are barren.

The age of the Amsden is still uncertain. Scott, (1935, p. 1023) first stated that the Amsden was late Mississippian (middle or upper Chester) in age. More recently he considered the Amsden to be mostly early Pennsylvanian (Morrowan) in age (Scott, 1945b, p. 1196) This last age determination is based upon three fusilinid zones. Perry (1945, p. 6) remarks that recent studies have indicated that in south central Montana the Amsden is divisible into a lower part with Mississippian affinities and a higher part with Pennsylvanian affinities.

He correlates the lower part of the Amsden with the lower part of the Minnelusa formation in the Dakotas.

Origin. The Amsden formation represents a marine deposit laid down in a transgressing sea, the lower part of the Amsden in Montana and northern Wyoming being characterized by basal sandstones and shales, and the upper Amsden by limestones (Scott, 1945,b, p. 1196).

Quadrant formation

Definition. The name Quadrant formation was given by Weed (1896) and derived from Quadrant Mountain in the Gallatin Range, in the northwest corner of Yellowstone Park. Peale who gave the names to the Paleozoic formations in the Three Forks Quadrangle after consultation with Weed, applied Weed's name already earlier (Peale, 1893, p. 39). The formation was described by Weed as consisting of white, yellowish and locally pink beds of quartzite, with intercalated beds of drab saccharoidal limestone. The formation was considered to be of late Mississippian and early Pennsylvanian age, but at that time the Quadrant included the beds that now make up the Amsden formation.

More recently Scott (1935, pp. 1011-1032) reworked the Amsden-Quadrant section at the type locality. He states that the Quadrant is the westward extension of the Tensleep as recognized in Wyoming, and that paleontological evidence indicates a Lower Pennsylvanian age. The basal part of the original Quadrant as described by Weed is now included in the Amsden formation. In this report Scott's emended definitions for Amsden and Quadrant are used and the Quadrant is considered to include all the beds above the Amsden and below the Phosphoria.

Distribution and thickness. The Quadrant formation and its equivalent (the Tensleep) are widespread in Montana and Wyoming.

In the Tendoy-Beaverhead area the Quadrant has the same distribution as the underlying Amsden. Hence the Quadrant formation is found mainly in the Tendoy Mountains. It occurs also west of Kate Creek and in the Muddy Hole area. It is present west of Big Sheep Creek Basin in the Beaverhead Mountains, along the north side of Simpson Creek.

At the type section the Quadrant is about 230 feet thick, but as much as 1000 feet are known from southwestern Montana (Scott, 1935, p. 1011 and 1017).

In the Tendoy-Beaverhead area the Quadrant reaches an even greater thickness locally and a maximum of 2636 feet is reported from the Big Sheep Creek area. In the northern part of the Tendoy Mountains, the Quadrant, like the Amsden, seems to be thinner and only 1000 feet were measured in the Armstead area.

Lithologic and stratigraphic features. The Quadrant formation of the Tendoy-Beaverhead area consists mainly of a dense, locally vitreous, quartzitic sandstone, white to tan where fresh and dark brown or red where weathered.

This quartzite is very resistant to erosion and it forms the most conspicuous peaks of the area. Graphite Mountain, Ellis Peak, Dixon Mountain, Timber Butte, and Indian Head Mountain are all capped with the Quadrant quartzite. The formation is well bedded and extensively jointed. These two factors are mainly responsible for the commonly well-developed and characteristic talus slopes, which surround the

various Quadrant peaks. The talus blocks, if not too fresh, are in most places covered by black lichens, which give the steep and bare slopes a dark appearance.

The quartzitic sandstone is thick bedded and cross bedding was observed in some places. It has a fine to medium grained texture, and is locally calcareous. Comparatively thin beds of limestone are found through the whole formation, but are especially abundant in the upper part. The limestone is always moreor less siliceous, as shown by chert nodules which are common.

Microscopic examination (specimen 32E48) shows a rather pure sandstone with ill-sorted, mostly sub-angular, rarely well-rounded, quartz grains ranging in size from 0.1 to 0.5 millimeter in diameter. Secondary quartz occurs in veinlets and irregular blebs, forming a very fine grained mosaic. Some parts are "dirty" because of the large amount of yellow and red iron oxide, which is mostly associated with the secondary quartz mosaics. Besides quartz and a few grains of zircon are noticeable. Less common is feldspar (plagioclase). Some white mica is in the cementing material.

The Quadrant formation as exposed in Big Sheep Creek Canyon was measured by Mr. R. C. Weart of the University of Illinois, who kindly submitted the section to the writer. In this locality the formation seems to be disturbed by local faulting to such an extent that a considerable thickness of strata has beenrepeated. Weart (personal communication) states that complete measurement of the Quadrant shows approximately 4500 feet of rock, and that subtraction of the repeated sequence gives a final thickness of 2636 feet. The repetition of beds can be proved by fossil

evidence (fusulinid zones) but not enough work has been done yet to warrant any definite conclusions. The same microfossil zones were recognized in the Little Sheep Creek area farther south.

Section of the Quadrant formation as exposed along Big Sheep Creek, about one mile south of the Range station. Sec. 35, T. 13 S., R. 10 W., measured by R. C. Wear.

		Thickness feet	inches
23.	Limestone, black, shaly, dense, phosphatic	11	6
22.	Sandstone, light gray to white, medium grained	16	
21.	Limestone, dolomitic, light gray, white and blue chert nodules and bands	11	3
20.	Siltstone, gray, calcareous	1	6
19.	Sandstone, white	6	3
18.	Limestone, gray, arenaceous at top, few gray chert nodules	43	
17.	Sandstone, yellow, very cherty, large crinoid stems	3	
16.	Chert, blue, bedded, fossil fragments	1	6
15.	Limestone, tan and silty. Chert, gray. Grades downward into tan sandstone and chert. Sandstone dominant at base	24	
14.	Sandstone, tan to white, medium bedded	13	
13.	Limestone, brown to gray. Upper part contains abundant gray chert nodules	32	
12.	Sandstone, white, cross bedded, very calcareous, fine to medium grained	22	
11.	Sandstone, tan, massive to medium bedded, slightly quartzitic, fine to medium grained	97	
10.	Chert, blue to white, bedded, abundant fusulinids	1	9

9. Sandstone, tan to white, fine to medium grained thin to massive bedded, some cross bedding 215

8. Shale, gray to black. Thin beds of blue-white chert about 1 inch thick intercalated in the shale. Fusulinids 22 6

7. Limestone, dark to light gray, thin bedded, contains blue and white chert nodules 23

6. Covered interval. Composed of 6 feet of sandstone at the base, and apparently chert, sandstone and limestone beds above 20

5. Sandstone, white to tan, some beds quartzitic 110

4. Sandstone, gray, white, brown, weathers red, massive to thin bedded, fine to coarse grained, cross bedded in part 406

3. Mostly covered, sandstone, white, buff, brown, red. Massive to thin bedded, fine to coarse grained, cross bedded in part 1445

2. Dolomite, light gray, thin bedded, few thin bands of brown and blue-white chert 15

1. Sandstone, tan to white, friable, massive to thin bedded 105

Total measured 2636

Correlation. A sharp lithologic break exists between the Amsden and the Quadrant, but no angular unconformity is indicated. No unconformity of any sort and no lithologic break exists between the Quadrant and the overlying Phosphoria. Deposition may have been continuous. In the Big Sheep Creek section there is a noticeable change in the lithologic characteristics above unit 12, but Weart hesitates to draw the top of the Quadrant formation at the top of this unit. At present he prefers to place the boundary between the Quadrant and the Phosphoria at the top of unit 23 (personal communication).

The quartzitic facies of the Quadrant formation is commonly without any fossils, but poorly preserved brachiopods and crinoid columnals are present in some places. Of more importance for the age determination are the microfossils of the calcareous zones (Weart, personal communication). In the Big Sheep Creek section there are several horizons containing fusulinids.

Scott (1945, II. p. 1196) also mentioned foraminifera (Fusulinella, Wedekindellina) from the Quadrant and established the age of the formation as late Lower Pennsylvanian (Des Moines). In Idaho and southward the Quadrant thickens and is called the Wells formation. The Rocky Mountain quartzite of British Columbia can be correlated with the Quadrant. In southeastern Montana and northeastern Wyoming the Minnelusa formation is equivalent in age. The quartzite facies of the Quadrant grades eastward into 50 to 100 feet or more of cross-bedded, friable sandstone and in south central Montana and central Wyoming is called the Tensleep formation (Perry, 1945, p. 7).

Origin. The Quadrant formation is clearly of marine origin as evidenced by the faunal content. The large amount of clastic material suggests the presence of crustal activity. No beds younger than the Quadrant are recognized in northern Wyoming and southern Montana, but farther west Upper Pennsylvanian strata are present in geosynclinal facies (Scott, 1945b, p. 1196).

General remarks

In Montana no Permian strata have been recognized north of the Yellowstone River (Perry, 1945, p. 8). In southwestern Montana the Permian is represented solely by the Phosphoria formation. More to the west in Idaho a great volcanic series makes up part of the Permian (Casto volcanics).

Phosphoria formation

Definition. Richards and Mansfield (1912, pp. 683-689) were the first to apply the name Phosphoria formation. They established a type locality. The strata were described as phosphatic shales with some thin limestones and at the top the Rex chert member. The formation was named after Phosphoria Gulch, near Meade Peak (Idaho). It overlies the Pennsylvanian Wells formation of Permian age.

Because of its economic importance the Phosphoria has been the subject of many investigations. A bibliography listing every reference to the Phosphoria prior to 1930 has been compiled by Branson (1930).

Distribution and thickness. The Phosphoria is found in northeastern Utah, eastern Idaho, central western, central southern, and southwestern Montana, and western Wyoming (Wilmarth, 1938, p. 1651).

In the Tendoy-Beaverhead area the formation crops out in the Tendoy Mountains and the area north of Horse Prairie. The Phosphoria occurs in the Muddy Creek-Big Sheep Creek area and is part of the sequence of strata which form the Little Water syncline. This occurrence is usually referred to as the Dell Phosphate field. The Phosphoria is also found in the extreme northern part of the Tendoy Mountains.

At the type locality the thickness of the Phosphoria is 415 feet (Branson, 1930, p. 9). In southeastern Idaho and northeastern Utah the thickness varies from 75 to 627 feet.

In the Little Water syncline the Phosphoria is much thicker and 830 feet were measured by Lowell (McKelvey, 1949, p. 273). More to the east

the formation becomes thinner and Honkala (1949, p. 39) reports a thickness ranging from 80-600 feet. Also in the northern part of the Tendoy Mountains the thickness is less than in the southern part, as 400 feet of Phosphoria are found in the Armstead area.

Lithologic and stratigraphic features. The Phosphoria formation of the Tendoy-Beaverhead area consists mainly of carbonate rocks with interbedded minor amounts of sandstone, siltstone and shale. Chert beds are especially common in the upper part of the formation but also the lower limestones contain much chert. The formation is noted for its phosphorus content. The phosphatic rock is intercalated in the phosphatic shales which occur at two principal horizons in the series. Recent investigations by the United States Geological Survey indicate that the Phosphoria in southwestern Montana can be divided into five units (McKelvey, 1949, p. 274):

Unit E: Chert member
Unit D: Upper phosphatic member
Unit C: Upper carbonate member
Unit B: Lower phosphatic member
Unit A: Lower carbonate member

The Rex chert member of the type locality is not found as such in the Tendoy Mountains, but is represented by unit E, which consists of about equal amounts of shale and chert beds.

The various members of the Phosphoria formation show different resistance to erosion. The shaly members and phosphate rock are easily attacked, are slope-forming and covered by soil and grass. The cherty limestones on the other hand are more resistant and form ledges. As a whole the formation is less resistant than the underlying Quadrant and does not form high mountains but occurs in valleys.

The limestones are light gray to buff. Some of the members of the

Phosphoria can easily be mistaken for Madison limestone. In the Little Water syncline a rock outcrop, which superficially resembled the Madison, was assigned to the Phosphoria on faunal evidence. Bedding in the limestones of the Phosphoria is not very conspicuous. The sandstones which are found intercalated in the limestones are commonly brown, calcareous and fine grained. The shales in which the phosphate beds occur are black to brown and more or less phosphatic. They are very petroliferous, will burn when lighted, and are properly termed oil shales as they contain no free liquid petroleum but only hydrocarbons in the solid state (kerogen), which can be freed only by distillation. The interbedded phosphate layers are dark colored and locally distinctly oölitic. The bluish-white phosphorus bloom on the weathered surface of the phosphate rock, shale, and phosphatic chert, is very characteristic. It aids in detecting the phosphatic members which are commonly covered by means of the float.

Condit (1919, pp. 23-24) measured a detailed section probably of the upper phosphatic shale member as exposed in a prospect drift 1200 feet above the north side of Big Sheep Creek Canyon. Although the exact stratigraphic position in the Phosphoria is unknown, the section will be repeated here to illustrate the relationships between phosphate rock and other strata.

Partial section of the Phosphoria formation as exposed 1200 feet above Big Sheep Creek in prospect tunnel sec. 35, T. 13 S., R. 10 W. Measured by Condit, U. S. Geological Survey.

	Thickness Feet	Inches
Tunnel mouth		
22. Phosphate rock, oölitic	2	0
21. Clay shale	-	3

20.	Phosphate rock, oölitic	1	3
19.	Clay, hard, gritty	1	6
18.	Shale, dark brown	5	0
17.	Clay shale, gray	1	0
16.	Shale, black	-	8
15.	Phosphate rock	1	0
14.	Shale, black	1	2
13.	Clay, gray, gritty	1	6
12.	Phosphate rock, gray	-	9
11.	Shale, black	1	0
10.	Clay, hard, gritty	1	3
9.	Shale, black	1	0
8.	Clay shale, gritty	3	2
7.	Shale, black	1	8
6.	Phosphate rock	-	5
5.	Clay, hard, gritty	-	9
4.	Phosphate rock, black, oölitic	1	1
3.	Shale, black	1	3
2.	Clay, brown, gritty	2	2
1.	Shale, black back end of tunnel	-	6
	Total measured	33	2
	Total phosphate rock	6	6

A complete section of the Phosphoria in the Dell area was measured by Lowell. It was published in graphic form (McKelvey, 1949, p. 273), but could be worded as follows:

Section of the Phosphoria formation as exposed in Big Sheep Creek Canyon, Tendoy Range. Measured by W. R. Lowell (U. S. Geological Survey).

	Unit E	Thickness feet
54.	Mudstone	25
53.	Mudstone, cherty	25
52.	Limestone, sandy	15
51.	Chert	55
50.	Mudstone	40
	Total thickness, Unit E	150
	Unit D	
49.	Mudstone	20
48.	Phosphate rock	1
47.	Mudstone	3
46.	Phosphate rock	1
45.	Mudstone	3
44.	Mudstone, phosphatic	8
43.	Mudstone	12
42.	Mudstone, phosphatic	10
41.	Phosphate rock	1
40.	Mudstone, phosphatic	12
	Total thickness, Unit D	71
	Unit C	
39.	Limestone	25
38.	Limestone, sandy	10
37.	Limestone, cherty	40
36.	Limestone, sandy	35
35.	Limestone, cherty	15
34.	Limestone, sandy	40

33. Limestone, sandy 40

Total thickness, Unit C 205

Unit B

32. Mudstone, calcareous, phosphatic, contains chert 40
31. Phosphate rock 2
30. Mudstone, calcareous, phosphatic 8
29. Phosphate rock 2
28. Mudstone, phosphatic 7
27. Phosphate rock 1

Total thickness, Unit B 60

26. Limestone 10
25. Mudstone 5
24. Limestone 10
23. Mudstone, calcareous 35
22. Mudstone, sandy 5
21. Mudstone 35
20. Mudstone, calcareous 4
19. Mudstone 2
18. Mudstone, calcareous 4
17. Chert 10
16. Limestone, cherty 5
15. Sandstone 5
14. Limestone, sandy 15
13. Limestone 8
12. Phosphate rock 2
11. Limestone, cherty 25

10.	Limestone	20
9.	Mudstone	5
8.	Limestone, sandy	20
7.	Limestone, sandy, with chert	20
6.	Limestone, sandy	10
5.	Limestone	20
4.	Limestone, cherty	35
3.	Limestone, sandy	10
2.	Limestone, cherty	20
1.	Limestone	15
	Total thickness, Unit A	345
	Total thickness, Phosphoria	831

The economic implications of the presence of certain rare elements , phosphorus and oil in the Phosphoria formation will be discussed in the chapter on Economic Geology.

Correlation: In the Big Sheep Creek area the Phosphoria conformably overlies the Quadrant and no sharp lithologic break separates the two formations. Deposition may have been continuous in this area and the base of the Phosphoria is uncertain (Weast, personal communication). The contact between the Triassic Dinwoody formation and the underlying Phosphoria is easier established, but no unconformity of any sort seems present.

About the fauna of the Phosphoria formation Branson (1930, pl 14) writes: "The Phosphoria exhibits an extensive vertical faunal variation in itself. The variation is attributable in large part to faunal facies, rather than to development with age. The faunas of the phosphate beds

are unlike those of the other members because of the peculiar conditions of the water in which the animals lived. The oölitic phosphate beds are of syngenetic origin for their faunas are typically depauperate. " In the Tendoy-Beaverhead area relatively few well-preserved fossils were found. Most of the fossil material is fragmental and consists of brachiopods, bryozoa, crinoid columnals, sponge spicules, and corals. Two brachiopods, a Productus sp. and Bucsonia sp., were identified. Both were collected from SW ¼, sec. T.13 S., R. 10 W. From the Lima Peaks area a few miles to the south Dillon (1949, p. 28) reports the following brachipods: Pustula nevadensis Echinoconchus nevadensis (Meek), Composita parva Branson, Composita plana Branson.

The Phosphoria formation is usually assigned to the Permian period. Branson (1930, p. 14) believes that the lower part is of Pennsylvanian and the upper part of Permian age. The youngest beds are assigned to the Middle Permian (Guadalupian) by Miller and Cline (1934, p. 284). Exhibiting a different facies but supposedly of approximately the same age are the Minnekahta and Opeche formations in eastern Wyoming and southeastern Montana. These strata resemble the overlying Spearfish and in some places the underlying Minnelusa (Perry, 1945, p. 8). In southern Montana the Embar formation and in British Columbia the uppermost part of the Rocky Mountain quartzite are about equivalent in age to the Phosphoria. Correlations which seem to be well established are with the Manzano formation in New Mexico and with the Forelle formation of the Laramie Basin in southeastern Wyoming (Branson, 1930, p. 23).

Origin. The Phosphoria formation is of marine origin as indicated by its faunal content. Sedimentation took place over a long period, as

the formation consists mainly of limestone, chert, mudstone, and phosphate rock which are deposited slowly. Also the thinness of the formation combined with the long time during which sedimentation took place as evidenced by the faunas, indicates the slow accumulation of material (Branson, 1935, p. 14).

The origin of the phosphate rock is not yet clear but Mansfield (1931, pp. 366-369) suggested the following process. Sedimentation took place on the bottom of the sea where foul conditions prevailed. No scavengers removed the organic remains of the mostly soft-bodied animals and anaerobic bacterial decay was promoted. Decomposition products like carbon dioxide and ammonium phosphate were readily produced. The sea bottom was therefore rich in phosphate solutions or perhaps in phosphate colloids. From these were formed the oölites, probably by bacterial action. The formation of oölites fixed the phosphoric acid of the sea bottom in the form of relatively insoluble calcium phosphate. More recently Mansfield (1940, p. 877) suggested that fluorine might be an active agent in turning phosphoric acid into phosphates. Fluorine is one of the minor constituents of phosphate rock. The oolites were eventually aggregated and cemented into the present phosphate beds.

The sea in which the Phosphoria was deposited came from the north and west rather than from the southwest as in previous innundations (Manfield, 1931, p. 360). It was relatively shallow and surrounded by low-lying lands, whose oscillations were reflected in the sedimentation of the Phosphoria. In northeastern Utah and southeastern Idaho the sea was deepest and remained longest (Branson, 1930, p. 23). The sediments deposited in southwestern Montana were probably derived from the east.

TRIASSIC SYSTEM

General remarks

No Triassic strata have been recognized in northern Montana. In central, eastern, and southern Montana the Triassic appears in a continental facies. From east to west it grades into marine sediments in western and southwestern Montana (Perry, 1945, p. 8).

In the Tendoy-Beaverhead area the Triassic system was subdivided into three formations of lower Triassic age. These are in ascending order: Dinwoody, Woodside, and Thaynes. In most areas of Montana where the Triassic has been recognized it was mapped as one unit and called Woodside formation. However, the present field investigations show that three mappable units can be distinguished on the basis of lithology. It is difficult to establish the exact boundaries between them.

In this report the writer follows the divisions of the Triassic as employed by Newell and Kummel (1942, pp. 937-996). The Triassic of southwestern Montana is the subject of a detailed study by Moritz (now at Dartmouth College), but the results have not yet been published.

The Dinwoody, Woodside, and Thaynes together can be correlated with the Moenkopi formation of Arizona and southern Utah, and the Candelaria formation of Nevada (Kellum, 1948, chart).

Dinwoody formation

Definition. The Dinwoody formation of lower Triassic age was named by Blackwelder (1918, pp. 425-426) from exposures in Dinwoody Canyon in the Wind River Mountains near Du Bois, Wyoming. As originally defined

the formation consists of 200 feet of pale-green to white clay and shaly limestone, weathering brown. The lower boundary was the top of the Phosphoria and the upper limit was defined by the bright red shales and siltstones of the Chugwater formation.

However, Newell and Kummel (1942, p. 941) showed that the change from grey to red beds does not follow a stratigraphic plane, but varies in position from place to place. They therefore proposed to include only dominantly silty strata between the Phosphoria and the top of resistant siltstones about half way toward the summit of the original Dinwoody. Thus defined the Dinwoody is 90 feet thick at the type locality. The same investigators divided the Dinwoody into three members which are in ascending order: Basal siltstone, Lingula zone, Claraia zone. Because of the poor exposures in the writer's area no such subdivision was attempted, although some of the fossils may be clearly assigned to one of these zones.

Distribution and thickness. The Dinwoody formation has been recognized in southwestern Montana, southeastern Idaho, and western Wyoming. In the Tendoy-Beaverhead area the Dinwoody is exposed in the Tendoy Mountains and on the west flank of the Armstead anticline. A complete Triassic sequence is present in the Little Water syncline. A good exposure of the limestone members of the Dinwoody is along Little Water Canyon road in S 1/2, sec. 2, T. 13 S., R. 10 W. In the northern part of the Tendoy Mountains only the Dinwoody was recognized. It is, however, possible that other Triassic formations also are present there but they were not discovered because of poor exposure. The exceptional thickness of Dinwoody measured in the Armstead area (800 feet) suggests this.

Henkala (1949, p. 45) reports 358 feet from the Gravelly Range. Less than 190 feet were measured by Dillon (1949, p. 33) southwest of Lima.

In the Little Water syncline approximately 200 feet are present.

Lithologic and stratigraphic features. The Dinwoody in the area of this report is dominantly a series of limestones and interbedded shales.

The limestones are somewhat more resistant and form ledges, but the shales, and in some places the limestones too, weather easily into slopes. The limestones are evenly bedded. The beds are about a foot thick. Between the limestones are thinner bedded shales or siltstones. The limestones commonly contain a great amount of argillaceous material, and the main difference in appearance between the limestones and siltstones is the thickness of the bedding. Both have a gray to light-brown color on a fresh surface, but more characteristic is the chocolate-brown color of the weathered surface. Also the soils that cover the slopes of the Dinwoody exhibit this typical dark brown color.

The section of the Dinwoody formation given below was measured in the Little Water syncline by the field party of Lipp and Becker (1948). The upper limit of the Dinwoody was determined on the basis of lithological characteristics. As a result of the work of Dillon (1949, p. 30-45) this boundary has been placed much lower. Dillion's conclusions are based on the finding of some ammonites in what was supposedly Dinwoody in an area southwest of Lima. These ammonites were identified as from the Thaynes formation. Most of the strata formerly assigned to the Dinwoody and Woodside in this general area therefore belong really to the Thaynes. In view of this new evidence the writer has emended the Triassic sections measured by Lipp and Becker in the Little Water syncline. The lithologic

sequence of the Triassic as a whole remains unchanged, but new boundaries were drawn between the various formations. These new boundaries are based on the sections as given by Dillon (1949, p. 33, 35, 36).

Section of the Dinwoody formation as exposed in W ½, Sec. 26, T. 13 S., R. 10 W. Measured by Lipp and Becker

		Thickness (feet)
7.	Same as unit 5	2.0
6.	Covered interval. Shaly slope	7.0
5.	Limestone, weathers reddish, one foot thick, white beds interbedded with thin shale partings, ...	4.0
4.	Calcareous shale, brownish-red, weathers red and tan, thin bedded	44.1
3.	Covered interval	10.0
2.	Limestone, gray, weathers reddish-brown, slightly conglomeratic, thin bedded, cliff former	153.7
	Total thickness	225.8

Correlation. In the Tendoy Mountains no physical evidence of an unconformity was recognized between the Phosphoria and the overlying Dinwoody. This apparently conformable relationship seems to be common, although a hiatus of considerable magnitude involving all of the Capitan and the Ochoa is assumed between the Middle Permian Phosphoria and the early Triassic Dinwoody (Newell and Kummel, 1942, p. 938). On a regional scale a marked overlap of the Dinwoody on the underlying Phosphoria becomes evident. The Woodside formation conformably overlies the Dinwoody.

Some beds of the Dinwoody are quite fossiliferous and the following fossils were collected (identification by Dr. L. B. Kellum):

1. From Little Water Canyon in S. ½ sec. 2, T. 13 S., R. 10 W., collected by Wallace and Smith.

Brachiopods : Lingula borealis Bittner

Pelecypods: Claraia clarai (Emmrich)

2. From the narrow gulch on the western side of Indian Head Mountain in W ½, sec 3, T 10. S., R. 11 W. Collected by Elmer and Gillespie.

Brachipods: Lingula borealis Bittner

Pelecypods: Pseudomonotis (Eumorphotis) ? sp.
Eumorphotis multiformis ? Bittner
Monotis ? sp.
Anodontophora (Myacites) canalensis Catullo
Myalina sp. ?
Lima ? cf. Lima striata Schlotheim

Cephalopods: Ophiceras (Leptophiceras) dubium ? Spath
Ophiceras (Leptophiceras) cf. subplatyspira Spath
Orphiceras subdemissum ? Spath

These fossils, all of which come from the lower part of the formation, indicate that the strata belong to the Dinwoody. The mere presence of Lingulas, however, is not as previously assumed by workers in this general area. Dillon (1949, p. 34) has observed Lingulas in several places in the Thaynes limestones. However, these fossils are more abundant in the Dinwoody and the associated fossils listed above show that beds belonging to the Dinwoody occur in the writer's area.

According to Newell and Kummel (1942, p. 938) the marine invertebrate fauna of the Dinwoody is of Lower Triassic age (Scythian stage) and has a marked affinity with the Otoceras-fauna from east Greenland. Regarding the stratigraphic relationship of the Dinwoody formation and the Woodside there is considerable confusion and the correlation will be discussed under the heading Woodside formation.

Origin. The faunal content of the Dinwoody indicates its marine origin. The sediments were deposited in a sea which advanced from the

west and the south over an exceedingly flat surface. The sea was very shallow as shown by the great number of Lingula shells (Newell and Kummel, 1942, p. 954 and 953).

Woodside formation

Definition. The Woodside formation was named by Boutwell (1907 p. 446) after Woodside Canyon in the Park City mining district, northeastern Utah. The formation underlies the Thaynes and overlies the Permian Park City formation (Phosphoria) at the type locality. It is of early Triassic age. It is composed from bottom to top of fine-grained, thinly bedded, dark-red shales.

The red beds of the type locality seem to grade into non-red rocks, north of Montpelier, Idaho. Newell and Kummel (1942, p. 945-947) believe that not enough is known about this gray facies to justify the erection of a separate formational unit at this time. "Red" beds are in the writer's area and the Woodside in the Little Water syncline probably belongs to the red facies of Newell and Kummel.

Distribution and thickness. The Woodside formation is present in northeastern Utah, southwestern Wyoming, southeastern Idaho and southwestern Montana.

In the Tendoy-Beaverhead area the Woodside is poorly exposed. It was not recognized in places other than the Little Water syncline, but may be present especially in the Armstead area where the Dinwoody formation is represented.

At the type locality the thickness is a little more than 1000 feet. Honkala (1949, p. 48) reports 564 feet from the Gravelly Range.

To the south in the Red Conglomerate Peak area Dillon (1949, p. 35) found 136 feet.

In the Little Water syncline about 125 feet were measured.

Lithologic and stratigraphic features. The Woodside formation consists of a series of shales with subordinate limestones.

The shales comprise the major part of the section, are poorly exposed and in most places covered by soil. Brown is the prevailing color, but at the top of the formation some of the shales are red. The shales are more or less calcareous and some reddish limestones occur near the base.

The following section was measured by Lipp and Becker:

Section of the Woodside formation as exposed in the Little Water syncline W ½, sec. 26, T. 13 S., R. 10 W.

		Thickness (feet)
9.	Covered interval	25.7
8.	Same as unit 6	6.3
7.	Covered interval	23.4
6.	Limestone, gray-brown, weathers reddish, interbedded with shale partings, forms a ledge	9.3
5.	Covered interval	39.8
4.	Same as unit 2	2.0
3.	Covered interval	6.0
2.	Shaly limestone, reddish on fresh and on weathered surfaces, massive	3.0
1.	Covered interval, shaly slope	7.0
	Total thickness	122.5

Correlation. The Woodside formation conformably overlies the Dinwoody in the Little Water syncline. The Thaynes conformably over-

lies the Woodside.

No fossils were found in the Woodside of the Tendoy-Beaverhead area. Also in other areas the formation seems to be barren, at least its red facies (Newell and Kummel, 1942, p. 951)

The Woodside has been assigned to the Lower Triassic (Scythian stage, Otoceras and Genodiscus zones) on the basis of stratigraphic evidence (Newell and Kumel, 1942, p. 949). The Dinwoody is perhaps equivalent in age with the lower part of the Woodside in the type area. These lower beds grade into the Dinwoody formation. The higher Woodside beds overlap on the Dinwoody farther north. The Dinwoody cannot be regarded as a member of the Woodside formation, because the Dinwoody (fossiliferous non-red unit) and the Woodside (non-fossiliferous red unit) are too different to be put in one formation (Newell and Kummel, 1942, p. 947).

The Dinwoody and Woodside together can be correlated with the Grayling formation in British Columbia (Kellum, 1948, chart). In western Wyoming and southern Montana the Dinwoody is overlain by red beds referred to as Red Peak, Chugwater or Red Woodside. These beds belong to the same facies as the type Woodside but correspond stratigraphically only to the upper part of the type Woodside. These red beds between the Dinwoody and the Thaynes are regarded as a northeastern tongue of the Woodside (Newell and Kummel, 1942, p. 947). The red Woodside of the Tendoy-Beaverhead area apparently belongs to this tongue and therefore is to be correlated with part of the Chugwater and Red Peak formations. Perry (1945, p. 8) correlates the Dinwoody and Woodside with the lower part of the Spearfish formation in eastern Wyoming and southeastern Montana.

Origin. The origin of the red facies of the Woodside formation is uncertain. Most of the red beds have been classified as marine by Branson (1927, p. 630), whereas Reedside (1929, p. 62) advanced arguments for a possible non-marine (aeolian) origin. The Woodside formation is so poorly exposed in the Little Water Canyon area that no conclusions as to its origin can be drawn.

Thaynes formation

Definition. The name Thaynes formation was first employed by Boutwell (1907, p. 439) to an essentially calcareous formation overlying the Woodside and underlying the Ankareh formation. In the type section, the Park City mining district (Utah), limestones, calcareous sandstones, normal sandstones and shales are grouped into two parts separated by a red shale member. Most of the true limestones are found in the upper part and the sandstones predominate in the lower part, although each type is found throughout. The formation was named after Thaynes Canyon where it is well exposed. It is of Lower Triassic age.

The name Thaynes is also used in Idaho and Wyoming where Kummel (1943, p. 319-321) was able to divide the formation into seven units. The lowest of these is the Meekoceras-limestone which contains abundant cephalopods of the Meekoceras type. This limestone is now commonly considered the base of the formation.

Distribution and thickness. The Thaynes is found in northeastern Utah, southwestern Wyoming, southeastern Idaho and southwestern Montana.

In the Tendoy-Beaverhead area it was recognized only in the Little Water syncline. The best outcrops are on the north side of the road and on the divide to Muddy Creek Basin. At this last locality the gray

limestone superficially resembles the Madison limestone but can be distinguished from it with the aid of its fossil content.

In the Park City mining district the formation attains a thickness of 1190 feet (Boutwell, 1907, p. 439). In Gros Ventre Canyon (Wyoming) only 400 feet were reported by Newell and Kummel (1942, p. 968). Honkala (1949, p. 50) found 138 feet in the Centennial region. The much greater thickness of 1940 feet was measured by Dillon (1949, p. 41) in the Red Conglomerate Peaks area, southwest of Lima.

In the Little Water syncline the Thaynes is little more than 1000 feet thick.

Lithologic and stratigraphic features. In the Tendoy Mountains the Thaynes formation consists of a series of limestones and calcareous siltstones.

The limestone is well exposed and forms a prominent cliff on the divide between Little Water Canyon and Muddy Creek Basin. On the north side of the syncline the limestone beds form a series of conspicuous "flatirons." The siltstones between the limestones are more easily eroded and are slope forming.

The limestones are gray and in places possess a distinctly pinkish to buff hue. They are finely crystalline and massive. Some of the beds seem to be dolomitic, some are sandy. The limestones are favored by the growth of orange lichens. Chert is in some of the higher beds. The siltstones are tan to gray and mostly covered with vegetation.

Section of the Thaynes formation as exposed in the Little Water syncline, W ½, sec. 26, T. 13 S., R. 10 W. (Measured by Lipp and Becker).

		Thickness (feet)
34.	Partially covered interval. Some limestone, tan, thin bedded, silty, some chert	84.4
33.	Limestone, light gray, finely crystalline, weathers with rough surface, fossiliferous	4.5
32.	Limestone, buff, silty, thin bedded, some sandy layers	68.8
31.	Partially covered interval. Some limestone, gray to buff, finely crystalline	50.5
30.	Siltstone, tan, calcareous, some chert	22.9
29.	Limestone, dark gray, weathers to light gray and pitted surface, massive, fine grained	18.3
28.	Partially covered interval. Some siltstone, light gray to buff, calcareous	18.3
27.	Limestone, light gray, crystalline, thin bedded	18.3
26.	Covered interval. Float of some limestone, gray and chert	18.3
25.	Covered interval. Float of some limestone, gray and chert	22.9
24.	Limestone, buff to gray, massive, thin bedded, crystalline, hard, forming prominent ridge	27.5
23.	Covered interval. Float of some siltstone, tan, calcareous, and some chert	27.5
22.	Limestone, light gray to buff on fresh and weathered surface, some pink mottling, massive, coarsely crystalline, resistant, forms prominent ledge, numerous columnals of Pentacrinus sp.	15.0
21.	Covered interval	314.2
20.	Limestone, gray brown, weathers gray, thickly to thinly bedded, forms a prominent ledge with thin covered intervals	32.7

19.	Covered interval	26.8
18.	Limestone, gray brown to chocolate brown, very dense, thick and thinly bedded	21.0
17.	Shaly limestone, gray, weathers reddish brown, sandy, thinly bedded	4.7
16.	Covered interval	37.4
15.	Limestone, gray, weathers dark gray, hard, massive	4.7
14.	Covered interval	2.0
13.	Limestone, gray, weathers dark gray, shaley	1.0
12.	Covered interval	14.0
11.	Limestone, gray, weathers dark gray, dense, hard	2.0
10.	Covered interval with limestone bed in the middle	9.3
9.	Limestone	1.0
8.	Covered interval	4.7
7.	Limestone, gray, weathers buff, shaly	6.0
6.	Covered interval	18.7
5.	Limestone, gray, weathers dark gray, massive	1.0
4.	Covered interval	14.0
3.	Limestone, gray, weathers reddish, thinly bedded	6.0
2.	Covered interval with three-foot limestone bed in the middle, float shaly	14.8
1.	Limestone, brownish red, weathers red to brown, thinly bedded, shaly, fossiliferous, some small shale partings, forms prominent ledge	63.9
	Total thickness	1002. 1

Correlation. The Thaynes formation conformably overlies the Woodside. It is overlain by Middle Jurassic strata with apparent conformity, although all of the Middle and Upper Triassic and Lower Jurassic is absent.

The Meekoceras-zone in the type area occurs in 5 to 15 feet of strata comprising the upper third of the basal limestone of the Thaynes (Kummel, 1943, p. 321). The remainder of the limestone unit contains no cephalopods. The Meekoceras zone was not observed in the Tendoy-Beaverhead area, but fossils belonging to this zone were found by Dillon (1949, p. 41) a few miles to the south. The limestone in which they had previously been assigned to a lower part of the Triassic section. The only Thaynes fossils in the Tendoy-Beaverhead area were abundant Pentacrinus sp. columnals. These occur in the upper part of the section.

The Thaynes is assigned to the Lower Triassic (Scythian) and is equivalent in age to the following standard faunal zones: Meekoceras-zone, Tirolites-zone, Columbites-zone (Newell and Kummel, 1942, p. 949). The Thaynes formation has been correlated approximately with the Spearfish formation of the Black Hills (South Dakota). The Alcova limestone together with the Popo Agie formation of west central Idaho are also believed to be the same age as the Thaynes, (Kellum, 1948, chart).

Origin. The Thaynes is undoubtedly of marine origin as is demonstrated by its fauna.

JURASSIC SYSTEM

General remarks

Marine Jurassic strata similar to those in Wyoming and Alberta are found throughout Montana (Perry, 1945, p. 9). These strata were until recently designated as the Ellis formation. In 1945 Cobban divided the Ellis of the Sweetgrass Arch area into three units to which he gave formational rank, thereby raising the Ellis to the rank of a group. He established the following division:

Swift formation
Rierdon formation } — Ellis group
Sawtooth formation

This nomenclature will be followed in the present report. The distribution of marine Jurassic rocks in Montana and the paleogeography of this region during the middle part of the Jurassic is discussed by Imlay and others (1948). The Ellis group is of Middle and Upper Jurassic age. Overlying the Ellis group in the Tendoy-Beaverhead area are continental beds of Upper Jurassic age belonging to the Morrison formation.

Sawtooth formation

Definition. The name Sawtooth formation was first employed by Cobban (1945, p. 1263) to designate the oldest unit of the Ellis group. The name Ellis was used previously in the sense of a formation by Peale (1893, Pl. 1) who gave the name after Fort Ellis, a few miles southeast of Bozeman, Montana. Cobban (1945, p. 1270) established the type section of the Sawtooth formation in Rierdon Gulch in the W 1/2 sec. 23, T. 24 N., R. 9 W., Sawtooth Range, Montana. The formation is named from the Sawtooth Range in which it is well developed and

exposed.

The formation is of Middle Jurassic (Bajocian and Bathonian) age and consists of a basal fine-grained sandstone, a medial dark gray shale containing a few thin dark limestone layers and an upper highly calcareous siltstone.

Distribution and thickness. The Ellis group is widespread in Montana and northwestern Wyoming. The Sawtooth formation has been described from north central and southwestern Montana.

In the Tendoy-Beaverhead area it crops out in the Little Water syncline, the only place where Jurassic rocks are exposed.

At the type locality the formation has a thickness of 137 feet. In the Centennial Range 138 feet were measured (Honkala, 1949, p. 51). Dillon (1949, p. 47) found 200 feet in an area southwest of Lima.

In the Tendoy Mountains the thickness is 190 feet (Imlay and others, 1948).

Lithologic and stratigraphic features. The Sawtooth formation in the Little Water syncline consists of sandstone, limestone and shale.

The Jurassic rocks in the Tendoy-Beaverhead area are in general not well exposed. The Sawtooth consists for the greater part of rocks that are easily eroded. The formation forms low, rounded hills, which lap onto the more resistant Thaynes limestone. In most places it is covered by a characteristic yellow-brown soil.

Sandstone and sandy limestone occur at the base of the formation. In the basal 1 1/2 feet are chert fragments identical with chert in the underlying Thaynes (Imlay, personal communication). This part of the section is in most places covered.

Shales make up the larger part of the Sawtooth. Most of the shale is calcareous and friable. It is gray to light brown and weathers darker brown with mottled appearance due to white spots on the brown. In some places, light brown, sandy limestone beds are interbedded.

The following generalized section of the Sawtooth formation in Little Water Canyon was kindly submitted to the writer by Dr. R. W. Imlay (U. S. Geological Survey):

Section of the Sawtooth formation as exposed in the Little Water syncline, NE 1/4 SW 1/4 sec. 10, T. 13 S., R. 10 W. Measured by Wayne Lowell and associates.

		Thickness (feet)
3.	Shale, yellowish, silty, interbedded with limestone, sandy	44
2.	Shale, gray, calcareous, splintery	88
1.	Sandstone, gray and limestone, sandy. In basal 1 1/2 feet chert fragments	58
	Total thickness	190

Correlation. The Sawtooth formation concordantly overlies the Thaynes. The contact between the Sawtooth and the overlying Rierdon formation is conformable.

Poorly preserved pelecypods (Ostrea ?, Gryphaea ?) are the only fossils collected.

On the basis of faunal evidence Cobban (1945, p. 1277) assigned the Sawtooth formation to the Middle Jurassic, and more specifically to the upper Bathonian. The Ellis group, as recongized in Montana, can be correlated with the Sundance formation in Wyoming and the

Dakotas (Peay, 1945, p. 9). The Piper formation of eastern Montana is correlative to the Sawtooth (Imlay and others, 1948). The Gypsum Springs formation of north central Wyoming is partly of Bathonian age and is in its upper part equivalent in time with the Sawtooth. The Twin Creek limestone of Wyoming and southwestern Idaho is partly of Middle Jurassic (Bajocian and Bathonian) and partly of Upper Jurassic (Callovian) age, and its lower units are therefore of the same age as the Sawtooth formation (Imlay, 1945, p. 1020).

Origin. The Sawtooth is of marine origin as indicated by its fauna. The marine Jurassic of the interior of North America was deposited in a shallow epicontinental sea, which had but one northwestern connection with the Pacific Ocean (Logan, 1900, p. 273).

Rierdon formation

Definition. The name Rierdon formation was given by Cobban (1945, p. 1277) to a group of alternating gray limy shales and limestones overlying the upper sandy beds of the Sawtooth and underlying the Swift formation. The Rierdon was defined solely on the basis of its lithologic character.

At the type locality in Rierdon Gulch the lower part of the formation is of upper Bathonian age and the remainder of lower Callovian.

Distribution and thickness. The Rierdon has been described from north central, southwestern, central and south central Montana.

It is in the Tendoy Mountains and more specifically in the Little Water Canyon area.

At the type locality the Rierdon is 137 feet thick. In the

Centennial Mountains it has a thickness of 43 feet (Honkala, 1949, p. 52).

In the Tendoy Mountains a thickness of 86 feet was measured by Imlay and others, 1948.

Lithologic and stratigraphic features. The Rierdon formation in the Tendoy Range consists of limestone and shale.

The limestone is fairly resistant to erosion and is well exposed in a small cliff on the north side of Little Water Canyon, where the beds stand nearly vertical. The limestone is grey to buff when fresh and weathers white. It is massively bedded and at the base distinctly oölitic. This limestone is the most conspicuous member of the formation.

The interbedded shales are poorly exposed and have a gray to a light brown color. The following is a generalized section measured by Wayne Lowell and associates and kindly submitted to the writer by Dr. R. W. Imlay.

Section of the Rierdon formation as exposed in the Little Water syncline, N E 1/4, S W 1/4 sec. 10, T. 13 S., R. 10 W.	Thickness (feet)
2. Shale, gray limestone, gray, interbedded	66
1. Limestone, oölitic, gray to buff, massive	20
Total thickness	86

Correlation: The Rierdon formation overlies the Sawtooth conformably. The Swift overlies the Rierdon formation. As the contact between these two formation was not observed, the writer does not know if an unconformity is present on top of the Rierdon. An erosional unconformity is the result of early Divesian erosion has been reported

from the Sweetgrass Arch (Cobban, 1945, p. 1290).

No fossils were collected in the Tendoy Range, nor in areas more to the south. This seems to be due mainly to the poor exposure of the formation, as fossils are abundant elsewhere (Cobban, 1945, 1280).

Different faunal zones indicated upper Bathonian, lower Callovian and middle and upper Callovian age (Middle and lowest Upper Jurassic). The Rierdon formation is equivalent in age to the upper part of the Twin Creek limestone, (Imlay, 1945, p. 1020). The upper part of the Carmel formation of the San Rafael group in eastern Utah is of the same age as the Rierdon formation (Kellum, 1948, chart).

Origin. The Rierdon formation is of marine origin and the rather uniform character of the limestones and shales indicates quiet water deposition (Cobban, 1945, p. 1287).

Swift formation

Definition. The Swift formation was named by Cobban (1945, p. 1281) after Swift Reservoir on Birch Creek where the beds are well exposed. It is the youngest marine Jurassic unit of the Sweetgrass Arch and consists of dark gray, non-calcareous shale overlain by glauconitic flaggy sandstone.

Distribution and thickness. The Swift has been described from north central, southwestern, central and south central Montana.

In the Tendoy-Beaverhead area Swift beds occur in the Little Water syncline. Because of the thinness of the formation in this locality and its poor exposure, it is not readily recognized. It is exposed in a trench recently dug by the U. S. Geological Survey with

the special purpose to explore the Jurassic section. This trench is in NE 1/4 SW 1/4 sec. 10, T. 13 S., R. 10 W. (Imlay, personal communication).

At the type locality the thickness of the Swift is 135 feet. In the Gravelly Range the formation is considerably less thick and only 21 feet were measured by Honkala (1949, p. 52).

In the Little Water syncline, the westernmost exposure, the thickness is even less and not more than 10 feet are reported (Imlay and others, 1948).

Lithologic and stratigraphic features. The Swift was not recognized by the author, but is mentioned here because it is part of the Jurassic section measured by Lowell and associates in Little Water Canyon (Imlay and others, 1948).

In the Tendoy Mountains the Swift consists of a sandstone which is highly glauconitic.

Correlation. The Swift conformably overlies the Rierdon and is conformably overlain by the Morrison.

No fossils have been reported from the Little Water syncline. In other places of Montana ammonites were found. On the basis of these finds the age of the Swift has been determined as Oxfordian and perhaps including some late Callovian (Imlay and others, 1949).

In southeastern Idaho and Wyoming the Stump formation is about equivalent in time to the Swift. In Utah the upper part of the San Rafael group is correlative (Kellum, 1948, chart).

Origin. A high glauconite content is characteristic of the Swift formation. It indicates a shallow sea and at the end of Swift

time the sea retreated entirely from the area.

Morrison formation

Definition. The Morrison formation was named by Eldridge (Emmons and others, 1896, p. 60-62) after the town of Morrison near Denver (Colorado).

At the type locality the formation consists essentially of fresh-water marls, some clays, sandstones and limestones.

In Montana shales make up the greater part of the formation, at the top of which occurs a coal bed.

Distribution and thickness. The Morrison has been described from Colorado, northern New Mexico, and northeastern Arizona, eastern Utah, Wyoming, western South Dakota, central southern and southwestern Montana, western Oklahoma, and western Kansas (?) according to Wilmarth (1938, p. 1423).

In the Tendoy-Beaverhead area the Morrison crops out in the Little Water syncline.

The thickness at the type locality is 200 feet. Honkala (1949, p. 56) reports 181 feet in the Gravelly Range.

In the Little Water Canyon 71 feet were measured by Lowell and associates (Imlay, personal communication).

Lithologic and stratigraphic features. Like the Swift the Morrison was not recognized by the writer. It is now better exposed in a trench and is included in the Jurassic section.

The Morrison of the Tendoy Mountains is typical of the formation in western Montana. It consists of light-yellow to green, soft claystone with a black carbonaceous layer on top (Imlay, personal communication).

Correlation. The Morrison conformably overlies the Swift. It is discordantly overlain by the massive conglomerate at the base of the Kootenai.

It is not known to the writer if fossils have been collected from the Morrison of the Tendoy Mountains. The age of the formation was long questioned (Wilmarth, 1938, p. 1424), but it is now considered to be Upper Jurassic (Kimmeridgian and lower Portlandian) according to Imlay and others (1948).

The Ephraim conglomerate of southeastern Idaho is in part equivalent to the Morrison (Kellum, 1948, chart).

Origin. The Morrison formation is made up of continental strata reflecting the first uplift connected with the Laramide orogeny.

CRETACEOUS SYSTEM

General remarks

After deposition of the Swift formation in the Upper Jurassic the sea finally retreated from southwestern Montana. No marine deposits younger than the Swift are found. Continental deposition started in the Upper Jurassic with the Morrison and continued during the Lower Cretaceous with the Kootenai formation.

No Upper Cretaceous strata are believed to be in the area. In nearby regions the Upper Cretaceous Bear River, Aspen and Mesa Verde formations are found.

Kootenai formation

Definition. The name Kootanie was first applied by Dawson (1885, p. 531) for a thick series of shales, seams of coal, sandstones and conglomerates in southwestern Alberta. The name was derived from a tribe of Indians who hunted over that part of the Rocky Mountains. The formation as defined by Dawson contains a Jurasso-Cretaceous flora and included what is now called the Morrison formation.

The name Kootanie was changed to its present spelling by Fisher (1908, p. 78) who applied the name for coal-bearing strata near Great Falls (Montana). He redefined the boundaries of the Kootenai to exclude the underlying non-coal bearing Morrison shales and the overlying Upper Cretaceous Colorado shale. Thus defined the Kootenai is of Lower Cretaceous (Comanchean) age.

In Canada the spelling Kootenay is used and the formation does not include strata as young as the highest units of the Kootenai (see under Correlation).

Distribution and thickness. The Kootenai formation is found in southern Alberta and British Columbia and is widespread in Montana, except in the southeastern part (Wilmarth, 1938, p. 1119).

In the Tendoy-Beaverhead area it occurs exclusively in the Tendoy Mountains. It is in the core of the Little Water syncline, on the western flank of the Armstead anticline and in the extreme northwest part of the Tendoy Mountains in the Garfield Canyon area.

A thickness of 450 to 475 feet of the Kootenai was recorded in the Great Falls region. Dillon (1949, p. 56) mentions a little more than 1000 feet from the Red Conglomerate Peaks south of Lima. To the east Honkala (1949, p. 59) estimated a thickness of 700 feet.

In the Tendoy Mountains the Kootenai is poorly exposed and accurate measurement of the formation was not possible. The thickness was estimated at about 1200 feet.

Lithologic and stratigraphic features. The Kootenai of the Tendoy-Beaverhead area consists of a basal conglomerate overlain by a series of sandstones and shales with a few intercalated limestone beds. The formation as a shale is not very resistant although some of the harder sandstones and the conglomerate bed stand out as small cliffs in places. Especially in the northern part of the Tendoy Mountains the rounded small ridges made up of Kootenai conglomerate are characteristic. Most other parts of the formation are covered by vegetation.

The conglomerate forms a good marker bed, as it is wide-spread throughout Montana and easily recognized (Bevan, 1929, p. 444). It

contains very well rounded and polished chert and quartzite pebbles and cobbles ranging in size from 1/2 inch to 2 1/2 inches. The color of the conglomerate is dark brown on both the fresh and weathered surface. It is poorly sorted and bedded. The pebbles are embedded in a siliceous cement in which finer sand grains can be noticed. The conglomerate grades into the typical "salt and pepper" sandstones of the Kootenai formation. The following pebble count which included only quartzite and chert, shows that there is a preponderance of quartzite over chert and that darker colored quartzite is more abundant than lighter colored varieties.

Quartzite	white	10%)	
"	gray-green	26%)	
"	dark gray	6%)	62%
"	brown	20%)	
Chert	gray	7%)	
"	brown	15%)	38%
"	black	16%)	

Besides the basal conglomerate at least two other conglomeratic beds were noticed, but these are thinner and less conspicuous than the basal bed.

The sandstones of the Kootenai formation are commonly coarse grained and designated as "salt and pepper" sandstones. These "salt and pepper" sandstones, although typical for the Kootenai, are not confined to that formation. They are also in younger Cretaceous formations, which are not exposed in the Tendoy-Beaverhead area but found nearby. The "salt and pepper" effect of the sandstones is due to the relatively large amount of dark mineral grains such as hornblende, admixed with quartz grains.

The shales of the Kootenai are more or less calcareous and have a reddish-brown, yellow and in places a purple color. They weather easily, forming a reddish-brown soil.

Several limestone beds are interbedded in the shale. One of these is persistent and contains numerous small fresh-water gastropods which make up a coquina-like rock. This "gastropod-layer" in the Kootenai has been described from various places in southwestern Montana, where it forms a useful marker bed. It is only a few feet thick and occurs in the upper part of the Little Water Canyon section. Emmons and Calkins (1913, pp. 32-34) reported a gray limestone with abundant gastropods at the top of the Kootenai in the Philipsburg region.

Partial section of the Kootenai formation as exposed in the Little Water syncline E1/2, sec. 9, T. 13 S., R. 10 W. (measured by Wallace and Krusekopf)

		Thickness (feet)
7.	Partially covered interval. Slope covered with gray and brown shales. Limestone bed, 6 feet thick with abundant gastropods	702
6.	Shale, red	21
5.	Sandstone, light brown to gray, medium grained, friable. Towards top coarser salt and pepper sandstone, generally thin bedded, pebbles of black chert .	36
4.	Shale, variegated red, purple and brown	42
3.	Shale, light gray, hard, sandy	52
2.	Shale, red, calcareous, gastroliths(?)	109
1.	Sandstone, salt and pepper, coarse, limonite concretions, massive	70
	Total measured section	1132

Correlation. The Kootenai unconformably overlies the older Jurassic formations. It is unconformably overlain by the Tertiary Beaverhead Conglomerate.

The only fossils found in the Kootenai are the gastropods from the limestones. The following species were identified: Viviparus montanensis Stanton, Campeloma harlowtonensis Stanton (?), (Dillon, 1949, p. 54). From other areas floras are reported which established the formation as being of Lower Cretaceous age (Comanchean). According to Perry (1945, p. 10) the Kootenai can be correlated with the Cloverly formation as recognized near Gardiner, north of Yellowstone Park. The Kootenai of Montana is equivalent to the Kootenay and the lower part of the Blairmore formation of southwestern Alberta (McLearn and Hume, 1927, p. 241).

Origin. The Kootenai is of continental origin and consists of clastic material laid down on the floodplains and in the channels of rivers at the foot of the rising Cordilleran geanticline to the west (Bartram, 1939, p. 1146). Especially is significant in this respect the widespread occurrence of the conglomerate at the base of the Kootenai. The "gastropod limestones" indicate temporary fresh-water lakes, which occupied great parts of the floodplain.

The Cordilleran geanticline emerged during the upper part of the Jurrassic and the during the Lower Cretaceous. The floodplain deposits which resulted from this uplift are of Upper Jurassic (Morrison) and Lower Cretaceous (Kootenai) age.

TERTIARY SYSTEM

General remarks

All Tertiary sediments are of continental origin in Montana. In the Tendoy-Beaverhead area three units are recognized. The lowest is the Beaverhead formation, the second consists of the "Basin Beds," and the highest comprises the High-level gravels.

After deposition of the Beaverhead formation volcanic activity became important in this part of the country. Volcanic material such as tuffs, flows, and agglomerates makes up part of the "Basin Beds," but will be discussed separately under the heading Igneous Rocks.

Beaverhead formation

Definition. The name Beaverhead formation is new and has not yet appeared in publications. It will be used by W. R. Lowell and M. R. Klepper, who have a paper on the formation in preparation. The Committee on Geologic Names of the U. S. Geological Survey has now authorized the name Beaverhead formation for the conglomerates and associated fine-grained rocks in southwestern Montana (Lowell, personal communication). The Beaverhead is probably of early Tertiary age. As far as the writer knows no definite type section has been selected yet. The name is derived from Beaverhead County, where extensive outcrops of the formation are found.

Prior to the official acceptance of the name Beaverhead, the name "Red Rock" was used for the conglomeratic assemblage by field parties of the University of Michigan and by other workers. This name was derived from Red Rock Valley, where the red conglomerate is conspicuously

exposed at several places. Although the name "Red Rock" seems more appropriate for this formation, which consists chiefly of red rock, its use is discontinued because it has already been applied to a Pennsylvanian sandstone in Iowa (Wilmarth, 1938, p. 1788).

Distribution and thickness. The Beaverhead formation crops out over at least 400 square miles in Beaverhead County and extends eastward into Madison County, Montana (Lowell, personal communication). It is found discontinuously over 3000 square miles in southwestern Montana (Honkala, 1949, p. 74). Future studies may reveal an even greater areal extent.

In the Tendoy-Beaverhead are the conglomeratic series is present in the Tendoy Mountains only. The best exposures area along the eastern side of these mountains and especially in the McKnight Canyon area in sec. 21, 27, 28, and 34, T 12 S., R. 10 W. An easily accessible outcrop is along Big Sheep Creek road at the front of the Tendoy Mountains. A conspicuous exposure, called Red Butte, is east of Dell, just outside the area of this report and is visible from U. S. Highway 91. The most extensive outcrops are in the northwest part of the Tendoy Mountains. Smaller exposures are along Little Water Canyon and in Bell Canyon.

According to Lowell (pereonal communication) the formation has a maximum thickness of 9000 feet. Honkala (1949, p. 69) reports 3000 feet from the Centennial Region.

In McKnight Canyon 5000 feet were estimated, but the top is truncated by the Limekiln thrust sheet.

Lithologic and stratigraphic features. The Beaverhead formation in the Tendoy-Beaverhead area is predominantly conglomeratic, but contains

in addition at least one fresh-water limestone and several sandstones. In the McKnight Canyon area the following three units were recognized: a lower conglomeratic member, an intermediate member consisting of fresh-water limestone, and an upper conglomeratic member.

The Beaverhead as a whole is fairly resistant and forms steep cliffs, where recently exposed. Not dissected outcrops show a gently rolling topography and are grass-covered.

In the McKnight Canyon area the lower member is a coarse conglomerate, reddish brown and consists of pebbles, cobbles, and boulders ranging from 1 to 10 inches in diameter embedded in a matrix, which is sandy and red. The deposit is well cemented, massive and does not exhibit any distinct bedding but some cross-bedding in places. Sorting is very poor and pebbles are not well rounded (figure 23). The angularity is quite different in other exposures. At some places very well-rounded and polished quartzite boulders were noticed. The limestone pebbles are commonly more angular. A pebble count was made in this unit:

Limestone, gray with calcite veins	40%	
" white	3%	46%
" tan	3%	
Quartzite, red	15%	
" tan	9%	30%
" white	6%	
Sandstone, tan	6%	
" red	7%	13%
Chert, tan	8%	
Shale, tan	3%	
	100%	

FIGURE 23.- Beaverhead formation

Coarse conglomerate of Beaverhead formation exposed at mouth of Big Sheep Creek Canyon.



In the McKnight Canyon area the intermediate member is a fresh-water limestone, dark gray, weathering brownish-gray with mottled appearance. It is in some parts oölitic, in other parts it contains algal concretions. The beds are one to three feet thick. This limestone is resistant and forms two conspicuous cliffs striking east-west. Because of its grayish appearance the limestone can be easily mistaken for Madison limestone. Between the two cliffs is a slope underlain by a lighter-colored, thinner-bedded limestone. The beds stand nearly vertical and the algal limestone is about 250 feet thick.

In the McKnight Canyon area the upper member is much like the lower member, but the color of the beds is more distinctly reddish. A pebble count was made in this unit with the following results:

Limestone, oölitic	30%	
" dark gray	1%	
" light gray	14%	47%
" tan	2%	
Quartzite, tan	8%	
" red	13%	22%
" white	1%	
Chert, tan	14%	
" black	8%	22%
Sandstone, red	8%	
Shale, tan	1%	
	100%	

As in the lower unit the pebbles, cobbles, and boulders are derived from Precambrian, Paleozoic, and Mesozoic rocks.

The composition of the conglomeratic members of the Beaverhead formation is unlike in different places. Some conglomeratic units contain a preponderance of quartzite pebbles, whereas others contain

more limestone. One unit is entirely composed of gray and black limestone, and chert pebbles derived from the Madison. A pebble count was made in this unit at the head of Kissick Canyon in sec. 8, T. 11 S., R. 11 W., by Seglund and Bowers (1949, p. 25 and p. 18):

Limestone, black	14%)	
" gray	36%)	62%
" yellow	12%)	
Chert, black	18%	
Sandstone, tan	17%	
Quartzite, pink	3%	
	100%	

The count shows that probably as much as 80% of the material is derived from the Madison group of this locality.

At other places (Big Sheep Creek) tan sandstone beds are interbedded with the conglomerates. They do not seem to be of great lateral extent. Some show cross-bedding. The beds range in thickness from a few inches to several feet. The sandstones are generally friable, lighter colored than the conglomerates and massive. They become apparently more important to the south. Scholten (personal communication) states that near Monida the conglomerate disappears and the Beaverhead consists of a coarse to fine grained sandstone with interbedded siltstone. The formation becomes also more sandy and less conglomeratic going farther east along the southeast flank of the Snowcrest Range (Honkala, 1949, p. 74). Sandstones also form conspicuous layers in the conglomerate just south of Ruby Dam (Heinrich, personal communication).

Correlation. The Beaverhead formation unconformably overlies the Kootenai formation in the Little Water syncline. In other areas it apparently overlies younger strata, as Lowell (personal communication) states that the formation rests unconformably on rocks of Upper Cretaceous age. Honkala (1949, p. 74) also reports the Beaverhead overlying the latest Cretaceous with angular unconformity. Shenon (1931, p. 16) who had no regional information about the conglomeratic assemblage assigned it to the Triassic. In the Tendoy-Beaverhead area the "Basin Beds" unconformably overlie the Beaverhead but no exact age can be assigned to the "Basin Beds." In other areas the Beaverhead was found to be overlain unconformably by vertebrate-bearing Eocene and Oligocene fluviatile and lacustrine beds (Lowell, personal communication). The Beaverhead is the youngest formation involved in the great Laramide thrust sheets. At the head of McKnight Canyon, the Madison rests on the Beaverhead with a thrust contact. This situation has been reported from various places in this region. The Beaverhead therefore clearly predates the period of Laramide thrusting. From all this stratigraphic evidence it is concluded that the Beaverhead is of Paleocene age.

No fossils have been found within the Tendoy-Beaverhead area to aid in the age determination. Besides the concretions made by algae in the limestone one poorly preserved gastropod was observed in the same unit. These are the only evidences of former life that have been reported from the Beaverhead conglomerate except fossils in pebbles which only indicate the age of the pebble and a maximum age of the conglomerate. In Wyoming the Hoback formation of late Paleocene-early Eocene age contains beds with algal concretions similar to those in the Beaverhead. Also at several other places in the Rocky Mountains algal concretions mark

formations of Paleocene and earliest Eocene age (Hardley, personal communication).

The Unnamed conglomerate of Honkala (1949, p. 67) is the same as the Beaverhead which can also be correlated with the Sphinx conglomerate of Sphinx Mountain in the Madison Range. This conglomerate was tentatively referred to the Eocene by Peale (1896, folio), but probably belongs to the Paleocene. A similar conglomerate was described by Weed (1896, folio) as the Pinyon conglomerate from the southern end of Yellowstone National Park. The Pinyon is now considered to be of early Paleocene age (Hibbard, personal communication). Table 5 shows correlations with other formations.

Origin. The Beaverhead formation is of continental origin and is a product of the first phases of the Laramide orogeny. It represents the material eroded from the mountains which became uplifted at the end of the Cretaceous and in earliest Paleocene time. This material was deposited on flood plains by large rivers and also represents some deltaic deposits. The material was probably derived from the north and west as the deposits become finer grained toward the south and east. Also the quartzite pebbles clearly derived from Beltian strata indicate that the source was to the west as no Belt quartzites are east of the Beaverhead Mountains. The quartzite pebbles were observed as far east as Ruby Dam (Heinrich, personal communication). The source of the material was probably not too far from the Continental Divide as the conglomerate in the Tendoy Mountains is extremely coarse in some places, which indicates a nearby source. The great variation in the Beaverhead conglomerate shows that the material was derived from local sources by different rivers. The lithology of the head

waters of these rivers is reflected in the present conglomerate. Eardley (personal communication) believes that the source was in the southwest in Idaho, but remarks that the distributions and lithologic variations of the conglomerate must be better understood before the location and character of the highland can be discerned.

"Basin Beds"

Definition. The name "Basin Beds" was used by University of Michigan field parties to designate the greatly varied assemblage of Tertiary strata in the broad intermontane valleys of southwestern Montana. The strata are characterized by a great amount of volcanic material. Besides tuffs, flows and agglomerates the assemblage consists of sandstones, conglomerates, shales and other less persistent sediments.

Strata of this kind were designated as "Tertiary Lake Beds" by the Hayden Survey. But although the beds are certainly of continental origin and although many of them were deposited in fresh-water bodies, most of the beds are not lacustrine deposits and the name "Lake Beds" seems therefore inappropriate. It is proposed to use provisionally the name "Basin Beds."

The "Basin Beds" unconformably overlie the Beaverhead and are overlain by Pleistocene deposits. In most cases no more specific dating than Tertiary can be given. In some localities diagnostic vertebrate fossils have been found, which date the beds more accurately. It was discovered that similar units of the Tertiary of southwestern Montana include strata of different ages and because of this faunal evidence various formations have been recognized in the "Basin Beds". The writer therefore treats

the "Basin Beds" as one unit comprising four formations. More is known about the "Basin Beds" in the area east of Dell and Armstead and south of Dillon, and the most complete section yet worked out may here be put together. The type sections of three formations are located in this area and ages have been established on the basis of vertebrate remains. The following division of the "Basin Beds" has been made (Keenmon, personal communication):

Top:	Madison Valley formation	} "Basin Beds"
	Blacktail (Deer) Creek formation	
	Cook Ranch formation	
Bottom:	Sage Creek formation	

The Sage Creek formation was named by Douglass (1903, p. 145) after a tributary to the Red Rock river. The type locality was accurately located by Wood (1934, p. 253) north of Sage Creek in sec. 29 and 30, T. 12 S., R. 8 W., Montana. Emended identifications by Wood of fossils collected by Douglass indicated a late Eocene age for the Sage Creek formation. An erosional unconformity is present between the Sage Creek beds and the underlying strata of the Beaverhead formation (Keenmon, personal communication).

The Cook Ranch formation was named by Wood (1933, pp. 134-135) after Cook Sheep Company, Home Ranch, 8.1 mile by road northeast of Dell railroad station. The type section is across the river west of the ranch in sec. 27, T. 12 S., R. 8 W. The formation was described by Wood (1934, pp. 250-255) as being of middle Oligocene age. It overlies the Sage Creek unconformably (Keenmon, personal communication).

The Blacktail (Deer) Creek formation was named by Douglass (1902, pp. 237-245) after a tributary to the Beaverhead River. Recently Hibbard

and Keenmon (1949, p. 2) located the type section near the center of sec. 8, T. 11 S., R. 6 W. The beds were originally described as of upper Oligocene (White River) age. Osborn (1909, p. 106) stated that a lower Miocene age was more likely. This has been confined by Hibbard and Keenmon, who also assign the Blacktail (Deer) Creek beds to the lower Miocene. The Blacktail (Deer) Creek rests unconformably across the Sage Creek and Cook Range formations.

The Madison Valley formation was named by Douglass (1903, pp. 151-155) for exposures in the Three Forks area. Beds belonging to this formation were recognized farther west in the Ruby River Basin by Dorr and Wheeler (1945, p. 11). These beds form the youngest unit in the "Basin Beds" and are of upper Miocene-lower Pliocene age.

The "Basin Beds" therefore range at least from the upper Eocene to the lower Pliocene. It is unknown whether beds younger than lower Pliocene are present or not. Lithologically these four formations are so similar that they can hardly be distinguished. No attempt was made by the writer to separate the "Basin Beds" into the different formations in the Tendoy-Beaverhead area, as no diagnostic fossils were found, which could aid in the separation.

As stated before the "Basin Beds" contain much volcanic material. Some of this is in the form of regular acid or basic flows. Where possible these definitely volcanic rocks were mapped separately as Tertiary volcanics (Tv). Because of the scale of the map this distinction could not be made in some places and the volcanic rocks were there included in the "Basin Beds". The acid and basic flows will be discussed separately

under the heading Igneous Rocks. The tuffs, which are water-laid, will be included under the "Basin Beds". In general no sharp distinction can be made between the Tertiary volcanics and the "Basin Beds", as the volcanic rocks are part of the "Basin Beds" deposition.

Distribution and thickness. The "Basin Beds", or strata comparable to it, are widespread in southwestern Montana, central eastern Idaho and northwestern Wyoming.

In the Tendoy-Beaverhead area the beds are confined to the intermontane valleys and do not occur at an altitude higher than about 7500 feet. They are well exposed in Muddy Creek Basin, where they consist mainly of volcanic tuffs and exhibit a lithology different from that in the other basins. Extensive exposures are also along North Medicine Lodge Creek, in Horse Prairie and Big Sheep Creek Basin. In these basins the beds are composed for the greater part of sandstones and have less tuffaceous material. In Big Sheep Creek Basin the Tertiary strata are mostly covered by younger deposits, but at three places continuous outcrops are present. One exposure is along the east side of the basin. The other two form ridges in the basin, one of which follows Nicholia Creek and the other Meadow Creek. In the smaller Kate Creek-Muddy Hole Basin the "Basin Beds" are in places very well exposed.

In the Blacktail Range a minimum thickness of 1500 feet was estimated for the lower three formations together (Keenmon, personal communication). Pardee (1913, pp. 233) found 3100 feet in the Flint Creek Basin.

In Muddy Creek Basin a well was drilled to a depth of 1000 feet without encountering hard rock and it seems probable that the bottom of

the "Basin Beds" was not reached (Winchester, 1923, p. 87). The thickness of the complete series in Big Sheep Creek Basin is at least 5000 feet as estimated by the writer. This estimation is based on the measurement of a partial section and the assumption that no repetition of beds by faulting or folding is present in the covered part of the complete section. Because deposition of the "Basin Beds" took place in isolated basins the thicknesses may be quite different in neighboring areas.

Lithologic and stratigraphic features. The "Basin Beds" as exposed in the Tendoy-Beaverhead area consist of a great variety of strata which are not very persistent. Conglomerates, sandstones, bentonites, and water-laid tuffs were observed at one place or another.

The formation as a whole is not very resistant to erosion and has low rounded outcrops and extensive flat surfaces. It is commonly covered by sagebrush and short grasses. A badland topography on a small scale has developed locally where the vegetation cover is removed, and soft rocks are exposed. Figure 24 shows a typical exposure in Muddy Creek Basin. During heavy rainfalls the water of Muddy Creek is clouded with the particles of these easily erodable beds, hence the name of the Creek. Some of the beds are notably harder and may form ridges mainly of sandstones and conglomerates. Also the fresh-water limestone is not easily eroded and forms a conspicuous white cliff along the eastern side of Big Sheep Creek Basin.

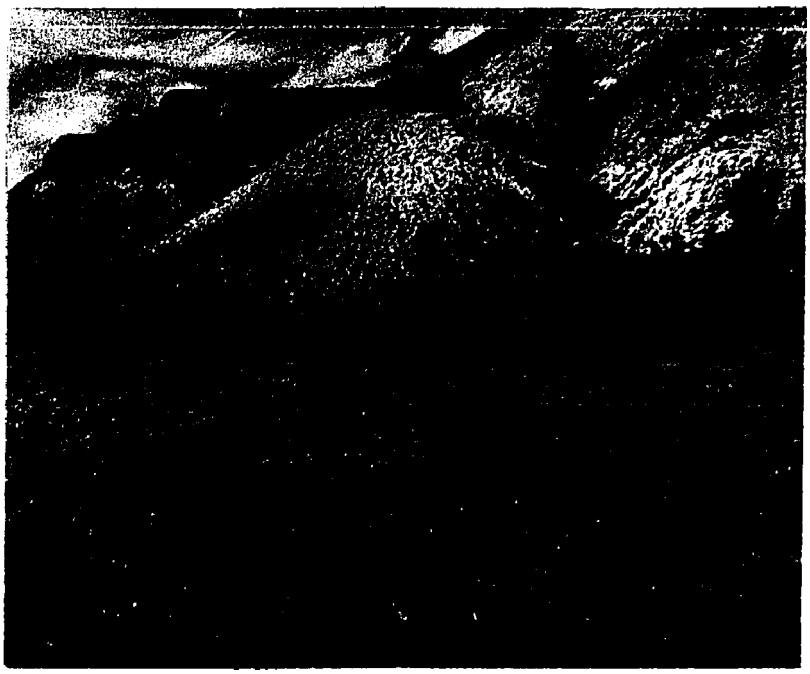
The conglomerates commonly show well-rounded pebbles which range from 1 to 2 inches. A coarse conglomerate was noticed at the base of the "Basin Beds" in Muddy Hole Basin. Here some particles of cobble size

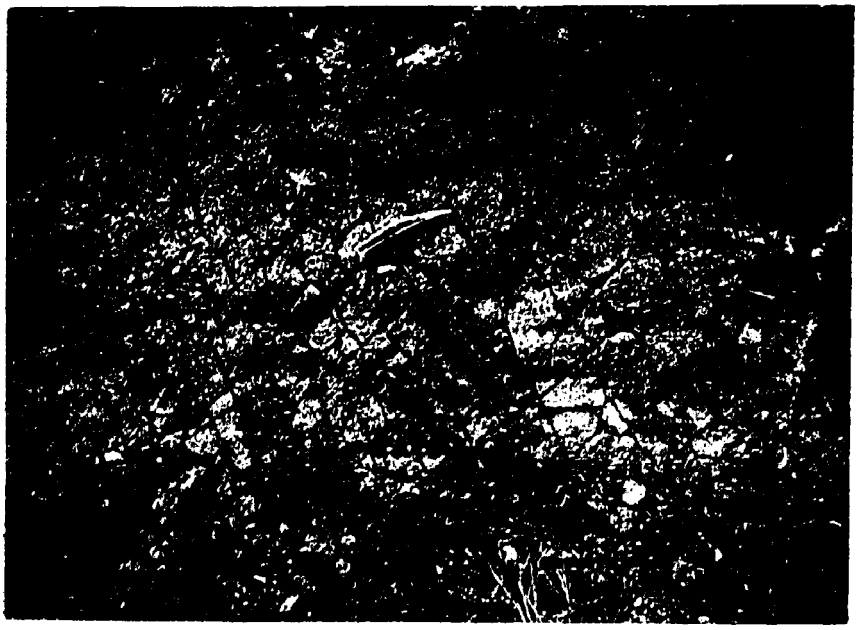
FIGURE 24.- "Basin Beds"

Rhyolitic waterlaid tuff of Eocene (?) "Basin Beds" exposed in Muddy Creek Basin.

FIGURE 25.- "Basin Beds"

Regular jointing in sandstone of Miocene (?) "Basin Beds" exposed in Big Sheep Creek Basin.





occur, the largest one with a diameter of about three inches. No such coarse conglomerates as in the Beaverhead formation were noticed in the "Basin Beds". The most common color of the conglomerates is cream to light brown and the cement sandy without any lime. The particles are derived from older rocks and from pebbles of Precambrian quartzites, Mississippian limestones, and Tertiary granite and lavas. In some places an abundance of flat pebbles was observed parallel to the commonly ill-defined bedding. The conglomerates are of no great areal extent but more or less lens shaped and imbedded in the sandstones into which they grade.

The sandstones are commonly yellowish brown and weather pink to brown, but vary widely in color and texture. A prominent and regular jointing was observed at some localities, notably N.E. 1/4 sec. 13, T. 15 S., R. 11 W. (figure 25). Lamination and cross-bedding are evident in many places, especially in the finer-grained sandstones. The friable and thin-bedded varieties are slope forming whereas the more massive ones form small cliffs in places. The cement is commonly sandy, in a few places it is limy. In some of the sandstones small pebbles of lava are common which might partly represent lapilli ejected by neighboring volcanoes. In Big Sheep Creek Basin on the cliff near the three-forked road in SE 1/4 sec. 11, T. 15 S., R. 11 W., a blue-gray to milky-white translucent chalcedony is on top and in the sandstone. This might have been deposited by hot springs. The conglomerates and sandstones are very well developed in Big Sheep Creek Basin, but they are not found in Muddy Creek Basin. The sandstones are also present in the southern part of Horse Prairie along Kissick Canyon. Here the sandstone is friable, poorly cemented, and contains some visible biotite. It is coarse grained. The particles

are angular and poorly cemented by quartz. The color is red, weathering to a dark red brown. Some interbedded white sands were observed here, weathering to a light gray and with a limy cement.

Thin shale beds were noticed in all basins. The shale is mostly brown to red, weathers white, and is commonly crowded with macerated plant fragments. It is paper thin and breaks easily into small fragments when exposed to weathering. It is soft, easily eroded and therefore mostly found under small overhanging cliffs of the harder overlying beds. Dense, fine-grained and thick-bedded siltstones occur at several places. A white siltstone was found in Big Sheep Creek Basin. The shales and siltstones probably consist largely or entirely of very fine volcanic material. In Muddy Creek Basin the shale member is more than 83 feet thick and several beds of different color or texture can be distinguished. This is evident from the following partial section (Winchester, 1923, p. 89):

Partial section of shale member of "Basin Beds" as exposed in Muddy Creek Basin, sec. 17 (?), T. 13 S., R. 10 W.

		Thickness (feet)	(inches)
11.	Sandstone	-	-
10.	Shale, brown, and black, with thin clay bands	10	-
9.	Partially covered interval	60	-
8.	Same as unit 2	3	4
7.	Shale, sepia-brown	2	1
6.	Clay shale	1	3
5.	Same as unit 1	-	8

4.	Shale, sandy	2	0
3.	Same as unit 1	-	8
2.	Shale, brown	3	4
1.	Shale, black	-	5
	Total measured	83	9

In Horse Prairie the shale is associated with coal beds and on distillation yields more or less oil (Condit, 1919, p. 26). The coal is an impure, low-grade lignite. The following section of one of these lignite beds shows the intimate relationship between the shale and the coal (Dobbin and others 1932, p. 62).

Section of lignite beds in the "Basin Beds" as exposed in Peterson Bros. Coal Prospect 14 miles south of Medicine Lodge, sec. 14, T. 12 S., R. 12 W.

		Thickness (feet)	(inches)
Roof: soft gray shale			
12.	Same as unit 1	-	2.5
11.	Clay, white	-	1.5
10.	Same as unit 2	2	0
9.	Shale, gray, soft	-	2
8.	Same as unit 2	1	2
7.	Same as unit 5	-	1
6.	Same as unit 2	-	6
5.	Clay, gray	-	1.5
4.	Same as unit 2	-	5

3. Shale, gray	-	2
2. Lignite, black	-	10
1. Lignite, black, bony	-	14
Floor: Bone		
Total thickness	6	9

Lignite seams of limited extent and not thicker than one inch are exposed in the sandstones at various places.

Fresh-water limestones occur in the "Basin Beds" but are not persistent over large areas. The limestone is white to cream, weathers gray or tan, locally with a pink crust on the surface. It is thick bedded, fine grained and dense. In places it is cavernous and some of the vugs are filled with calcite spheroids. A good exposure is along Cabin Creek Road in sec. 25, T. 14 S., R. 11 W. A similar, white, fresh-water limestone is found at the mouth of North Limekiln Canyon, where the limestone beds attain a thickness of only eight feet.

Bentonite was noticed in Big Sheep Creek Basin and Muddy Hole Basin. It is gray in color and weathers white. According to Ross (1928, p. 144) bentonite is composed essentially of a clay-like mineral formed by the devitrification and accompanying chemical alteration of a glassy igneous material, commonly a tuff. Gypsum crystals of the variety selenite are at several places in the bentonite and are characteristic of the deposit. The bentonite is poorly indurated, slope-forming and exhibits a typically cracked surface in places with a white crust. Volcanic ejectamenta are scattered through it.

The tuff beds, which are especially well developed in Muddy Creek Basin, are commonly white or light gray and in places pink to buff. In the tuffs some macerated carbonaceous plant material is found, which at some localities is abundant (along Wilson Creek, in NW 1/4 sec. 3, T. 13 S., R. 11 W.). Some of the foreign rock particles embedded in the groundmass show rounding. Fresh-water gastropods are in some of the beds. These observations lead to the conclusion that the majority of the tuffs was probably deposited in fresh-water bodies. In addition, bedding is clearly indicated in many outcrops. Megascopically several different varieties of tuffs can be distinguished on the basis of texture, color, etc. This is evident from the following partial section measured by the writer.

Partial section of the "Basin Beds" as exposed along the upper part of Johnson Creek, tributary to Muddy Creek, sec. 24, T. 13 S., R. 11 W.

		Thickness (feet)
16.	Volcanic tuff, purplish, weathering brown and greenish, laminated in brown and yellow, jointed, forms steep prominent cliff	60
15.	Volcanic tuff, greenish gray, coarse grained, jointed, cliff former	12
14.	Same as unit 12, but forms cliff	3
13.	Volcanic tuff, laminated in brown and gray, fine grained, dense	2
12.	Volcanic tuff, light gray, coarse grained, quartz crystals visible, carbonaceous plantfragments	8
11.	Volcanic tuff, gray brown, massive, chert layers, quartz veinlets with iron oxide, clay concretions, abundant gastropods	4
10.	Shale, light brown to grayish, weathering pinkish	3

9.	Volcanic tuff, pinkish to brown, very fine grained, quartz and iron oxide veinlets	2
8.	Covered interval	50
7.	Volcanic tuff, grayish green, fine grained, clay concretions, light brown	3
6.	Same as unit 4	30
5.	Same as unit 3, but contact with unit 4 is gradational, coarser grains are nearer to contact	1
4.	Volcanic tuff, greenish gray, fine grained parts friable and slope forming, harder layers form some ledges.	35
3.	Conglomerate, fine grained, particles not larger than 5 mm. in diameter. Some lenses of aphanitic tuffaceous material, greenish	1
2.	Volcanic tuff, grayish green, cliff forming, jointing prominent, large crystals of yellowish white weathering feldspar (sanidin), quartz and black to brown biotite can be seen megascopically	30
1.	Covered interval	50
	Total measured	294

The tuffs contain the following three components: glass, crystals of individual minerals, and rock fragments. The proportion of these three components varies greatly and according to the predominance of one or the other the distinction is made between vitric tuffs, crystal tuffs and lithic tuffs (Pirsson, 1915, p. 192). tudy of four thin-sections of tuffs in the Tendoy-Beaverhead area revealed the presence of these three different types. The groundmass of all tuffs appeared to be very pure with little admixture of sedimentary material. The tuffs are different enough to warrant a description of each:

1. Locality: Headwaters of Wilson Creek in Muddy Hole Basin, sec. 9, T. 13 S., R. 11 W. Megascopic: Tuff, gray on fresh surface, grayish brown on weathered surface, fine grained,

very thin bedded, containing many wood fragments. Microscopic: (Specimen 1048) Vitric to crystal-tuff of rhyolitic composition. Groundmass composed of volcanic glass, brown, with few glass shards in some places. Embedded in the groundmass are mostly angular and broken crystals, mainly of quartz, feldspar, and biotite. The feldspar occurs as sanidine and as plagioclase (oligoclase). Other minerals in smaller amounts are chlorite, calcite, zircon, apatite, and little iron oxide. A few rock fragments were noticed, but they are small and insignificant in amount. The rock consists of a glassy groundmass mainly, with a lesser amount of small crystal fragments.

2. Locality: Upper part of Johnson Creek, tributary to Muddy Creek, sec. 24, T. 13 S., R. 11 W. Bed 2 in the Johnson Creek section given above. Megascopic: Tuff, grayish green on fresh and weathered surface, thick bedded. Crystals of biotite, quartz, and white-weathered feldspar are clearly visible. Microscopic: (Specimen 2248) Crystal tuff of rhyolitic composition. Groundmass composed of brown volcanic glass. Angular crystal fragments of quartz, feldspar, and biotite are common. The feldspar is sanidine and oligoclase. This rock contains more crystals and less glass than specimen 1048. It has more and larger rock fragments and biotite is more abundant and in larger crystals. A few grains of apatite were noticed. Figure 26 is a photomicrograph of a representative part of the thin-section.

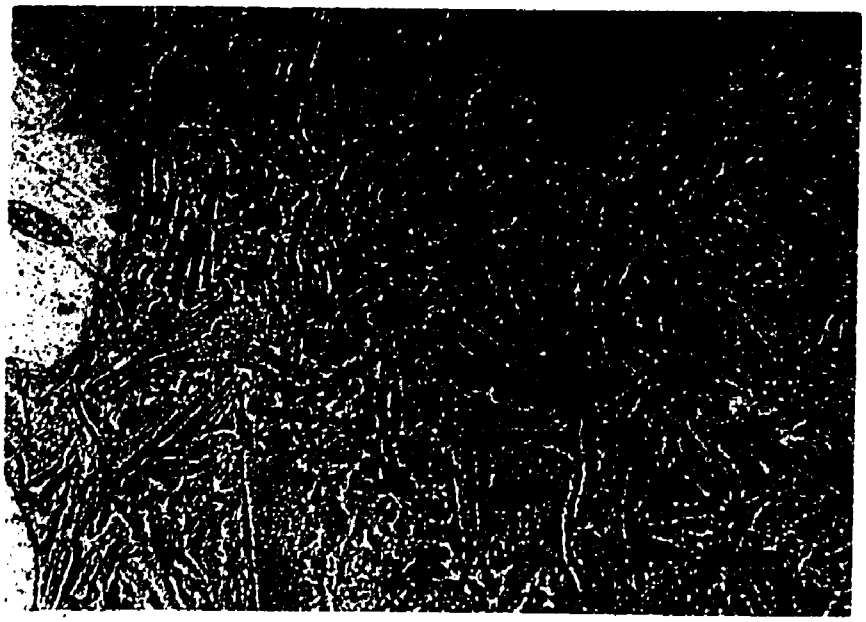
FIGURE 26.- "Basin Beds"

Rhyolitic crystal tuff. Photomicrograph of specimen 2248. Crossed nicols, 75x .
Groundmass is volcanic glass.
P - Plagioclase
Q - Quarts
S - Sanidin
B - Biotite

FIGURE 27.- "Basin Beds"

Glass shards in groundmass of rhyolitic vitric tuff. Photomicrograph of specimen 3348. Nicols not crossed, 75x .





3. Locality: Upper part of Johnson Creek, tributary to Muddy Creek, sec. 24, T. 13 S., R. 11 W. This rock was collected outside the measured section. Megascopic: Tuff, cream white, chalky, coarse grained with many crystals of water-clear quartz and gray sanidine clearly visible. Some crystals of smoky quartz are present. Microscopic: (Specimen 3348) Vitric tuff of rhyolitic composition with few but large crystals. In the groundmass of volcanic glass the vitroclastic structure is extremely well developed and glass-shards of different shapes can be recognized. Most common are rod and sickle shaped pieces (figure 27). In the groundmass large crystals of quartz and feldspar (sanidine only, no plagioclase) lie embedded. The minerals are mostly euhedral crystals. Smaller crystals of zircon and magnetite are present. A few fragments of a mineral which could not be identified were also found. This mineral is green-brown in color, pleochroic, from light to dark brown, has a high refractive index and a high birefringence. Other optical data could not be obtained. It may be allanite (?).

4. Locality: Upper part of Johnson Creek, tributary to Muddy Creek, sec. 24, T. 13 S., R. 11 W. This rock was collected outside the measured section. Megascopic: Tuff, gray with light yellow bands on weathered surface. Coarse grained with crystals of gray, cloudy feldspar and colorless clear quartz distinctly visible. Many black, commonly rounded fragments of older rocks are conspicuous. Microscopic: (Specimen 3448) Lithic tuff of rhyolitic composition. In the groundmass of volcanic glass crystals of

quartz and feldspar are embedded. The quartz is more rounded and not euhedral as in specimen 3348. The feldspar is mostly sanidine, although also some oligoclase is present. Most characteristic are the pieces of rock in the groundmass. They are mostly well rounded, consist of an aggregate of quartz, sericite, chlorite, biotite (?) and iron oxide, and probably represent some quartz-sericite schist derived from the underlying Precambrian (figure 28).

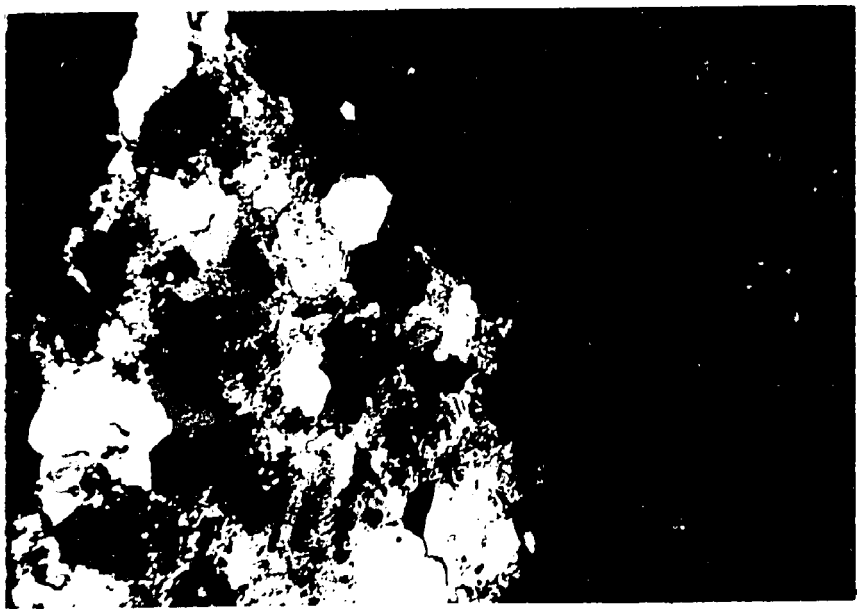
The following partial section of the "Basin Beds" in Big Sheep Creek Basin shows several types of lithology and is representative for the beds of this basin. The section was measured by the author in cooperation with Mr. Robert Scholten.

Partial section of the "Basin Beds" as exposed in Big Sheep Creek Basin, in sec. 31, 32, T. 15 S., R. 11 W., and 19 T. 15 S., R. 10 W.

		Thickness (feet)
16.	Same as unit 12	10.0'
15.	Shale, white, non fissile, non fossiliferous	0.5'
14.	Same as unit 12	70.0'
13.	Shale, brown, fissile, plant fragments	0.5'
12.	Sandstone and conglomerate in alternating layers, brown to yellow, thick bedded, cross-bedding in places, vertical jointing, petrified wood, lignitic layers, cliff forming. Pebbles of : quartzite, limestone, granite, basalt, rarely shale	10.0'
11.	Same as unit 7	100.0'
10.	Same as unit 8	2.0'
9.	Same as unit 7	100.0'
8.	Sandstone, dark brown, weathering grayish brown, fine to medium grained, well sorted, faint striations due	

FIGURE 28.- "Basin Beds"

Fragment of quartz-sericite schist enclosed in rhyolitic lithic tuff. Photomicrograph of specimen 3448. Crossed nicols, 75x .



to color differences, slope forming . . . . . 100.0'

7. Bentonite, gray to light brown, weathering white, not indurated, cracked surface, gypsum crystals, pyroclastic material, slope forming . . . . . 60.0'

6. Sandstone and conglomerate, brown, lighter colored sandstone interbedded, cross-bedding, grain size finer in upper part, less volcanic material than in 2, cliff forming . . . . . 750.0'

5. Same as unit 3 . . . . . 75.0'

4. Sandstone, light brown, weathering brown, well sorted, moderately indurated, coarse grained, faintly laminated . . 10.0'

3. Sandstone, white to light gray . . . . . 15.0'

2. Sandstone and conglomerate in heterogeneous mixture. Sandstone yellowish brown, weathering pink to brown, coarse grained, grains well rounded, cemented by siliceous material. Conglomerate in lenses in sandstone, pebbles well rounded and consisting of quartzite, granite, limestone, much basalt, also shale and red sandstone. Pebbles 1 to 2 inches, bedding indistinctive, petrified wood . . . 550.0'

1. Most of the basal part covered, except for a few beds of gray bentonite . . . . . 750.0'

Total thickness 2613.0'

Correlation. The "Basin Beds" unconformably overlie the conglomerate of the Beaverhead formation as can be observed in the northern part of the Tendoy Mountains, a few miles south of Medicine Lodge. In Big Sheep Creek Basin the Pleistocene glacial deposits overlie the "Basin Beds" unconformably.

Several fossils were found in certain strata of the "Basin Beds" but none of them is diagnostic as to the exact age of the deposits. The fauna and flora only indicate a Tertiary continental deposit.

In some of the sandstones in Big Sheep Creek Basin waterworn pieces of fossilized wood were found. Macerated plant fragments are common in some

of the shales, but the fragments are unfit for identification. Bowen (1917, p. 317) mentions the occurrence of Sequoia-leaves in the shales of Muddy Creek Basin. The writer found a well preserved conifer cone at the entrance of the Peterson Coal Mine at Keystone Gulch. This cone was identified by Dr. C. H. Arnold (University of Michigan) as belonging to Sequoia concinna Heer. Not much is known about the range of this species, which was discovered in the Upper Cretaceous of Greenland and later also in Massachusetts and Arkansas (Knowlton, 1919, p. 591). As far as the writer is able to determine it has not been reported previously from any other locality in the western United States.

The only invertebrate fossils are fresh-water gastropods in the limestones and some of the tuffs. Several specimens were collected by the writer along the upper part of Johnson Creek, tributary to Muddy Creek, sec. 24, T. 13 S., R. 11 W. in beds 10 and 11 of the measured section given above. The following could be identified by Dr. L.B. Kellum (University of Michigan) :

Planorbis cf utahensis Meek
Lymnaea cf minuscula White
Orechelix sp.

Although no statement as to the age of these fossils can be made, they are suggestive of an Eocene age. This confirms with a statement made by Dr. J. LeRoy Kay (personal communication) that the beds in Muddy Creek Basin resemble the Sage Creek beds (Eocene) more than any others he has seen.

The only remains of vertebrates are fish-scales found in great number in some of the shales along North Medicine Lodge Creek. They were collected by the writer at the entrance of Peterson's Coal Mine at Keystone Gulch. The scales are all of the cycloid type and some are very large. They

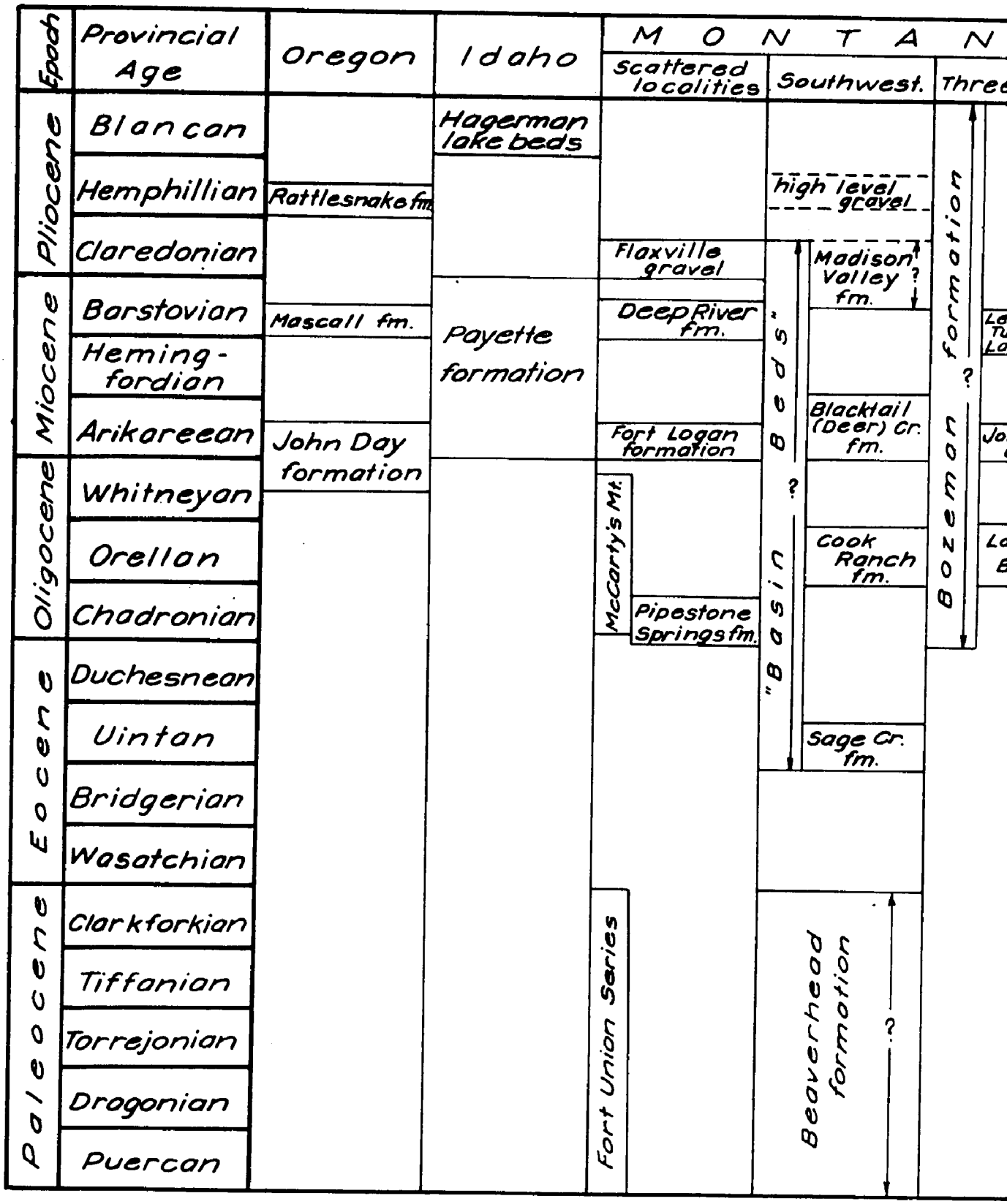
belong to fishes probably closely related to the modern minnows and common white suckers. One scale was suggestive of Amia, but definite identification of the mostly poorly preserved scales was not possible (Miller, personal communication).

As no fossils were indicative of the exact age of the beds, assignment of the strata to a certain epoch within the Tertiary period is not possible. As mentioned before, LeRoy Kay (personal communication) does not believe that the strata are of the same age in the various basins. On the basis of lithological similarities he believes that the beds in Horse Prairie are of Miocene age. Also the beds at South Bannack Pass at the southern end of Big Sheep Creek Basin are referred to the Miocene. The strata of the North Medicine Lodge area are probably Miocene too, although they yielded some fossil plants which in part resemble the upper Green River Eocene fossil faunas. The only beds which might belong to the Eocene are those of Muddy Creek Basin. These age assignments are doubtful, for they are not based on sufficient faunal evidence. The only conclusion that can be drawn is that deposition of similar terrestrial sediments and volcanics went on during the greater part of the Tertiary.

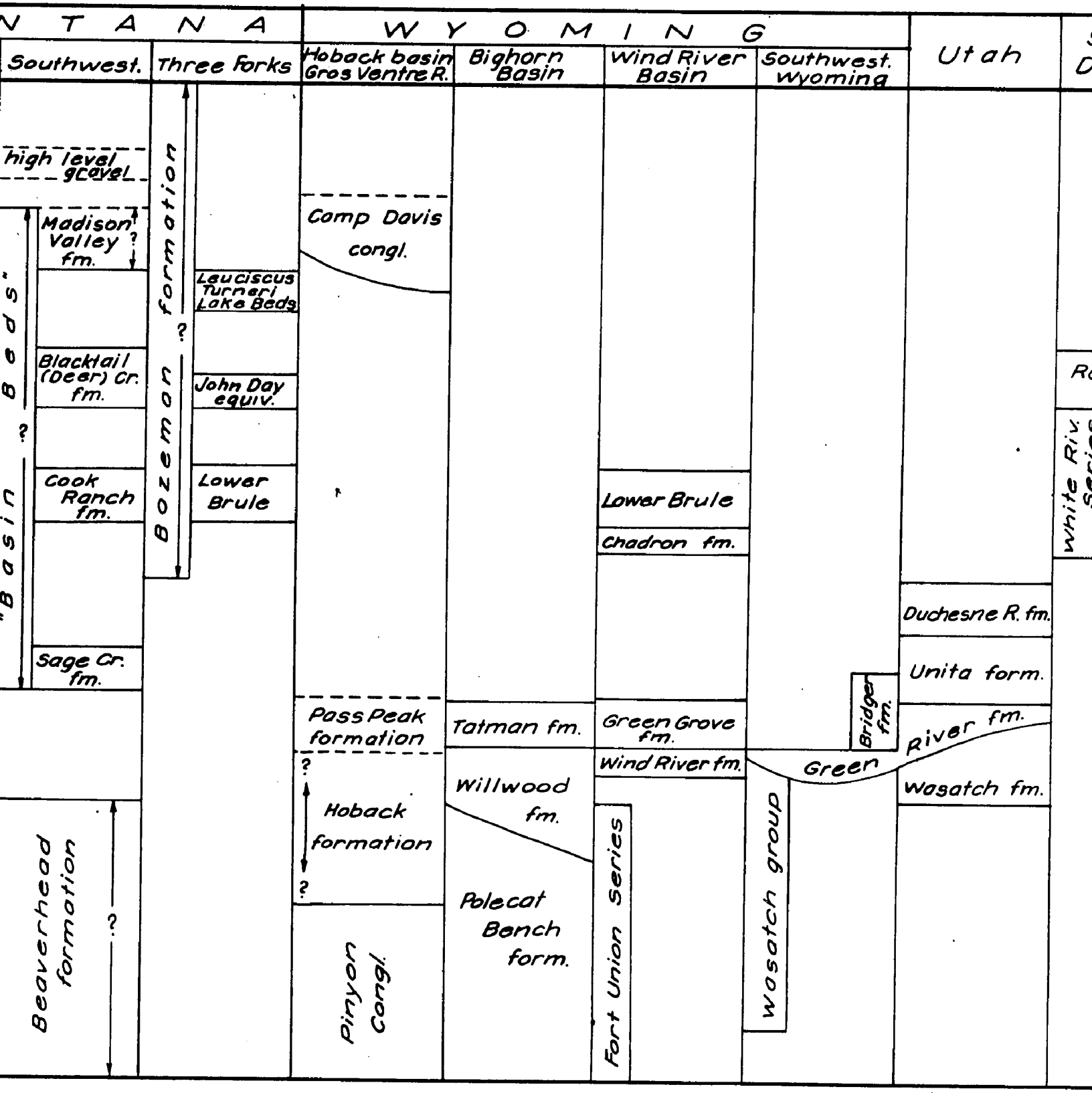
Correlations of the "Basin Beds" as recognized by field parties of the University of Michigan with other Tertiary continental deposits of the western states are shown on table 5.

Origin. The "Basin Beds" are of continental origin as indicated by the fresh-water gastropods, the fresh-water fishes and the plant fragments. Formerly it was assumed that the deposits were formed in bodies of stand-

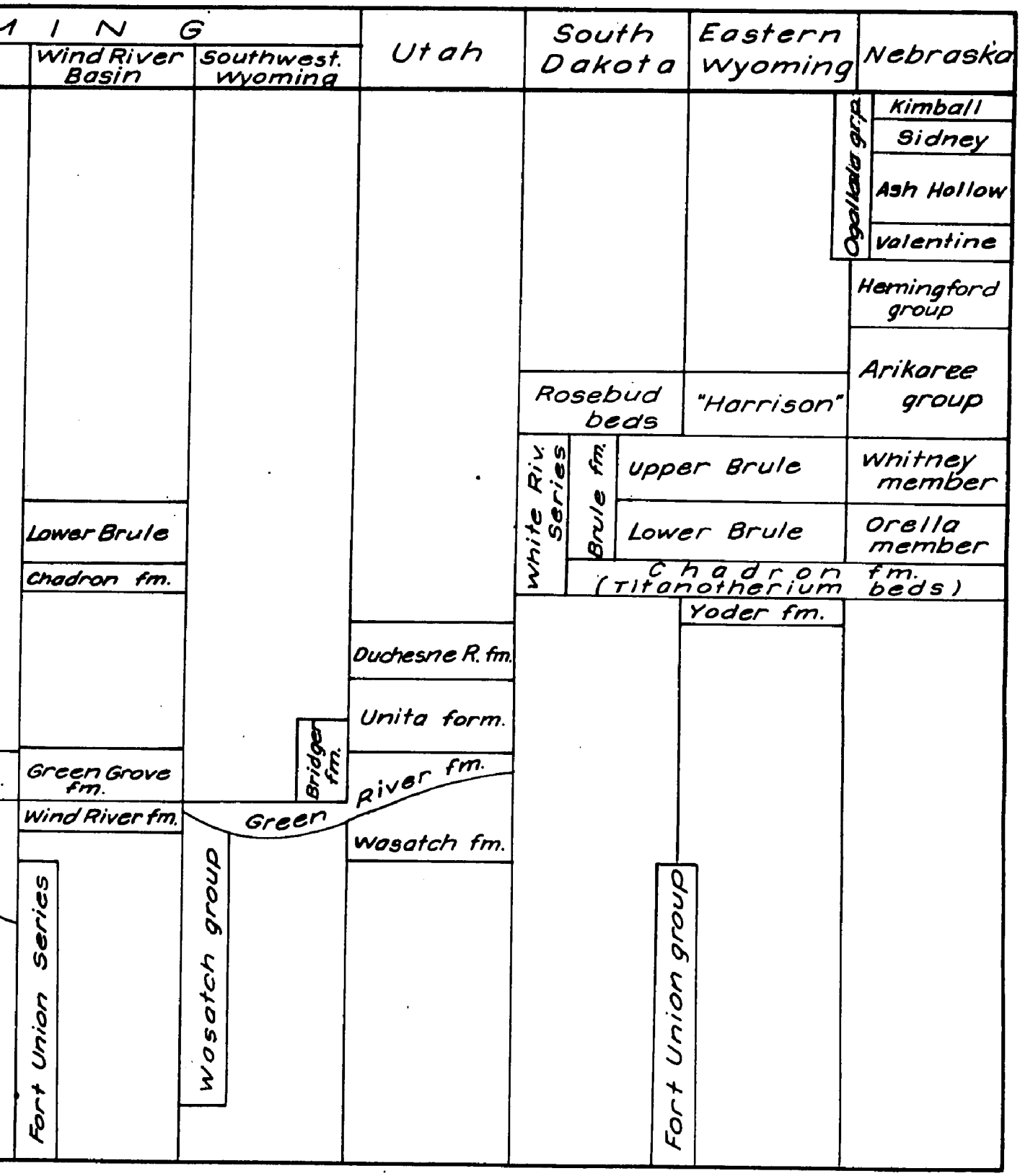
TABLE 5.- Correlation of Tertiary continental formations



Correlation cha
of the Northern Rocky M
Revised after v
Reed, E.C. 1943; Wilson, R
data from Eardley, A.J.
Prepared by K



elation chart of Tertiary continental formations
ern Rocky Mountains and the Northern Great Plains.
ised after Wood, H.E. 2nd et al 1941; Condra, G.E. and
3; Wilson, R.W. 1949; with additional unpublished
ardley, A.J. and Hibbard, C.W.
pared by K.A. Keenmon and W.O. Kupsch.



tinental formations
Northern Great Plains.
1941; Condra, G.E. and
tional unpublished

W. O. Kupsch.

ing water and strata were referred to as "Lake Beds". Especially the name "Bozeman Lake Beds" has been used very loosely to designate Tertiary beds of continental origin in southwestern Montana.

It is now believed that the deposits were formed by streams and temporary lakes. Blackwelder (1915, p. 107) lists the following five possible environments of deposition:

1. Lakes and streams
2. Floodplains of graded streams
3. Alluvial fans of wet-weather streams
4. Dry land surfaces by wind.

It is possible that all these agencies have taken part at one time or another. Also Russel (1902, p. 57) assumes that the deposits were partly formed by streams, but mentions that it is impracticable to determine what part is the result of still-water and what part of flowing water. In Big Sheep Creek Basin it is evident that some of the cross-bedded, lenticular sandstones and conglomerates with their water-worn pebbles were deposited by streams. The brown shales with the numerous plant fragments, on the other hand, probably represent marshy conditions in a shallow lake. Some of the coarser conglomerates at the base of the formation might well be fanglomerates.

High-level gravel

Definition. The name High-level gravel is used to designate the deposits of rounded loose material covering the A-surface or summit peneplain (cf. Physiography). The deposits were noticed at several places, but not everywhere indicated on the geologic map in order not to obscure the underlying rocks (plate I).

Distribution and thickness. Similar gravels are south of the Tendoy-Beaverhead area along South Medicine Lodge Creek. (Stearns and others, 1939b, p. 23-24). To the east in the Gravelly Range they are reported by Honkala (1949, p. 91).

In the Tendoy-Beaverhead area the gravel is at an altitude of about 8500 feet in the Beaverhead Mountains. It can be observed at three different places viz.: south of the intrusive mass along the Continental Divide in sec. 1, T. 15 S., R. 12 W., and sec. 16, and 28, T. 16 S., R. 11 W. North of the intrusive mass it covers most of the Carboniferous rocks which here form the Continental Divide. The High-level gravel is found at several places in the Tendoy Mountains, especially in the northern part.

The gravel forms only a thin veneer on the older rocks and the thickness probably does not exceed a few feet anywhere.

Lithologic and stratigraphic features. The gravel is a loose, uncemented deposit consisting of more or less well-rounded and ill-sorted pebbles, cobbles and a few boulders. Commonly the particlesdo not exceed pebble size. The comparatively good rounding suggests that many of the pebbles were derived from the already rounded particles of the Beaverhead conglomerate. Precambrian metamorphic rocks, Beltian quartzite, Flathead quartzite, Paleozoic limestone and chert, and Tertiary volcanic material are pebbles of the High-level gravel. At the head of Trail Creek in the Beaverhead Mountains the gravel consists almost entirely of gray limestone pebbles, whereas white and pink quartzites of probable Beltian origin dominate in the gravel deposit west of Sourdough Creek on

the west flank of Muddy Creek Basin.

Correlation. The High-level gravel occurs at a much higher altitude than the Quaternary glacial deposits, the Quaternary gravels that form a veneer on the "Basin Beds" and the Quaternary Terrace gravels.

The age of the gravel is uncertain. It is on the highest erosion surface, which bevels only Paleozoic rocks in the Tendoy-Beaverhead area. Just outside the area along Pine Creek gravels overlie the presumably Pliocene lavas of Bannack Pass (Scholten, 1948, p. 35). If these gravels are correlative with the High-level gravel, then this would establish a late Pliocene to early Quaternary age for the High-level gravel.

Origin. The High-level gravel represents fluviatile deposits of rivers on the highest erosion surface.

QUATERNARY SYSTEM

General remarks

At various places in the Tendoy-Beaverhead area the older rocks are covered by deposits of loose material of the Quaternary system. These deposits can be divided into four categories, the distinction of which is based mainly on their physiographic appearance. In some cases the assignment of certain deposits to one category or another had to be more or less arbitrary. The following divisions were made: Glacial deposits (which can be divided into older glacial deposits and a younger glacial deposit), Terrace gravel, Landslide material, Alluvium.

Older glacial deposit

Definition. Pleistocene deposits of glacial origin are clearly recognizable in the western part of the Tendoy-Beaverhead area. The distinction between Older and Younger glacial deposits as shown on the geologic map (plate I) is based on their topographic forms. Because the Older glacial deposit is poorly preserved its extent is not as accurately known as that of the younger deposit.

Distribution. Pleistocene glaciation was widespread over many of the ranges of the western Cordillera. Glacial material occurs at several places in the mountain valleys and along the eastern front of the Beaverhead Mountains. In the mountain valleys the Older glacial deposit is everywhere concealed by the Younger deposit. Along the front of the mountains the older material is exposed more toward the basin, as the younger glaciation was apparently hot as extensive and did not move as far out into the basin as the older one did.

Lithologic and stratigraphic features. The Older glacial deposit

consists of loose, ill-sorted little rounded clastics derived from the adjacent mountains. It contains pebbles, cobbles, and boulders of quartzite, limestones, volcanic rock, and granite, with interstitial finer grained material. Most of the deposit is grass covered and exposures are few. It is likely that it includes along its eastern border some glacial outwash from which it can be distinguished only when the original topographic form is sufficiently well preserved.

Correlation. No fossils were found in the glacial deposits and an accurate dating is not possible. Because glacial features are still readily recognizable the deposits are assigned to the latest stage of glaciation during the Pleistocene.

Similar deposits were described from central western Wyoming by Blackwelder (1915, p. 321-333). The Older glacial deposit probably correlates with Blackwelder's Bull Lake drift, which was in turn correlated with the Iowan drift (Blackwelder, 1931, p. 918). This Iowan drift is now considered to represent the oldest substage of the Wisconsin stage (Kay and Leighton, 1933, p. 672). The Older glacial deposit therefore probably belongs to the earliest Wisconsin (table 6). A third glacial drift corresponding to a stage older than the Wisconsin was not recognized in the Tendoy-Beaverhead area. More to the north in Glacier National Park pre-Wisconsin drift has been described by Alden (1912) and it is possible that this Kennedy drift is also present in some parts of southwestern Montana.

Younger glacial deposit

Definition. The Younger glacial deposit has retained its original topography to such a degree of perfection that different kinds of

TABLE 6.- Correlation of Pleistocene glacial deposits

TENTATIVE CORRELATION CHART OF GLACIAL STA

(modified after Blackwelder, 193

Stages	Substages	Southwestern Montana	Wyoming (Wind Riv.)	Colorado (San Juan)	Utah (Wasatch)
Recent interglacial					
Wisconsin glacial	Mankato (Late Wisc.) Cary (Middle Wisc.) Tazewell (Early Wisc.) Iowan	? Younger glacial deposits ? Older gla. dep.	Pinedale Bull Lake	Wisconsin Durango	"Younger" "Older"
Sangamon interglacial					
Illinoian glacial					
Yarmouth interglacial					
Kansan glacial		Kennedy?	Buffalo	Cerro	
Aftonian interglacial					
Nebraskan glacial					

ATION CHART OF GLACIAL STAGES IN WESTERN U.S.

(modified after Blackwelder, 1931)

ern a	Wyoming (Wind Riv.)	Colorado (San Juan)	Utah (Wasatch)	Nevada (Ruby Mts.)	Eastern Sierra Nevada	Yosemite
er / its	Pinedale	Wisconsin	"Younger"	Angel Lake	Tioga	Wisconsin
ep.	Bull Lake	Durango	"Older"	Lamoille	Tahoe	
				— ? —		
?	Buffalo	Cerro		— ? —	Sherwin	El Portal / Glacier Pt

moraines can easily be recognized.

Distribution and thickness. The Younger glacial deposit is in the mountain valleys on the eastern side of the Beaverhead Mountains and extends into Big Sheep Creek Basin but not as far as the older deposits. Outside the Beaverhead Mountains glacial drift is probably present along the upper part of McNinch Creek on the east side of Muddy Creek. This till was assigned to the Younger glacial deposits.

The thickness of the younger till varies greatly in places, but judging from the highest terminal moraine it does not exceed 60 feet.

Lithologic and stratigraphic features. The material of which the younger till is composed contains a greater percentage of boulders than the older till. Weathering has not affected the particles so much and glacial scratches can be found, especially on limestone pebbles.

The material is clearly derived from local sources, and in the central part of the Beaverhead Mountains consists mainly of granite.

Correlation. The Younger glacial deposit is tentatively correlated with the Pinedale drift in the Jackson Hole country, Wyoming (table 6). It is clearly younger than the Older glacial drift which underlies it. No other indications as to its age were found.

Terrace gravel

Definition. Extensive parts of Big Sheep Creek Basin are covered by coarse grained gravels forming two distinct sets of terraces. The present rivers have cut into these terraces and are at a lower level, where they developed valley flats. Less extensive deposits of the gravels are in North Medicine Lodge Basin. In Muddy Creek Basin the gravels occur in small interrupted strips on both sides of the creek.

Horse Prairie between Armstead and Medicine Lodge is completely covered with this older alluvium. Along the east side of the lower course of North Medicine Creek the "Basin Beds" are covered by gravel, which in part is in the form of an alluvial fan. This fan was also mapped as Terrace gravel. Also along the east front of the Tendoy Mountains the gravels are found as great alluvial fans. Two conspicuous sets of river terraces are in the center part of Red Rock Basin. These older alluvial deposits effectively conceal the "Basin Beds" and related volcanic rocks, which crop out in only two places along the mountain front.

The thickness of the gravels varies greatly depending on local conditions. The greatest exposed thickness is in Big Sheep Creek Basin where the creeks have cut inmore than 80 feet gravel. Along Highway 91 several gravel pits are present and 40 feet of gravel was measured in one of them. Probably much more is present, as the bottom of the deposit was not exposed.

Lithologic and stratigraphic features. The gravel in Big Sheep Creek Basin contains well-rounded, well-sorted particles, mainly of pebble size. The bedding is not very evident and cross-bedding is only faintly developed in places. Pockets of green sand were noticed in one outcrop on the north bank of Tex Creek about 100 feet above Martinel's Ranch. In the same exposure the largest particle was a cobble with an eight inch diameter. Most of the pebbles here are limestone and covered with a white crust of calcium carbonate which acts as cementing material. Loose, calcareous, brown sand commonly occupies the interstices between the pebbles, and the deposit as a whole is loosely cemented. The gravel

consists of the products of erosion of the Beaverhead Mountains and pebbles derived from the "Basin Beds" and Tertiary volcanics.

The gravel deposits of Red Rock Basin consist of well-rounded material, slightly indurated and exhibiting good sorting, and no bedding.

Origin. The two sets of terraces in Big Sheep Creek Basin and Red Rock Basin are probably formed by glacial streams carrying waste from the valley glaciers during Pleistocene time. The highest terrace was perhaps deposited during the Older glaciation and the lower terrace during the Younger glaciation. Both terraces were mapped as a single unit on the geologic map (plate I).

Alluvium

Definition. The term Alluvium is used to designate the river deposits occupying the floodplains along the streams. The boundary between the younger alluvium and the older alluvium (Terrace gravels) is the boundary between the meadow lands at the lowest level in the valley and the dry, sagebrush covered higher levels consisting of gravel. In most places this boundary was determined with the aid of aerial photographs on which the various levels can be readily distinguished.

Distribution. Not all the Alluvium recognized was mapped. In many places it is limited to only a few feet on both sides of the stream. In the basins, however, the Alluvium-coated floodplains are considerably wider. In general it is along all the permanent streams, where these flow through a basin. All the ranch houses are on or close to these young alluvial deposits, which make good grazing grounds.

Lithologic features. The Alluvium consists mainly of sand, silt, and clay brought down from the mountains and washed out from the older alluvial deposits. The transporting power of the streams in the basins is not sufficient to carry boulders. Pebbles form the stream bed.

In the various lakes, filling by sediments derived from the adjacent hills has taken place. Some of the lakes are completely filled. The lake sediments were not mapped separately, but were included in the alluvial deposits, wherever they were extensive enough.

Landslide material

Definition. The term Landslide material is used here in the broad sense and includes all materials of loose rock accumulated mainly by the action of gravity.

Distribution. Most "slump", which also belongs to this category, is of such small extent that it was not mapped. Only some of the larger slides, which conceal large areas of older rocks are shown on the geologic map (plate I). A well-developed landslide occurs on the west side of Nicholia Creek Canyon, mainly in sec. 23, T. 16 S., R. 11 W. Another good example is on the north side of the head of Kate Creek.

Lithologic features. The material of which the landslide is composed depends of course on the location of the slide. No formation seems to be particularly favored by landslides. The Nicholia Creek slide consists in its northern half of quartzite blocks and in its southern half of basalt blocks. Because of the difference in color between the light colored quartzite and the dark brown to black basalt, the two comprising parts are easily distinguished.

Time of origin. The landslides have supposedly taken place in the Recent epoch, but long enough ago to be covered with vegetation in most places.

INTRUSIVE IGNEOUS ROCKS

General remarks

A granitic pluton is present in the Beaverhead Mountains. Other intrusive bodies of much smaller size are at various other places in the Tendoy-Beaverhead area. They include quartz veins, lamprophyre dikes, and acid and basic hypabyssal bodies which probably represent feeders to the Tertiary lava flows.

The names given to all igneous rocks conform to the classification of Grout (1932, p. 50). The age relationships of the igneous rocks will be discussed at the end of the chapter on Extrusive igneous rocks.

Granitic pluton

Distribution. A discordant pluton of large size and consisting of granitic rock forms the Continental Divide east of Big Sheep Creek Basin (frontispiece). This mass of acid intrusive rock extends from sec. 21, T. 16 S., R. 11 W., in a northwesterly direction to sec. 35, T. 15 S., R. 12 W. It has a length of more than six miles and an average width of two miles. The body is elongated parallel to the general trend of the Beaverhead Range.

Description. The pluton consists of granitic material ranging in composition from granite to quartz-monzonite. Coarse quartz veins and small aplite dikes of the same composition as the main body but much finer texture cut the mass.

These rocks resist weathering to a much higher degree than the surrounding Paleozoic limestones. The highest peaks along the Continental

Divide (Eighteen mile Peak) are carved out of the granitic rocks. Weathering of the jointed granite produces large blocks of disintegration on top of these peaks (figure 29). On the southside of the pluton, where the rocks are more weathered, the blocks have broken down to much smaller boulders. Some of the granites show stains in iridescent colors, due to a thin film of iron oxide produced by weathering. These stains are especially well developed in SW 1/4 sec. 21, T. 16 S., R. 11 W.

The granitic rocks of the main body are moderately coarse grained and range in color from light gray to pink and light green. Quartz and pinkish feldspar can be recognized megascopically, but commonly no dark minerals can be detected. The rock is distinctly granular in texture (figure 30). Microscopic investigation reveals that a true granite with a paucity of dark minerals is the most prominent type. (specimens 2247, 2447, 2547, 2647, 5147, 5247). These specimens were collected at the head of Bear Creek in the southern part of the intrusive. There the rock consists of quartz and orthoclase in about equal amounts. The orthoclase is commonly greatly altered to a dense aggregate of very small sericite flakes. No microcline or plagioclase nor dark minerals seem to be present in any noticeable amount. Zircon, the only accessory mineral of significance, occurs locally in well crystallized individuals. Some hematite and clusters of magnetite were observed. At the head of Meadow Creek a specimen (8247) was collected which revealed a true granite with microcline as well as orthoclase.

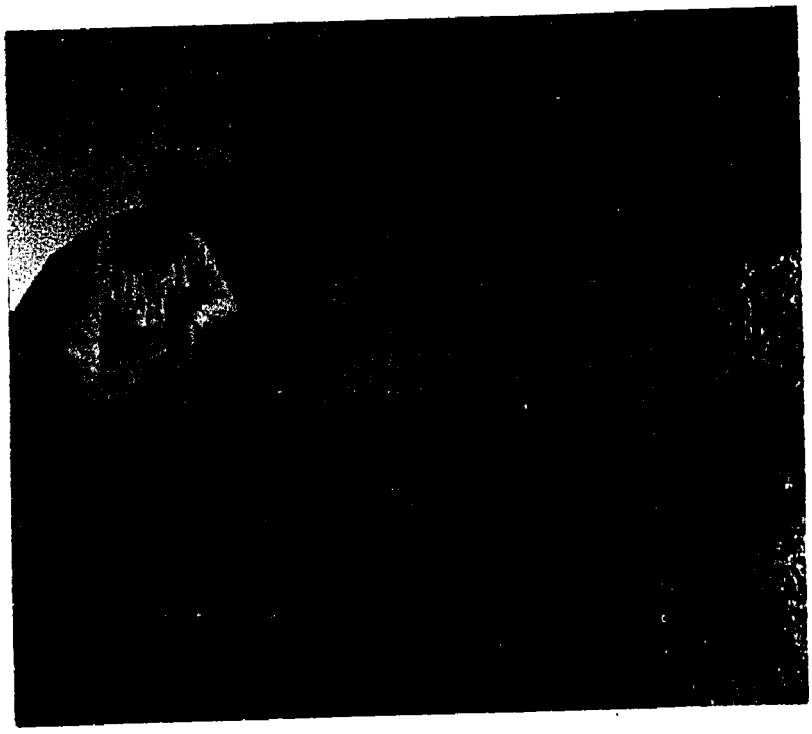
At the northern end of the intrusive a variety containing significant quantities of plagioclase was encountered (specimen 7947). This rock has

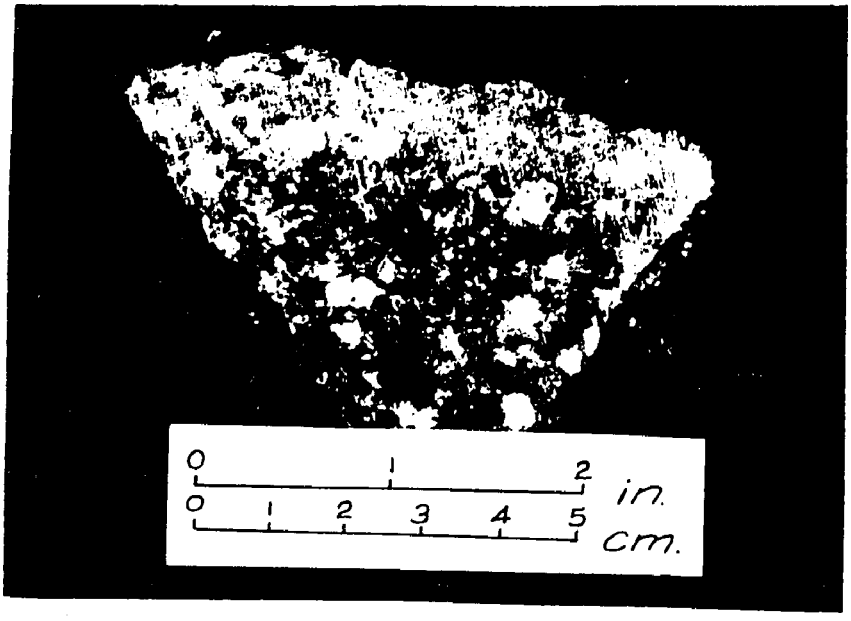
FIGURE 29.- Granite

Typical weathering of granite. Blocks of disintegration on top of Eighteenmile Peak. Note how feldspar phenocrysts resist weathering to form knobby surface.

FIGURE 30.- Granite

Granular texture of granite. Parallel striations are sawmarks.




0
1
2
in.
0
1
2
3
4
5
cm.

the composition of a quartz-monzonite. Quartz is an important constituent and makes up about 40% of the rock. The plagioclase has the composition of oligoclase and constitutes more than 1/3 of the total feldspar. Orthoclase, as well as more abundant microcline is present. Most of the feldspar is strongly sericitized and kaolinized. The microcline commonly exhibits perthitic intergrowths with some unidentified plagioclase. Micrographic intergrowths are abundant and in some thin-sections extremely well developed. Figure 31 shows the quartz in the microcline surrounding an earlier plagioclase crystal not involved in the intergrowth. The dark mineral content is much higher than in the granite and many flakes of biotite can be observed. Most of these are, however, greatly altered to chlorite and magnetite. Zircon is again the most abundant accessory mineral.

An aplite dike was observed in the southern part of the pluton. This dike is only a few inches wide, has the same color as the surrounding granite but a much finer texture. A sharp contact exists between the aplite and the granite. Microscopic investigation shows the aplite (specimen 8147) to be composed of quartz, microcline, plagioclase, and possibly orthoclase in small individuals of allotriomorphic habit forming an equigranular fine-grained rock. A few small flakes of biotite make up the only other primary material in the dike. Alteration products include kaolinite, sericite, and chlorite. The last named mineral replaces the biotite.

From the description of the granitic variety of the intrusive it is evident that this rock is quite distinct from the metamorphosed Blacktail granite gneiss. The coarser grain, the absence of gneissic banding and

FIGURE 31.- Granite

Microcline-quartz intergrowth surrounding an earlier sericitized plagioclase crystal. Photomicrograph of specimen 7947. Crossed nicols, 85x .



alignment of minerals, the almost universal sericitization of the orthoclase, the absence of plagioclase and any kind of intergrowth or reaction rims, and the paucity of microcline make the granite easily distinguishable from the granite gneiss.

The differences between the quartz monzonite and the granite gneiss are less, as microcline and oligoclase are abundant in the quartz monzonite, and various kinds of intergrowths occur. However, the metamorphic character of the granite gneiss, as shown in hand specimen and outcrop by the banding and under the microscope by the texture, is distinct enough to make the rock distinguishable from the unmetamorphosed quartz monzonite.

Correlation and age. The pluton along the Continental Divide is the same as described by Umpleby (1913a, p. 42) who mapped it on the other side of the stateline at the head of Willow Creek. Also Shenon (1928, p. 9) mentions the same intrusive. A similar but separate pluton of much smaller size was discovered by Anderson and Wagner (1944, p. 9) a few miles to the south in Lemhi County, Idaho. The intrusive here corresponds to the quartz monzonite variety of the larger intrusive body. Callaghan and Lemmon (1941, p. 8) describe anigneous body of similar composition from the Blue Wing district in Lemhi County, Idaho, southwest of the writer's area. All these intrusives are different from either the Idaho batholith or the Boulder batholith, the two largest plutons in this region.

The nearest exposures of the Idaho batholith are in central Idaho, about 90 miles west of the Tendoy-Beaverhead area. The closest outlier assigned to this batholith is in the vicinity of Gilmore in Lemhi Valley,

Idaho. The mean composition of the Idaho intrusive is a quartz monzonite and the presence of true granites is the exception rather than the rule (Ross, 1937, p. 43). The age of the Idaho batholith is uncertain but is probably early Cretaceous or possibly Jurrassic (Ross, 1928, p. 692).

The Boulder batholith is extensively exposed around Butte, Montana. The nearest outcrops are in the Dillon quadrangle (Winchell, 1914, p. 29). It is described as having a very uniform quartz monzonitic composition in the Butte area. The rock is dark in appearance, due to the presence of abundant hornblende and little less biotite. The feldspars are orthoclase and plagioclase of the composition labradorite (Weed, 1912, p. 31-32). The rock is hence much more basic in character than the intrusive west of Big Sheep Creek Basin. The age of the Boulder batholith is uncertain and the intrusive is shown as late Cretaceous - early Tertiary on the geologic map of Montana (Andrews and others, 1944).

Also the "Pink granite" mentioned by Ross (1934a, p. 35) from the Casto quadrangle seems to be of different composition, although closer related to the intrusive in the Beaverhead Range. It is described as a basic granite of comparatively coarse and irregular texture consisting mainly of two feldspars, biotite and characterized by abundant perthite and micropegmatite. This intrusive is assigned to the Miocene.

Anderson and Wagner (1944, p. 9) state that the granite in the Beaverhead Range is much more alcalic than the rock of the Idaho batholith. The writer believes that the same is true if the granite is compared with the rock of the Boulder batholith and to a lesser degree if compared with the Miocene intrusive in the Casto quadrangle.

A probable early Tertiary age of the intrusive along the Continental Divide could be determined from the available evidence in the Beaverhead Range. Field relations show that the intrusion took place after the Mississippian, as an intrusive contact with rocks of that age has been found. The granite is also younger than the Laramide orogeny as it intrudes folds which originated during this deformation, and as it cuts through a Laramide high angle normal fault. The upper age limit is given by the relation with the Tertiary volcanic rocks. These seem to be extruded on the surface of the previously eroded pluton, as shown at the head of Meadow Creek. Also the boulders derived from the granite and included in some of the agglomerates point to the conclusion that the volcanic rocks are younger. If the assignment of the agglomerates to the Oligocene and Miocene is true this would indicate that the intrusive is pre-Oligocene. As it is post-Laramide it is best assigned to the late Paleocene - early Eocene. Anderson and Wagner (1944, p. 9) state that the granite probably belongs to the group that was intruded in early Tertiary time.

Quartz Veins

Distribution. Veins consisting almost entirely of quartz are present at several places in the Blacktail granite gneiss. Most of these are not shown on the accompanying geologic map (plate I) because they are of too small a magnitude. On the map two quartz veins are indicated in the pre-Beltian complex east of Big Sheep Creek - North Medicine Lodge Basin. But quartz veins do not occur only in pre-Beltian rocks. They intrude Cambrian and Triassic formations in the Armstead area. They intrude the Mission Canyon and cut the thrust contact between this formation and the Blacktail

granite gneiss at the head of Bear Canyon in W. 1/2 sec. 28, T. 13 S. R. 11 W.

Description. The veins consist of massive milky-white quartz much broken by minute joints and faults (specimen 8447). Metallic minerals like chalcopyrite, magnetite and pyrite, can be recognized megascopically in some specimens. The rock is stained with brown and yellow spots of iron oxide and in places is covered by light-green malachite in radiating fibers and crusts.

Microscopic investigation shows that malachite also occurs in small veins that cross the rock in all directions. The quartz is very much shattered and commonly exhibits strain shadows. Magnetite and limonite are present in varying quantities. A few cubes of pyrite were noticed. In one thin-section large patches of chlorite are together with minor amounts of sericite.

Age. The relationships as exhibited at the head of Bear Canyon indicate that at least some of the quartz veins are later than the Laramide thrusting and are probably of early Tertiary age, but later than the granitic intrusive from which they were perhaps derived. The possible presence of older quartz veins has not been established.

Lamprophyre dikes

Definition. The dikes are of similar composition and can be classified as lamprophyres. As the rocks are greatly altered the original composition is uncertain and the more general term lamprophyre in the sense of a dark dike rock is prefereed to a more definite name dependent on the primary minerals present.

Distribution. In the southwest part of the Tendoy-Beaverhead area three basic dikes of limited extent were mapped. One occurs in Mississippian limestone in the N.W. corner of sec. 25, T. 15 S., R. 12 W. The second and third dike are both in a shaly member of the Mississippian. The second one lies in the southeast corner of sec. 27, T. 16 S., R 11 W., and the third one in N.W. 1/4 sec. 7, T. 17 S., R. 10 W. All three dikes are exaggerated in dimensions on the geologic map (plate I) in order to be shown. They are not more than 30 feet wide and do not have an exposed length of over 100 feet.

Description. Microscopical investigation (specimens 5347, 5747, 5847, 7647) shows that quartz occurs in veinlets and small clusters and is of secondary origin. Only remnants of feldspars are present, and some sericitic masses may represent completely altered crystals. The main dark mineral is augite, which is light purple in plain light under the microscope. It is the titaniferous variety and commonly exhibits a very distinct dispersion. Some augite crystals are strongly altered and a few consist almost entirely of an aggregate of chlorite, carbonates, iron oxides, and quartz grains. Alteration minerals such as chlorite and carbonates constitute an important part of the rock. In places the chlorite exhibits a distinct fibrous radial structure (specimen 7647). Other minerals are biotite, magnetite, apatite, sericite, limonite, and hematite. The dike on the Continental Divide at the head of Trail Creek (southeast corner of sec. 27, T. 16 S., R. 11 W.) locally contains abundant sphene in clusters and in individual crystals with a longest dimension up to 0.6 mm. (figure 32).

FIGURE 32.- Lamprophyre

Large crystals of sphene. Photomicrograph of specimen 5747. Nicols not crossed, 85x .
A - Augite
S - Sphene
C - Chlorite



Age. The age of these lamprophyre dikes is not clearly indicated. The dikes are most likely of Tertiary age and may be a differentiation product of the pluton along the Continental Divide for all are close to this intrusive.

Acid and basic hypabyssal bodies

Definition. Several igneous bodies of uncertain origin occur in the Tendoy-Beaverhead area. They all contain rocks whose features indicate a shallow depth of intrusion, but the compositions vary.

Distribution and Description. At the northern end of Muddy Creek Basin along Sourdough Creek a porphyry of limited extent is present. The rock is resistant to erosion and forms a cliff. In a hand specimen small phenocrysts of feldspar can be seen in a dense light pinkish groundmass. Microscopic investigation (specimen 4745) shows the presence of quarts in the groundmass which seems to consist mainly of orthoclase and some small grains of hornblende. Most of the orthoclase is altered to kaolinite. The groundmass is very fine grained and the relative abundance of the minerals can only be estimated. Hence the overall composition of the rock is not accurately known. Phenocrysts are fresh, unaltered oligoclase crystals. A few, long, flakes of brown biotite are conspicuous. The rock has approximately the composition of a rhyolite-porphyry, with a distinct paucity of dark minerals. It probably represents the intrusive equivalent of the extensive tuff beds of rhyolitic composition in Muddy Creek Basin.

Brant and others (1949, p. 85) describe an andesite from Garfield Canyon clearly intrusive into Triassic rocks. It has the same mineralogical composition but a coarser texture than the prevailing Tertiary lava flows in this area. This intrusive is interpreted as a feeder to the flows.

In NW 1/4 sec. 11, T. 14 S., R. 11 W., an andesite (?)-porphyry probably represents a shallow intrusive. It occurs in an area of pre-Beltian rocks, but the relations with the older rocks are uncertain and it is not known whether the porphyry is intrusive or extrusive. The rock texture suggests a hypabyssal body (specimen 4446). The rock is grayish-green, distinctly porphyritic and probably of andesite composition. It is so badly altered that no definite identification is possible. No quartz was observed. Feldspar occurs as large phenocrysts as much as 4 mm. in length. The crystals are commonly well developed but mostly altered to sericite, which gives a green color to the feldspar in the hand specimen. Under the microscope some of the phenocrysts have only the outline preserved. Others show indistinct albite lamellae. The composition of the plagioclase is probably oligoclase. The same feldspar occurs as small laths in the groundmass the rest of which consists of a great number of small magnetite grains, chlorite, biotite, colorless mica, and a little hematite. Although the relationships to the pre-Beltian are not clear, this rock is not of pre-Beltian age for it differs completely from any other rocks in that complex. As it is much closer related to the Tertiary volcanic rocks in texture it is assigned to that unit.

EXTRUSIVE IGNEOUS ROCKS

General remarks

Extrusive igneous rocks are of greater areal extent in this general region than intrusive igneous rocks. Extrusives have been described by various writers (Ross, 1934b; Umpleby, 1913a; Kirkham, 1927; Shenon, 1928; Anderson and Wagner, 1944) from the Lost River, Lemhi, and Beaverhead Ranges, as well as from the Snake River Lava Plateau, where flows of Quaternary age cover almost the entire surface.

In the Tendoy-Beaverhead area the extrusive igneous rocks are part of the "Basin Beds", which contain important quantities of tuffs, bentonites, and other products of volcanic activity. Deposits containing additional material of undoubtedly sedimentary origin or showing features that indicate that they were deposited in bodies of water have been described under the heading "Basin Beds". In the present chapter the more distinctly igneous varieties will be described. In some places this distinction between sedimentary and igneous rocks is hard to make. Especially some tuffs and the agglomerates are difficult to classify. An arbitrary decision had to be made and areas mapped as Tbb ("Basin Beds") on the geologic map (plate I) may include some rocks which could better be designated as igneous. Also the reverse, the inclusion of sedimentary material in areas mapped as Tv (Tertiary volcanic rocks) could not be avoided because of the scale of the map.

The extrusive igneous rocks include rhyolitic flows and tuffs, basalt flows, basalt tuffs, andesite flows and agglomerates.

Distribution. Acid extrusive igneous rocks cover large areas of Muddy Creek Basin. Also Muddy Hole - Kate Creek Basin contains abundant rhyolitic material. In Big Sheep Creek Basin acid extrusives are only in the northern part around Island Butte and are less widespread than basic volcanic rocks. Most of the acid extrusives are tuffs and as they commonly are waterlain, they have already been described under the heading "Basin Beds." Some rhyolitic material exhibiting a distinct porphyritic development may represent a hypabyssal intrusive, possibly a feeder (see under Acid and basic hypabyssal bodies).

At two places rocks of rhyolitic composition may represent actual lava flows. The first locality is north of Island Butte, N. E. 1/4 sec. 8, T. 14 S., R. 11 W. The second locality is southwest of Kidd in sec. 36, T. 12 S., R. 10 W.

Description. The rock north of Island Butte is dense, greenish-gray and has few, small, clear feldspar phenocrysts (specimen 6448). The pitted surface is characteristic. The pits have a maximum length of 4 millimeters and commonly a rectangular or square shape. They are due to the removal of feldspar phenocrysts by weathering. Microscopic investigation shows a cryptocrystalline groundmass probably consisting of a devitrified volcanic glass. In this groundmass a few, mostly small, feldspar phenocrysts are embedded. Most of the feldspar is sanidine, but also some plagioclase crystals are present. Some of the pits are filled with secondary quartz, others with calcite. No primary quartz was observed, but it is assumed that this mineral constitutes the major part of the groundmass. Without knowledge of the

actual composition of the groundmass no accurate name can be given. If the rock contains sufficient quartz the composition comes close to a rhyolite. In view of its texture the name felsite is most appropriate. This kind of texture seems to be characteristic for rocks with more than 26 per cent normative quartz (Grout, 1932, p. 56).

The rock of the second locality, southwest of Kidd, is similar in composition. The outcrop of this acid extrusive rock forms a small rounded hill completely surrounded by the younger Quaternary terrace gravels. It is light colored in shades of gray and brown to pinkish (specimen 6048). Phenocrysts are rather small but conspicuous because of their regular outline and glassy luster. The rock is dense but decidedly less so than the rock from Island Butte. Under the microscope the regular phenocrysts of sanidine are typical and appear more numerous than in the handspecimen. Also quartz occurs as phenocrysts. The groundmass consists of small irregular grains of quartz, fewer feldspar laths, and a large quantity of brown volcanic glass. Flow structures are developed in several places. Locally glass shards are abundant, and the rock has a tuffaceous character. No bedding is evident in the outcrop and no admixture of foreign material was noticed, hence the rock does probably not belong to the group of waterlaid tuffs. It is more likely to represent a lava flow with admixture of some volcanic ash.

Age. The rhyolitic extrusive rocks seem to be the oldest unit of the Tertiary volcanics. The deposits of Muddy Creek Basin, which consist for the larger part of rhyolitic waterlaid tuffs probably belong to the oldest "Basin Beds" (Eocene). Also Umpleby (1913a, p. 38) and

Pardee (1913, p. 233) noticed that the rhyolite occurs at the base of the "Basin Beds." The rhyolitic flow north of Island Butte is overlain by the dark colored basic extrusive rock which varies from andesite to basalt and which is the dominant extrusive in Big Sheep Creek Basin (see figure 33). That the andesite-basalt sequence is younger than the rhyolitic unit is also shown in Muddy Creek Basin where the dark colored extrusives overlie the basin. The same observation was also made by Wallace (1948, p. 32), who refers to the small patch of volcanic rocks in sec. 27, T. 13 S., R. 10 W. consisting of poorly exposed beds of waterlaid tuffs overlain by basalts. The rhyolite flow north of Island Butte, the rhyolitic hypabyssal intrusive at the northern end of Muddy Creek Basin, and the rhyolitic tuffs of Muddy Creek Basin are all tentatively referred to the Eocene.

The tuffaceous rhyolite of the Red Rock Valley southwest of Kidd possibly belongs to the same sequence. Beds of proved Eocene age are on the opposite side of the valley. On the other hand similar rhyolites of much younger (Pliocene) age have been described from this general region. These rhyolites are younger than the basin extrusives of Big Sheep Creek Basin (Scholten, 1948, p. 34). As the relationship between the tuffaceous rhyolite of the Red Rock Valley and the basic flows of Big SheepCreek Basin and vicinity is unknown, a greater uncertainty exists in the age assignment of this rhyolitic extrusive than in that of the other volcanic rocks of similar composition.

Basalt lava flows

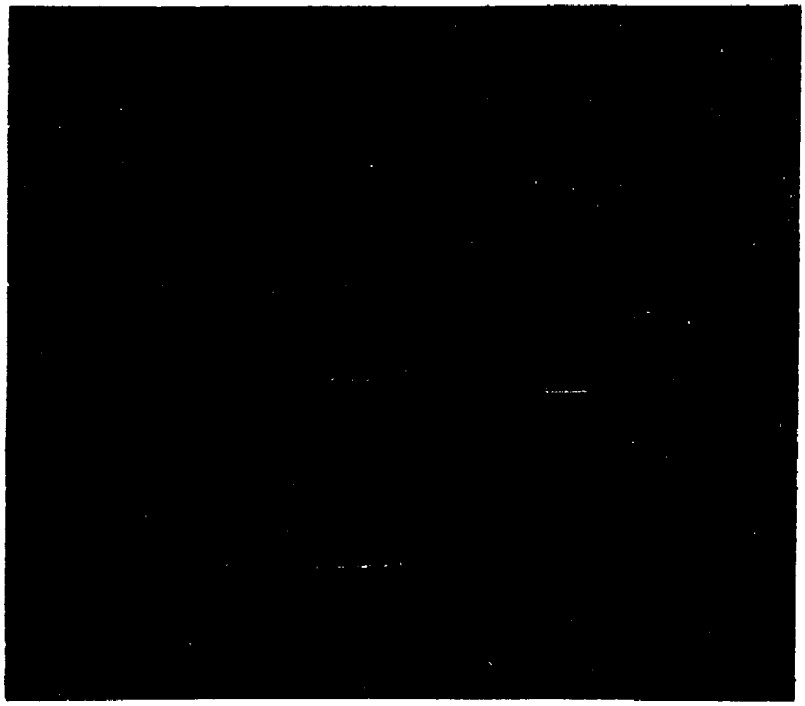
Definition. The basalts of the area do not differ much in composition from the andesites, but in general seem to be distinguished by

FIGURE 33.- Basic extrusives

Basic (basalt ?) lava flow capping rhyolite flow near Island Butte.

FIGURE 34.- Basic extrusives

Hornblende phenocryst with inner rim of magnetite and outer rim of carbonates in basalt. Photomicrograph of specimen 7447. Nicols not crossed, 85x .
H - Hornblende
M - Magnetite
C - Carbonates
G - Groundmass





a great amount of large crystals of brown, basaltic hornblende. No olivine was noticed in any of the basalts. As the composition of the plagioclase can only be determined by optical or chemical means no differentiation between the two rock types was possible in the field.

Distribution. The overall distribution of the basic extrusive rocks is indicated on the geologic map (plate I) by Tv, which includes only minor amounts of acid extrusives. The unit of basic extrusive rocks forms several remnants of a more extensive capping in the Trail Creek Nicholia Creek area. Large parts west and north of Island Butte are covered by dark colored extrusives which viewed from a distance are similar in appearance to the maroon colored Beltian rocks of this area. A good outcrop is north of Law Creek, a tributary to North Medicine Lodge Creek. In Muddy Creek Basin these extrusives are in the western part along McNinch Creek and on top of the divide to Muddy Hole Basin. They are also in the northwestern and northeastern part of the basin. East of Muddy Creek two small areas of volcanic rock, mostly dark colored, are found. In the rest of the Tendoy-Beaverhead area the basic extrusives are rare, and only one remnant is in the northern part of the Tendoy Mountains due south of Armstead. In Garfield Canyon west of the outcrop a hypabyssal body of the same composition occurs. Basaltic flows are north of Meadow Creek and in the vicinity of Island Butte. They are probably present in Muddy Creek Basin, but as no samples were taken here, the exact nature of the dark extrusive rocks in this basin is unknown.

Description. The basalt exposed along Meadow Creek is distinctly porphyritic, greenish-blue, and has a platy habit. Greenish-black

phenocrysts of hornblende, about 1/2 inch long, are prismatic and have their greatest dimension in planes parallel to the joints along which the rock breaks. In these planes the c - axes of the hornblende are unoriented.

Under the microscope (specimen 7447) abundant hornblende phenocrysts can be seen. The hornblende crystals are of the basaltic variety. They are strongly resorbed and commonly surrounded by a dark rim of minute magnetite crystals. Some individuals have a second outer rim consisting of carbonates (figure 34). The interior of the hornblende is mostly fresh, but some crystals show a partial alteration with chlorite and carbonates as the most important products. The groundmass is coarse grained and consists mainly of plagioclase laths with magnetite, augite, and a second generation of hornblende. Alteration minerals in the groundmass are chlorite and carbonates.

Locally brown chert is in the basalt, but this was collected only as loose material on a slope and not in place. White, bluish, and reddish quartz in veins and as incrustations is in place in SE 1/4 section 19, T. 15 S., R. 11 W., where calcite veins also occur. The quartz of the veins is probably due to the desilication of the silicates in the basalt. The silicates are broken down by weathering and silica is liberated and carried in solution into the crevices of the rock where it may be redeposited as veins of quartz (Lobeck, 1939, p. 77).

Age. In the Meadow Creek area the basalt is interbedded with tuffs of basaltic composition. No samples of andesites were collected here and the relationships between the andesites and basalts is not evident in other parts of the area either.

The basic extrusives are older than the "Basin Beds" of Big Sheep Creek Basin, as water-worn pebbles of these rocks are common in the conglomeratic parts of the "Basin Beds".

Basalt tuffs

Distribution. Tuffs with a preponderance of basaltic material are interbedded with basalt flows in the Meadow Creek area, mainly in sec. 30, T. 15 S., R. 11 W.

Description. The tuffs are slope forming and not well exposed. They are light colored in shades of green, purple and gray. Characteristic is the sandy texture, the abundance of small hornblende needles, and the presence of lapilli of purplish-brown color. These lapilli are about 2 inches long at the maximum and have an angular form with rounded edges. The hornblende needles are smaller than the ones described from the basalt lava flows and do not attain a length of more than 3 millimeters. They occur in the cementing material as well as in the lapilli. Microscopic investigation of several representative specimens (6547, 6647, 7247, 7347) shows the universal presence, but a wide range in abundance of plagioclase phenocrysts. In one specimen (7347) they are nearly absent, in another (6647) they are dominant. Hornblende is also universally present. It too shows a great variation in amount, and in specimen 6647 its place is nearly completely taken by biotite. The groundmass is rather coarse and does not have the felted appearance of the andesites, due to the greater irregularity in orientation and the great range in size of the feldspar laths. The plagioclase of the groundmass has the composition of labradorite. Some

volcanic glass is present in places, also hornblende, augite, and magnetite. The tuffs are mainly crystal tuffs with admixtures of pieces of volcanic rocks and sedimentary material. Pockets of this sedimentary material consist of quarts of typical detrital origin and oligoclase. Also orthoclase, hornblende, magnetite, sericite, chlorite, and limonite occur in this material.

Some of the tuffs in SW 1/4 sec. 30, T. 15 S., R. 11 W., are greatly altered. This alteration is so intense that it is most likely due to hydrothermal waters. The rocks have a distinct green and brown color. Microscopic investigation of two specimens (6847, 6947) shows an abundance of secondary minerals. In most parts this alteration has completely obscured the original composition and texture of the rock. The altered part consists of a fine-grained mixture of quarts, chlorite, and sericite with irregular patches of limonite, magnetite crystals and many veinlets of small quarts grains. In specimen 6847 the unaltered part is a pocket of sedimentary material as described above. It consists of loose crystals of quarts, orthoclase, oligoclase, hornblende, biotite, and magnetite. A tuff with pumiceous texture was collected in SE 1/4 sec. 19, T. 15 S., R. 11 W., (specimen 7747). The rock is greatly altered, and because most of the vugs are filled, the pumiceous texture is not evident in the handspecimen. Under the microscope the oval vugs with their longest axis in a common direction are conspicuous (figure 35). The rock consists mainly of alteration minerals like chlorite, limonite, and calcite. It contains pockets of sedimentary material.

Age. The basalt tuffs are in the sequence of basic extrusive rocks together with flows of basaltic composition. These flows overlie the tuffs. The tuffs also contain pieces of volcanic rock that are very similar to the material of the basalt flows. The flows and tuffs are therefore probably interbedded. Due to the poor exposure of the tuffs this relationship is not evident in the field.

The sedimentary material admixed in some of the tuffs has a composition very much like that of the main body of the intrusive along the Continental Divide and was probably derived from it. The presence of a piece of rock exhibiting a well developed micrographic intergrowth supports this suggestion. The basic extrusives are therefore younger than the granitic intrusive.

Origin. The absence of poorly developed bedding and the relative scarcity of pockets of sedimentary material makes it most likely that the pyroclastics were not deposited in a body of standing water. The admixture of sedimentary material in some of the tuffs may be due to reworking of the volcanic ash after its deposition.

Andesite lava flows

Definition. The andesites of the Tendoy-Beaverhead area are very similar to the basalts. The distinction is based only on the plagioclase crystals in the groundmass: andesine in the case of andesites, labradorite in the case of basalts.

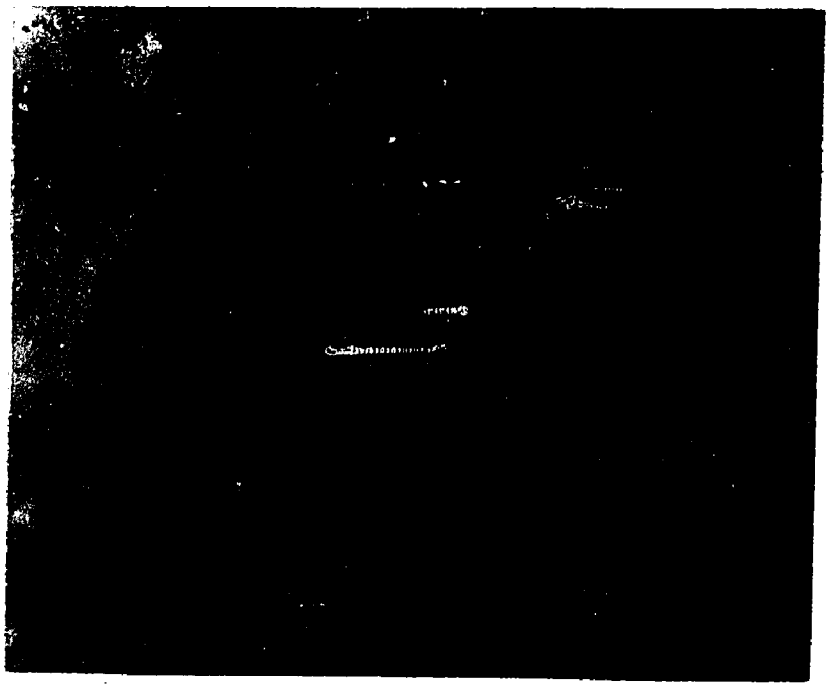
Distribution. Rocks which were identified as andesites by microscopical investigation, were collected from the patches of basic

FIGURE 35.- Basic extrusives

Pumiceous texture with ovoid cavities in basalt tuff. Photomicrograph of specimen 7747. Nicols not crossed, 85x .

FIGURE 36.- Basic extrusives

Andesite lava flow west of Nicholia Creek, with large scale flow structure.





extrusive rocks covering part of the Trail Creek anticline, west of Nicholia Creek. Also the rock exposed in the area south of Armstead has the composition of an andesite. At many other places within the areas of basic extrusives andesites may occur, as more extensive sampling might reveal.

Description. The andesite in the extreme southwestern part of the area is dark colored rock in different shades of brown and gray to black. No large conspicuous crystals can be seen megascopically but the fine grained rock is dotted with many small green, glassy grains of pyroxene. The andesite is generally cliff-forming and has a blocky appearance. Jointing is prominent in the cliffs and in places flow structures on a large scale are evident (figure 36). Dense lava is the most common variety, but minor amounts of vesicular lava are present (specimen 7647). Some vesicles are filled with calcite. The dense rocks in a few places exhibit spherical weathering. When struck with a hammer a concentric outer shell will split from the ball-like interior (figure 37).

Microscopic investigation of several specimens (1447, 1547, 1647, 1747, 4847) all collected in the Nicholia Creek area shows the complete absence of quartz and the dominance of andesine. The feldspar occurs as phenocrysts and as small laths in the groundmass, which has felted appearance. The plagioclase laths commonly have a more acid composition than the phenocrysts. The dominant dark mineral is pyroxene, which is mainly augite. Minor amounts of a rhombic pyroxene (hypersthene) are in most of the thin-sections. The pyroxene is developed as phenocrysts and forms an important part of the groundmass. The phenocrysts occur in many places

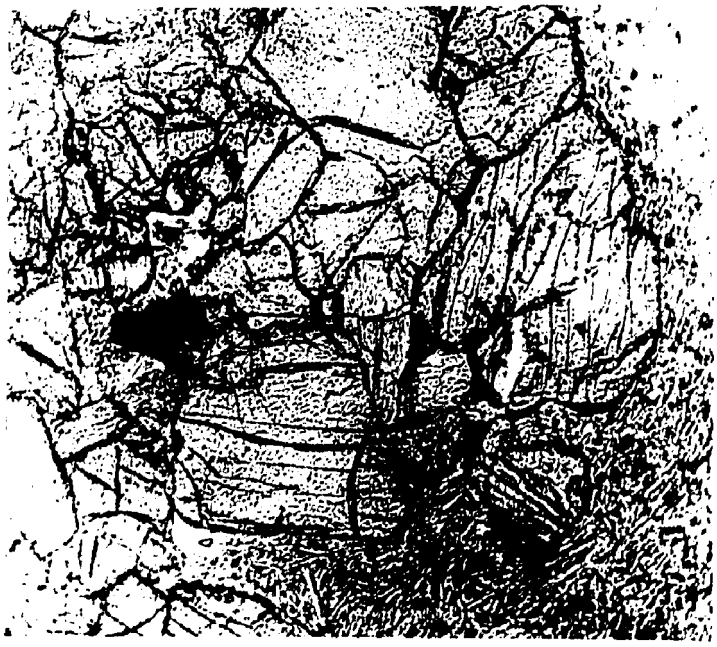
FIGURE 37.- Basic extrusives

Spherical weathering in andesite (SW¼ sec. 23, T. 16 S., R. 11 W.) .

FIGURE 38.- Basic extrusives

Glomeroporphyritic texture: clusters of augite and hypersthene phenocrysts in felted groundmass. Photomicrograph of specimen 1647 (andesite). Nicols not crossed, 85x .





in clusters causing a distinctive glomeroporphyritic texture (figure 38). In addition the groundmass contains various amounts of magnetite, apatite, and a little hornblende locally. Common secondary minerals are iron oxide, and chlorite.

Volcanic glass is also found in the groundmass but is mostly insignificant in amount. In the cliff exposed in SW 1/4 sec. 23, T. 16 S., R. 11 W., it was possible to distinguish megascopically two flows by their difference in color. The lower lava flow is brown, the upper one more yellow. A thin-section of the lower flow (specimen 4747) shows only little volcanic glass in the groundmass, which has the common pilitic texture (figure 39). The upper lava flow (specimen 4847) contains large amounts of volcanic glass in the groundmass, which therefore has a hyalopilitic texture (figure 40).

Some andesites carry green hornblende as phenocrysts and do not contain any pyroxenes. A specimen (6848) from an outcrop along Law Creek shows oriented hornblende crystals, as much as 1/4 inch in length. The rock is grayish-brown where fresh and chocolate-brown where weathered. It forms a prominent cliff along the right side of North Medicine Lodge Creek. A thin-section of this rock shows hornblende phenocrysts, commonly strongly resorbed. Plagioclase also occurs as phenocrysts which are greatly altered. The pilitic groundmass consists of minute but distinct labradorite laths of the composition labradorite. Other minerals are magnetite and chlorite. Some volcanic glass is in the groundmass. Quartz in distinct veinlets is of secondary origin. Andesites described from the Armstead area (Brant, and others, 1949, p. 87) have similar

FIGURE 39.- Basic extrusives

Pilitic texture: felted groundmass with insignificant amount of volcanic glass. Lower part of lava flow west of Nicholia Creek (fig. 36). Photomicrograph of specimen 4747. Nicols not crossed, 85x .

FIGURE 40.- Basic extrusives

Hyalopilitic texture: felted groundmass with large amount of interstitial brown volcanic glass. Upper part of andesite lava flow west of Nicholia Creek (fig. 36). Photomicrograph of specimen 4847. Nicols not crossed, 85x .
G - volcanic Glass





textures. They contain phenocrysts of biotite, andesine (commonly zoned crystals), and hornblende.

Age. The andesite flows together with the basaltic flows form a single unit. As shown above this unit is younger than the rhyolitic unit.

The age relationships within the sequence of basic extrusive rocks is not as clear. The rhyolite around Island Butte is everywhere overlain by basalt, not andesite. This suggests that the basalt is older than the andesite. Pebbles of andesite and basalt in the agglomerates suggest that the basalt is the oldest, as the agglomerates are interbedded with andesites. However, no conclusive evidence as to the relative age of andesites and basalts was obtained.

Agglomerates

Definition. The term agglomerate is used for a deposit consisting mainly of pyroclastics composed of 50 percent or more of large particles with a minimum diameter of 256 millimeters or more. The term does not imply any rounding of the material, nor does it exclude such rounding (Twenhofel, 1939, p. 291).

Distribution. Agglomerates are very well exposed at four places in the area. The first exposure is an isolated outcrop surrounded on all sides by glacial material, about 500 yards west of the place where Nicholia Creek road crosses Trail Creek in SE 1/4 sec. 9, T. 16 S., R. 11 W. The second exposure is in NW 1/4 sec. 26, T. 16 S., R. 11 W. Here the agglomerate is intercalated between flows. The third exposure is on the south side of the first landslide in Nicholia Creek Canyon,

S. 1/2 sec. T. 16 S., R. 11 W. This outcrop is also associated with flows but not clearly interbedded. Figure 41 shows part of this outcrop. The fourth exposure is in the Tendoy Mountains about 1 1/2 miles west of Dixon Mountain.

Description. The agglomerate consists of dark brown and gray pebbles and boulders of basic extrusive rock embedded in a gray, fine-grained matrix. It is resistant to erosion and stands out as a cliff. The material varies from sand to boulders as much as six feet in diameter. Particles of fist size commonly prevail. The material is well cemented and unsorted. In one or two places a faint stratification can be observed, where finer shaly material is along what seems to be a bedding plane. Most of the larger particles are little rounded, some are distinctly angular. Most of the enclosed pebbles and boulders consist of dark-colored basic extrusive rocks, but pieces of Mississippian limestone, quartzite, and granite also are found.

Microscopical investigation of a finer-grained part of the agglomerate (specimen 147) shows that the cementing material is a tuff very similar to the basaltic tuffs described above. It consists of labradorite, basaltic hornblende, and little biotite. In this mass are pieces of andesite showing the felted groundmass of andesine feldspar laths in which are embedded clusters of augite crystals. Pockets of sedimentary material are present as in some of the basaltic tuffs. They consist of quartz, feldspar, biotite, zircon, and rutile. There are also large fragments of basalt with conspicuous dark green to black hornblende needles in the agglomerate (specimen 247). This basalt is similar to the one described above under the heading Basalt lava flows. It

FIGURE 41.- Basic extrusives

Agglomerate on south side of landslide in Nicholia Creek Canyon.



contains large, commonly resorbed, phenocrysts of basaltic hornblende in addition to about an equal amount of augite. Plagioclase crystals are smaller than the crystals of dark minerals but larger than the bulk of the groundmass, which seems to consist of a cryptocrystalline mass of feldspar, sericite, and magnetite.

Age. The agglomerate is definitely younger than the granite, as it contains boulders of rounded granite. The agglomerates are interbedded with some andesite flows in a cliff west of Nicholia Creek in SW 1/4 sec. 23, T. 16 S., R. 11 W. The agglomerate exposed north of Trail Creek in sec. 10, T. 16 S., R. 11 W., contains basalt and andesite rock fragments. Although these observations do not give any definite clue as to the relative ages of the different flows and the agglomerates, it is suggested that in the unit of basic extrusive rocks the basalts are the oldest, the andesites younger, most of the agglomerates still younger, and occurring in the upper part of the andesites.

Origin. Rounded boulders, the faint bedding in a few places, and the admixture of detrital material suggest a deposit of volcano-clastic origin in which running water has played a role. The very large boulders in the exposure near Trail Creek and Nicholia Creek indicate that the site of volcanism was not far. The characteristics of the deposits are those of the large mudstreams which are common on the slopes of several volcanoes on the island of Java. These mudstreams carry large boulders over several miles distance.

Igneous events

Age relationships. The series of igneous events can be described as follows, and has been summarized in table 7. Intrusion of a granitic,

TABLE 7.- Igneous events during the Tertiary

TABLE 7. TENTATIVE SUMMARY OF IGNEOUS EVENTS DURING THE TERTIARY

PERIOD	EPOCH	MAIN EVENT	DESCRIPTION		CORRELATION	
Quaternary	Recent / Pleistocene	Basic extrusives	Basalt lava flows of Snake River lava plateau	Outside Tendoy Beaverhead area		Tertiary late lavas
Tertiary	Pliocene	Acid extrusives	Rhyolite lava flows of Bannock Pass and southern end of Beaverhead Range			
	Miocene	Basic extrusives	Volcanic ash (bentonites), tuffs, lapilli in the conglomeratic parts of the upper "Basin Beds" Agglomerates Andesite lava flows Basalt tuffs Basalt lava flows Some hypabyssal bodies of basic composition, probably feeders to the basic extrusives		Challis volcanics	Tertiary early lavas
	Oligocene					
	Eocene	Acid extrusives	Mainly rhyolite tuffs, lower "Basin Beds", less rhyolitic lava flows. Some hypabyssal bodies of acid composition, probably feeders to the acid intrusives			
	Paleocene	Intrusives	Lamprophyre dikes and quartz veins were intruded after the intrusion of granite and quartz monzonite containing quartz veins and aplites			

locally quartz-monzonitic pluton took place at the end of the Paleocene-beginning Eocene. Probably at the end of the time of intrusion of this body, smaller veins were intruded into the surrounding rocks. At other places and probably at a slightly later time lamprophyre dikes were intruded into rocks close to the granitic pluton. This was followed during the Eocene by some outpourings of rhyolitic lavas, but mainly by the deposition of ash beds of rhyolitic composition. These volcanic products of an acid magma were followed by products of a basic magma. As the rocks belonging to the basic magma are undoubtedly older than the clastic "Basin Beds" of Big Sheep Creek Basin, which are tentatively assigned to the Miocene, the basic unit is probably of Oligocene age. The probable order of extrusion and deposition was: basalt lava flows, basalt tuffs and andesite lava flows, and agglomerates. Interbedding occurs between some of these units. After deposition of the dark colored extrusives the "Basin Beds" were laid down in Big Sheep Creek Basin. In these beds volcanic ashes (bentonites) and some tuffs probably represent the last phase of volcanic activity. South of the writer's area in the vicinity of Bannock Pass two even younger phases of igneous activity are indicated (Scholten, personal communication). These consist of rhyolitic lavas poured out during the Pliocene followed by basalt lava flows during the Quaternary.

Correlation. Volcanic rocks of Oligocene-Miocene age have been described under the name "Challis Volcanics" from Custer and Lemhi counties, Idaho. They were named for exposures near the town of Challis, Idaho. Although first described as being of Miocene age, they are now considered to be: "... possibly, if not probably, of Oligocene age and

they can hardly be younger than Miocene." (Ross, 1947, p. 1121). Anderson and Wagner (1944, p. 11) correlate extrusive rocks just across the Idaho Border with the Challis Volcanics.

Kirkham (1927, p. 31-38) distinguishes between "Tertiary Early Lavas" of Oligocene and Miocene age and "Tertiary Late Lavas" of Pliocene age. The "Tertiary Early Lavas" seem to correspond with the Challis Volcanics and the acid and basic extrusives in the Tendoy-Beaverhead area. The "Tertiary Late Lavas" crop out more to the south where they are described from Bannock Pass (Scholten, 1948, p. 33) and from the southern end of the Beaverhead Range (Anderson and Wagner, 1944, p. 11).

Source of volcanism. The agglomerates are an indication that the source of the volcanic material was close by. Also the presence of some hypabyssal bodies interpreted as feeders to the flows suggests that there were several sources within the Tendoy-Beaverhead area. On the other hand some of the finer material may have been blown in by wind from farther off regions, most likely from the Yellowstone Park region and the Absaroka Range, where volcanic action started already in Paleocene (Fort Union) time (Howard, 1937, p. 4). To the west of the Tendoy-Beaverhead area volcanism was active during later parts of the Tertiary.

Episodes of Orogeny

The rocks of the Tendoy-Beaverhead area were deformed a number of times. The principle disturbances may be listed as follows: Precambrian, Laramide, and post-Laramide.

The local aspect of the structures will be treated first, and then the regional features will be discussed. For a better understanding the reader is referred to the geologic map and the geologic cross sections (plate I).

Precambrian orogenies

In nearby areas at least one episode of pre-Beltian deformation prior to the deposition of the Cherry Creek is assumed by Tansley and others (1933, p. 10). Another episode of deformation was responsible for the metamorphism of the Cherry Creek rocks and the Blacktail granite gneiss. The pre-Beltian deformations are mainly indicated by the metamorphic changes in the rocks. The common alignment of minerals, the development of schistosity and gneissic banding, as well as the typical metamorphic minerals show that the rocks have been subjected to great pressures and high temperatures connected with crustal deformation. In the Kate Creek - McBride Creek area the strike of the gneissic banding is nearly due north, and the dip almost vertical (Perry, 1948, p. 18). The Cherry Creek beds at the headwaters of Kate Creek dip uniformly 15° NE.

The unconformity between Belt and Cambrian is rarely angular in western Montana, which is the reason that many investigators have doubted its existence. Deiss (1935) reviewed the problem and reached the conclusion that the unconformity is present. No evidence to support either view

was obtained from the Tendoy-Beaverhead area. The Belt here is little metamorphosed and not much folded. It seems most likely that the Beltian - Cambrian unconformity, if present, represents a regional or broad folding rather than an intense local deformation. The small-scale folding which occurs in places in the grayish-green quartzites of the Belt (figure 12) is of the type formed prior to the consolidation and induration of the sediment. Because the disturbances that produced these folds took place during or shortly after the deposition of the sediments, they are due to what has been called penecontemporaneous deformation (Shrock, 1948, p. 258-262). The sediments were folded when still hydroplastic (made plastic or highly viscous by much interstitial water). The penecontemporaneous deformation is essentially a surface phenomenon. The folds therefore die out downward and pass into normally stratified undisturbed beds. They will commonly be eroded to some extent before burial and are hence truncated and buried by undisturbed beds. In the Belt the disturbed beds are not wider than about 10 centimeters. Because of its origin this folding is no evidence of large scale crustal movements, which produce secondary, not primary folds.

Laramide folds

General remarks. The first widespread deformation after the Precambrian disturbances took place during the end of the Mesozoic and in the beginning of the Tertiary. It started with a general uplift at the end of the Middle Jurassic. The Kootenai is believed to represent material eroded from the newly uplifted mountains (Eardley, 1949, p. 681). The uplift probably lasted through most of the Lower Cretaceous but was not vigorous during the Upper Cretaceous. To the south and west continued

uplift in Upper Cretaceous time gave rise to the clastic sediments of the Colorado group. In late Cretaceous (post-Colorado) or early Paleocene time folding of the older rocks took place. This folding trends north to northeast and marks the first phase of the Laramide orogeny. The early-Laramide orogeny is very pronounded in the Snowcrest Range. The Beaverhead formation of Paleocene age is for the largest part composed of the coarse grained clastics that resulted from the erosion of the folded mountains. A second phase of the Laramide orogeny took place after the deposition of the Beaverhead formation, which also became folded. Like the first phase the second phase produced folds trending in a general northerly to north-easterly direction. The mid-Laramide orogeny was followed by a third phase: the late-Laramide orogeny, in which major northerly and northwesterly striking thrust sheets overrode the Beaverhead conglomerate. Together with the thrusts folds with the same strike were formed. The late-Laramide orogeny preceded before an extensive interval of erosion which in turn preceded the deposition of the upper Eocene Sage Creek formation.

Laramide folds can be divided into three groups: those which originated during the early-Laramide orogeny, those of the mid-Laramide orogeny and those of the late-Laramide orogeny. Not every individual fold in the area can be definitely assigned to one or the other of these groups, but examples of all the three groups have been selected and will be treated below. The Armstead anticline, the Little Water syncline and the Trail Creek anticline belong to the oldest group. The nearly east trending folds in the Beaverhead formation are assigned to the second group. Examples of the youngest group are numerous northwest

trending folds which are especially well developed in the Carboniferous strata.

Armstead anticline. The name Armstead anticline was first used by Brant and others (1949, p. 44), for a large anticlinal structure west of Armstead. The structure was noted long ago by Hayden (1872, p. 145) but no name had been given to it. West of the axis of the central Armstead anticline are a syncline and another anticline and east of it a syncline; thus the complete structure consists of anticline-syncline-anticline-syncline.

The Armstead anticline extends for about 8 miles in the northern part of the area. Its total length is much more but unknown as the northern part of the structure was not mapped. The structure trends generally north-south and is divided into two parts by the west-east trending Horse Prairie valley.

South of Horse Prairie only a small part of the anticline is exposed. The axes of the western syncline and the central anticline converge here and plunge to the south, and southwest respectively. The axis of the easternmost syncline is not exposed but is covered by alluvial material of the Red Rock valley. At the southern extremity of the Armstead structure some smaller cross folds occur which die out over a short distance. An east-west elongated dome here consists of the Madison group, Amsden and Quadrant formation.

North of Horse Prairie the axes of the four composing folds are more or less parallel. The central anticline is asymmetrical with steeper dips on the east side. The flanks are composed of rocks that range from pre-Beltian to Kootenai, and the core consists of Blacktail

granite gneiss in the southern part and of presumably Pony rocks more to the north. Still farther north outside the mapped area Cherry Creek seems to make up the core. The outcrop of pre-Beltian rocks is about 1.5 miles wide and continues for about 7 miles. On the east side of this core a normal sequence consists of Cambrian, Devonian, and Mississippian rocks. The youngest formation is the Lodgepole, exposed along U. S. highway 91. In the northernmost part of the lower beds are broken by at least nine crossfolds, but of which most are too small to be shown on the geologic map but two of the larger ones were mapped. On the western side of the major anticline the lower Paleozoic formations are cut out by a normal fault which forms the western termination of the core. The Cambrian formations are partly preserved in only one place. On the downthrown western side of the fault is the Madison group, dipping approximately 35° W. West of the Madison the Amsden formation lies in normal sequence followed by three ridges of Quadrant quartzite separated by valleys in the easily eroded Phosphoria. A syncline with a Phosphoria core and Quadrant flanks, and a normal fault west of this syncline account for the repetition. The Triassic is in normal sequence west of the Phosphoria. The Jurassic is absent, or so poorly exposed that it was not recognized and the Triassic seems to be overlain directly by the Kootenai.

Little Water syncline. The name Little Water syncline was first employed by Wallace (1948, p. 36) and Krusekopf (1948, p. 39), who used it for the synclinal cross fold in secs. 2 and 10, T. 13 S., R. 10 W. This structure was named after Little Water Canyon which is eroded in the northeast end of the fold. After the structure of this general area became better known, the name Little Water syncline was used to designate

the much larger structural basin of which the original Little Water syncline represents a cross fold in the northeast part. As used in this report the Little Water syncline comprises all of the almost closed structural basin occupying the eastern part of T. 13 S., R. 10 W. This basin bifurcates in its northern half into two cross synclines, the northeastern of which is the original Little Water syncline and the northwestern of which is unnamed. These two cross synclines are separated by an anticline. The complete structure approximates the form of a heartshaped bowl.

The Little Water syncline is about 4 miles wide and 7 miles long. As it is terminated on the west side by a normal fault, it was probably still wider originally and almost quaquaversal. On the east side the basin is truncated by another high angle normal fault. The whole structure has been thrust upon the Beaverhead formation. This thrust contact forms the northern and southeastern termination. In its northwestern part the basin is overlain by another thrust sheet. The Little Water syncline trends generally north-south, and forms both a structural and topographic depression. Small parts of the structure are covered unconformably by patches of Tertiary volcanics, Beaverhead conglomerate, Quaternary landslides, and alluvium. The eastern limb of the syncline is a thick series of Paleozoic and Mesozoic sediments dipping from 20° to 30° W. In the western limb the dips are shallower and the formations expose wider outcrops; thus the structure is asymmetrical. The formations involved in the folding range from Mississippian to Cretaceous. The western limb exhibits only part of the Triassic, the Jurassic, and the Cretaceous. The eastern limb consists of Mission Canyon at the base, and Amsden,

Quadrant, Phosphoria, Dinwoody, Woodside, Thaynes, Sawtooth, Kierdon, Swift and Morrison successively above. The Kootenai formation is in the core of the syncline.

The cross synclines in the northern part of the structure strike northwesterly and northeasterly respectively. The northeasterly trending Little Water syncline sensu strictu is better known, because better exposed. It is asymmetrical with steeper dips on the north side. It dips southwest and merges with the larger structural basin. In the northwest part the synclinal cross fold is broken by two small faults. Along both faults the block on the north side has moved up relative to the south block,and brings the Dinwoody against the Thaynes.

Trail Creek anticline. The name Trail Creek anticline is applied by the author to the structure exposed in the center of T. 16 S., R. 11 W. Trail Creek follows approximately the axis of the major anticline. More to the east is a syncline which minor structure will be included in the name Trail Creek anticline.

The Trail Creek anticline is about 3 miles wide and has an exposed length of only 2 1/2 miles. Its western termination is formed by an unconformable cover of Tertiary volcanic rocks and part of the pluton along the Continental Divide. At the north and east the anticline is covered by glacial deposits of Nicholia Valley, which conceal the contact between the Belt rocks in the anticline and the Madison on the opposite side of Nicholia Creek. This contact is presumably a thrust along which the whole Trail Creek anticline was superimposed onto the Madison. The southern extension of the anticline into Idaho was not mapped. In the

southeast part it is bounded by high angle faults. The structure is partly covered by Tertiary volcanic rocks and Quaternary landslide material. The central part of the anticline is eroded into a valley, the flanks form high mountains. The structure has a north-south strike and plunges to the south. The southern part is broken by a transverse high angle normal fault along which the southern block has come up relative to the northern block and has brought white quartzites (Kinnikinic?) in contact with the Madison. On the eastern flank of the asymmetrical anticline the beds dip at an average angle of about 30°. Dips are shallower at the western flank and average about 20°. The anticline is composed of Precambrian and Paleozoic rocks. The core contains maroon colored Beltian quartzites which are flanked by white quartzites assigned to the Kinnikinic (?), but which may be Belt. These are overlain by poorly exposed shales that probably represent the Threeforks. Above these are thin-bedded Lodgepole limestones and Mission Canyon beds. The Lodgepole is very well exposed at the headwaters of Trail Creek.

The Trail Creek anticline has been interpreted as an Early Laramide fold because of its northerly trend and because its relationship to later thrusting is similar to that of the Little Water syncline. The reason for assuming that the entire Trail Creek anticline has been thrust upon the Madison will be discussed under the heading Laramide thrusting.

After the thrusting that brought the Trail Creek anticline in its present position, the granite intruded the western part of the structure and cut through the western transverse fault. This fault is therefore older than the intrusion and belongs to the Laramide faults.

The granite intrusion, being younger than the fault and older than the Oligocene-Miocene mafic volcanics, can thus best be assigned to the late Paleocene or early Eocene.

Northeast folding of Beaverhead conglomerate. After the Armstead anticline, the Little Water syncline, and the Trail Creek anticline were formed as a result of the early-Laramide folding with its northerly trend, deposition of the Beaverhead took place. This is shown by the unconformably relationship of the Beaverhead conglomerate to the older structures as in sec. 9, T. 12 S., R. 10 W. and several other places outside the Tendoy Range.

The Beaverhead itself is also folded and as these folds commonly show a different trend than the prevailing northwesterly trend of the late-Laramide orogeny, it is assumed that an intermediate disturbance was responsible for most folds in the Beaverhead. Evidences for this mid-Laramide orogeny are not abundant in the Tendoy area, but abound in adjacent areas where the Beaverhead is more extensively exposed.

In the conglomeratic beds of the Beaverhead stratification is commonly not well developed and folding is not obvious. In the large area of Beaverhead rocks southwest of Kidd the intercalation of the fresh-water limestone makes it possible to determine strike and dip of the beds. No closed folds were observed but the steep dip (mostly around 40°, in places even vertical) indicates that the beds were deformed. The strata strike slightly north of east. In nearby areas a northeasterly trend was noticed.

Northwest folding. The late-Laramide orogeny produced very pro-

nounced changes by imposing distinct northwesterly structures on the older strata. Not only folds of this direction originated but also thrusts. The thrusts will be discussed under the heading Laramide thrusts. The northwest direction of the structures prevails and is superimposed on the older folds, in places almost obliterating them.

Northwest striking folds can be observed in many parts of the area. They are especially well developed in the Madison and the Quadrant. They were mapped in the Beaverhead Range in the vicinity of Lake Gulch secs. 21, 22, and 27, T. 14 S., R. 12 W. A syncline lies north of an anticline and clearly plunges to the southeast. Its northern flank consists of Madison, Amsden and Quadrant which dip 25° SW. The southern flank consists of Quadrant; the Amsden and Madison are not exposed. In the anticline only the Quadrant crops out. Several northwest striking folds are in the ridge between Big Sheep Creek Basin and Muddy Creek Basin. They are especially well developed south of Ellis Peak, where they occur in the Madison. In the Tendoy Mountains northwest trending folds were observed at several places.

Minor folding is conspicuous in the Brazer (?) limestone. These folds are on the ridge north of Tex Creek, near the head of the canyon in sec. 2, T. 15 S., R. 12 W. Here the minor folds give a very complicated appearance to the beds which lie nearly horizontal where the minor folds are absent. The intensely folded masses seem to have an irregular distribution, a fact also noticed by Ross (1947, p. 1131). He describes a similar folding in the Brazer limestone of the Lemhi Range and believes that it is due to erratically applied localized forces and formed under relatively thin cover.

Laramide thrusts

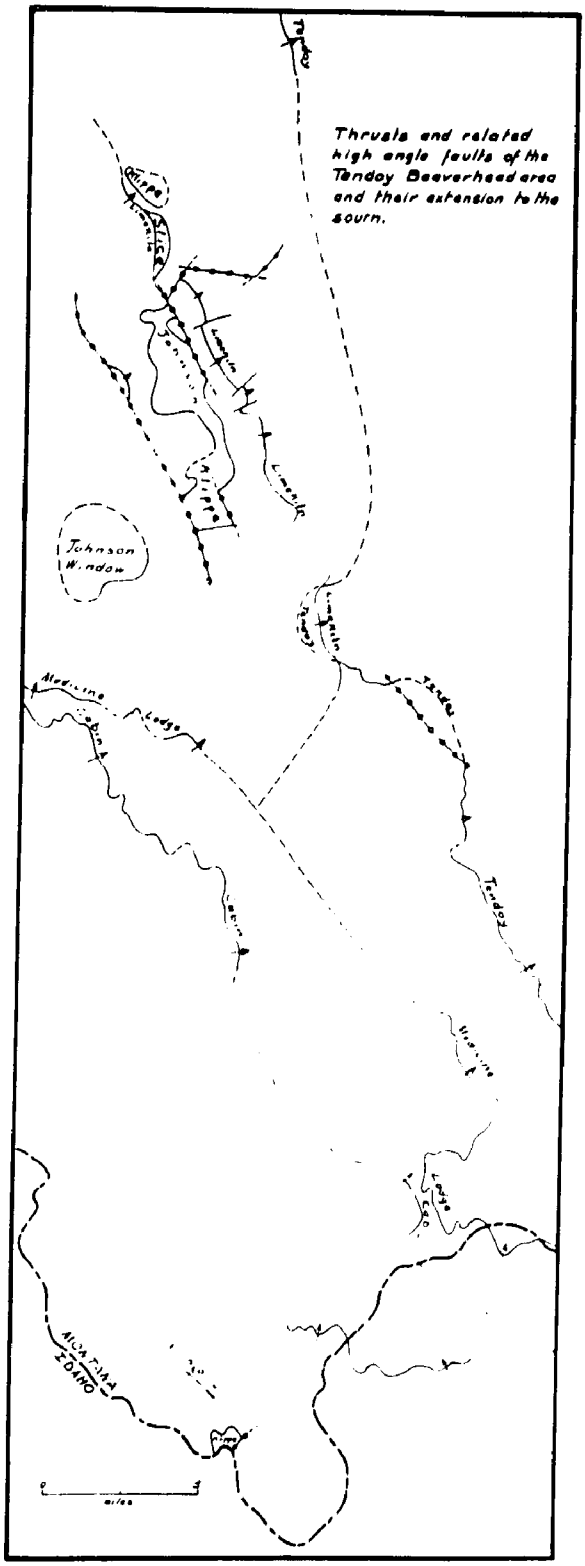
General remarks. Laramide thrusting took place during the late-Laramide orogeny of presumably late Paleocene or early Eocene age. The thrusting involves the Beaverhead formation of Paleocene age and is considerably older than the late Eocene Sage Creek formation. Compressional forces produced six different thrusts (figure 42) in the Tendoy-Beaverhead area, all trending in a general northwesterly direction. The thrusts overlie each other in an imbricate fashion. Not enough data were obtained to give horizontal and vertical displacements of these thrusts, but it is likely that the horizontal displacement must be measured in miles. Folds of northwesterly strike were also produced during the late-Laramide orogeny.

Tendoy thrust. The Tendoy thrust is the easternmost thrust and extends along the front of the Tendoy Mountains. It is clearly an extension of the frontal thrust south of Big Sheep Creek. The name Tendoy was tentatively applied by Wallace and Krusekopf (1948, p. 39) for a thrust under Muddy Creek Basin, which here is called Limekiln thrust. In the early stages of mapping the overall picture structurally was not known, but it now seems advisable to call the main thrust under the Tendoy Mountains the Tendoy thrust.

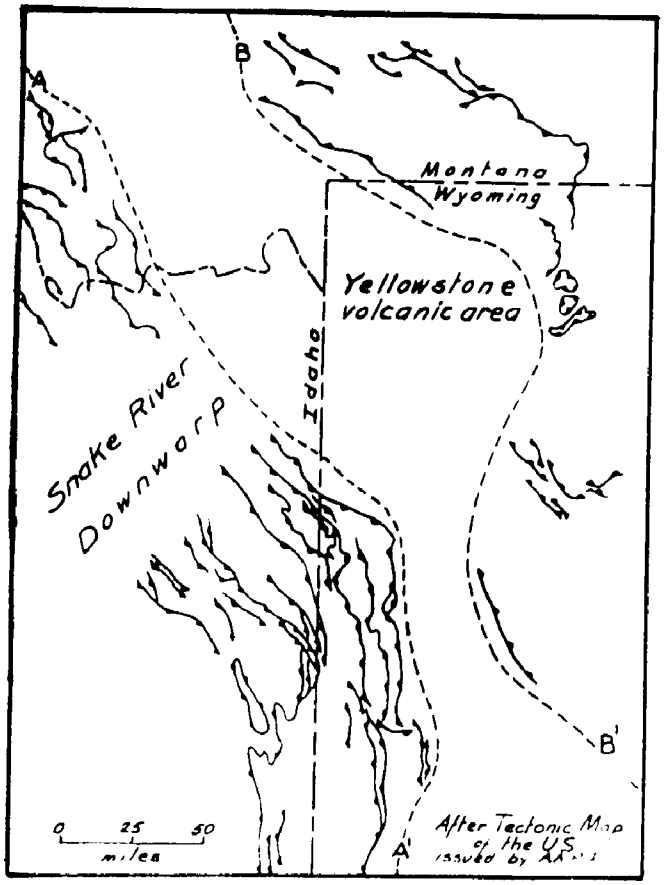
In the Tendoy-Beaverhead area only parts of the Tendoy thrust are exposed. Other parts are dropped by later high angle faults and are covered by Quaternary terrace gravels. At the mouth of Big Sheep Creek the Mission Canyon is thrust upon the Beaverhead conglomerate. The Mississippian limestone is highly contorted into a series of tight

FIGURE 42.- Tectonic features

Upper right map: Distinct parallelism of mountain ranges in eastern and western belt of thrusting. Diversity of trends in the intermediate belt.
Lower right map: Eastern and western belt of thrusting separated by intermediate belt. Snake River downwarp.
Left map: Thrusts and related high angle faults of the Tendoy-Beaverhead area and their extension to the south.


Thrusts and related high angle faults of the Tendoy Beaverhead area and their extension to the sourn.
Johnson Window
Lemhi Range
Tendoy
Lemhi
Lost River Range
Mountains
Idaho
0
miles


Idaho Falls
Pocatello
After Reiss


A
B
Montana
Wyoming
Yellowstone volcanic area
Snake River Downwarp
Idaho
B'
A'
0
25
50
miles
After Tectonic Map of the U.S. issued by

and broken folds overturned to the east (Wallace, 1948, p. 40). About a mile north of the canyon the thrust cuts across the formations and brings the Quadrant on top of the Beaverhead. The strike in this area is north-south and its northern part is cut off by a normal fault. The thrust reappears north of Little Water Canyon, where it trends northwest and brings Quadrant on top of Beaverhead. At its western end this part of the Tendoy thrust disappears under the Limekiln thrust.

The whole structure described under the name Little Water syncline is part of the Tendoy thrust and overrides the Beaverhead conglomerate. The Tendoy thrust emerges from beneath the Limekiln thrust in Kelmbeck Canyon only to be covered again by Quaternary terrace gravels about 1/4 mile farther. It reappears in the northeast corner of the area and can be traced from there on for several miles to the north (Lowell, 1949). It brings Madison on top of the Beaverhead conglomerate. The Beaverhead has not only been overridden, but has also been carried on top of the Tendoy thrust sheet in the Bell Canyon area.

Limekiln thrust. The name Limekiln is given to a thrust fault west of the Tendoy thrust, because it passes conspicuously across the head of South and North Limekiln Canyons.

The southern termination of this thrust is covered by "Basin Beds" of Muddy Creek Basin, but it is believed that the thrust disappears under the Medicine Lodge thrust which overrides it from the west. The most southern exposures of the thrust are west of Timber Butte, where it trends northeast and brings Madison on top of Quadrant. About a mile farther north the trend changes to northwest, and Madison is on top of

Beaverhead. Here the Limekiln covers the Beaverhead conglomerate which lies on the back of the Tendoy thrust. North of Kelmbeck Creek and south of McKenzie Canyon the Limekiln is difficult to trace because there Mississippian limestones rest on Mississippian limestones. In Kelmbeck and South Limekiln Canyon local thrusting in the Madison can be observed (Plank, 1949, p. 21), and a continuous thrust has therefore been assumed between Kelmbeck Canyon and McKenzie Canyon to connect two parts where the thrusting is more obvious. North of McKenzie Canyon the Limekiln thrust trends in a northwesterly direction and can be traced up to Horse Prairie. At the head of Bell Canyon two high angle cross faults cut it. In North Limekiln Canyon one fault causes a displacement.

In most places Madison has been thrust upon Quadrant or Amsden, but also Madison on Madison was mapped. Steep dips and overturning of beds are in the Mississippian limestones along the thrust front. At the head of Garfield Canyon the thrust is broken by a high angle fault and the fault trace is displaced to the west. West of Garfield Canyon the thrust brings limestone of the Madison on Quadrant, Phosphoria, Triassic rocks, and beds as young as the Kootenai. Here the fault plane breaks into two parts and a slice of Madison and some Quadrant and Amsden is present. To the east of this a klippe of the Limekiln, partly covered by older alluvium, contains the same formations in the same orientation as in the slice.

The Limekiln lies upon the back of the Tendoy thrust and is overlain by the Johnson and Medicine Lodge thrusts. Large areas of the Beaverhead cover the back of the Limekiln south of Horse Prairie and north of Kissick Canyon. Other parts show distinct folding like the syncline north of Baker Canyon.

Johnson thrust. On the Limekiln thrust sheet large areas of pre-Beltian rocks are part of another thrust sheet here named the Johnson after Johnson Gulch at the head of which the thrust is exposed. The structural pattern of the Johnson thrust is very complicated, and especially in the southern part the relationships are not well understood.

In the vicinity of McBride Creek the thrust brings pre-Beltian, Cambrian, Devonian, and Mississippian on top of Madison of the Limekiln. Between Kate Creek and Warm Springs Creek a large area is interpreted as part of a window in the Johnson thrust and the Madison limestone exposed belongs to the underlying Limekiln thrust. An extensive area of this window is covered by Tertiary and Quaternary deposits.

The Johnson thrust sheet is divided into two parts by a high angle normal fault, striking parallel to the thrust fault. West of this normal fault the underlying Madison is everywhere covered by the Johnson thrust except in the window described above. The overthrust mass in turn is covered in many places by younger deposits, especially in the northern part where "Basin Beds" conceal large areas of the overthrust pre-Beltian rocks.

East of the normal fault, rocks belonging to the Limekiln thrust are predominant, for the eastern block has been uplifted along the high angle fault. Only two klippes of pre-Beltian rocks represent erosional remnants of the Johnson overthrust mass. The largest extends from the headwaters of Rock Canyon to those of Baker Canyon. A portion of its western contact is concealed by a landslide. It overlies the Madison group, Amsden formation, and Beaverhead conglomerate all belonging to

the Limekiln thrust sheet. In many places its eastern front has been broken by normal high angle faults which have the same structural significance as the large strike fault that divides the Johnson thrust in two parts. Along these faults the east side has come up exposing the Madison of the Limekiln underlying the Johnson thrust fault, (cross sections in pocket). The second klippe between Johnson Gulch and Kissick Canyon is much smaller. The western termination between Johnson Gulch and Kissick Canyon is formed by the high angle fault dividing Johnson in two parts. At all other places erosion has removed the pre-Beltian rocks carried by the Johnson thrust. It has exposed the underlying rocks of the Limekiln thrust as for example the Beaverhead formation in sec. 26, 27, T. 11 S., R. 11 W., which was unconformably deposited on the Limekiln before the thrusting of the Johnson took place.

Medicine Lodge thrust. The name Medicine Lodge was first employed by Kirkham (1927, p. 27) for a north-west trending thrust along the east side of South Medicine Lodge Creek in Idaho. Kirkham estimated the vertical displacement of the Medicine Lodge thrust to be at least 10,000 feet and the horizontal displacement several times that much. The same investigator believed this thrust to be the northern extension of the Bannock overthrust described from the south side of the Snake River lava plains by Richards and Mansfield (1912) but this cannot be demonstrated. The Medicine Lodge has been traced for several miles into Montana by Scholten (personal communication). It superposes Madison limestones on rocks as young as the Beaverhead.

In the Tendoy-Beaverhead area a thrust fault west of the Johnson and partly covering it brings the Madison on top of Amsden and Quadrant. This

thrust trends more westerly than northwesterly between Muddy Creek Basin and North Medicine Lodge Basin. It is especially well defined on the south side of Graphite Mountain, but is partly concealed by "Basin Beds" of Muddy Hole Basin and Kate Creek Basin and disappears underneath these beds in Muddy Creek Basin. Although its southern extension is unknown it projects toward and is probably a continuation of the Medicine Lodge thrust which disappears under the "Basin Beds" at the south end of Muddy Creek Basin.

Cabin thrust. A few miles west of the Medicine Lodge another fault was formerly described under the name Beaverhead thrust (Kupsch, 1948, p. 62). It was believed to be the same thrust as in the Nicholia Creek Basin area in the Beaverhead Mountains. More extensive investigation, however, has shown that the two fault traces cannot belong to the same thrust. It is therefore proposed to use the name Cabin for the thrust east of Big Sheep Creek Basin. The name is taken from one of the main streams in the basin and seems more appropriate than Beaverhead, as the ridge in which the thrust is exposed is not part of the Beaverhead Mountains.

The Cabin thrust extends from sec. 13, T. 14 S., R. 11 W., in a northerly and a northwesterly direction to North Medicine Lodge Creek. At its south end it disappears under "Basin Beds" but emerges again south of Big Sheep Creek where it can be traced for another few miles to a cover of younger material at Bannock Pass (Scholten, personal communication). Where exposed the Cabin thrust brings pre-Beltian rocks in contact with Mississippian limestones. In its northern part, where the fault contact between the pre-Beltian and the Madison

is very well exposed in the Gulch leading to Sweeney's mine, the thrust has the steep dip of 60° W. It is not known if this steep dip prevails all along the thrust.

The western part of the thrust has been down faulted along high angle faults bounding Big Sheep Creek Basin, and Belt strata are exposed in the northern part of the basin. In the southern part the Belt is unconformably overlain by Tertiary and Quaternary deposits. The Belt is presumably underlain by pre-Belt, which rests with a thrust contact on the Mississippian strata. On the west side of Big Sheep Creek Basin the Cabin thrust is not exposed because the block rose so high that erosion removed all overthrust strata and exhumed the underlying Paleozoic rocks.

Nicholia thrust. In the southwestern part of the Tendoy-Beaverhead area a sixth and most western thrust is found. It is named after Nicholia Creek. It had previously been named Beaverhead thrust (Kupsch, 1948, p. 62) and it was postulated to be the same thrus t as the one now named Cabin thrust.

Field work during the summer of 1948 revealed the existence of a klippe of Belt rocks superposed on Mississippian limestones in sec. 25, T. 16 S., R. 11 W. It was therefore assumed that the Trail Creek anticline, which for the greater part also consists of Belt, was superposed in the same manner on the Madison of the east side of the creek, although the fault trace is completely concealed. In view of the changes made in the structural interpretation of this area and the uncertainty which exists in regard to the existence of the thrust fault, the writer prefers to discard the name Beaverhead thrust and use the name Nicholia

thrust instead for the inferred thrust east of the Trail Creek anticline and the well-exposed klippe south of that anticline.

Laramide normal faults

General remarks. Besides folding and thrusting, normal faulting took place during the Laramide deformation and most likely in the last stages of the late-Laramide orogeny. However, most of the larger northwest trending normal faults are due to the post-Laramide disturbance. It is not everywhere possible to assign the normal faults to either one of these two groups.

Examples. A good example of a high angle normal fault of Laramide age is at the south end of the Trail Creek anticline, along the Continental Divide. This fault trends in an east-west, then in a northwesterly direction. It brings white quartzite (Kinnikinic ?) in contact with limestone of the Madison group. The northern part of the fault appears to be cut by the granitic intrusive. The north end of the fault disappears under Tertiary volcanic rocks, which is an indication of the Laramide age of the fault. The same kind of faulting occurs a few miles southwestward in Idaho around the Viola Mine, described by Anderson and Wagner (1944, p. 12). These authors write: "Many of the faults appear to have been accompanied or to have been more or less closely associated with the (Laramide) folding. Among these are the faults that have brought limestone of Middle and upper Paleozoic age in contact with Ordovician quartzite."

In other parts of the area faults of Laramide age are probably present, but the relationships commonly are not so well exposed. The intricate fault pattern at the headwaters of Kate Creek and Warm Springs Creek

may have originated during the late Laramide orogeny. The large northwest trending fault that divides the Johnson thrust into two parts, is, however, due to the post-Laramide disturbance.

In theTendoy Mountains several northeast or east trending faults are probably of Laramide age. Two faults of this type are in the Little Water Canyon. Others break the Limekiln thrust in Bell Canyon and North Limekiln Canyon. These faults are clearly younger than the Beaverhead conglomerate and also normal and younger than the thrusting. If they belong to the Laramide deformation, they are part of its latest phase.

In the Armstead area the north-south trending high angle normal faults on the west side of the anticline and the smaller cross faults on the east side are perhaps Laramide in age (Brant and others, 1949, p. 45).

Post-Laramide disturbance

General remarks. After the latest phase of the Laramide orogeny, at the end of the Paleocene, the intrusion of a granitic magma occurred in the western part of the area, followed by a long episode of erosion during lower, middle, and early upper Eocene time. This erosion was responsible for the formation of the broad intermontane valleys in which the"Basin Beds" were deposited. It is possible that warping and faulting took place and are partially responsible for the basins, but details are not known. In late Eocene time volcanism started and the previously formed basins were filled by volcanic and sedimentary materials. The Tertiary volcanics and "Basin Beds" were locally deformed and gentle folds were produced.

More significant is the high angle normal faulting that took place during and after the deposition of the "Basin Beds." In the area more

to the east, where the ages of various strata in the "Basin Beds" are better known, it has been possible to distinguish three episodes of block faulting (Keenmon, personal communication). The earliest took place during the late Oligocene prior to the deposition of the lower Miocene Blacktail (Deer) Creek formation. The second episode occurred during the late Miocene but before the upper Miocene-lower Pliocene Madison Valley formation was laid down. The third episode of block faulting was at the end of the Tertiary. Renewal or continuation of the faulting in Recent times is indicated at several places along the front of the Tendoy Mountains.

As it was not possible to distinguish separate episodes of deformation the folding and faulting younger than the Laramide movements are treated together as the post-Laramide disturbances.

Folding. The "Basin Beds" clearly postdate the deformation due to the Laramide orogenies, because the beds unconformably overlie the older structures. In these "Basin Beds" gentle folding is evident at some places. This folding belongs to the post-Laramide disturbance. The age relationship of this folding to the Tertiary block faulting is not clearly defined, but it is likely to have taken place before the faulting.

North-south trending folds in the "Basin Beds" have been reported from the Kissick Canyon area along North Medicine Lodge Creek (Seglund, 1949, p. 35). Also in other parts of this intermontane valley folding is obvious. In Big Sheep Creek Basin no folding is indicated, but the beds dip uniformly east. However, gentle monoclinal folds may be

present for variations in dip ranging from 10° to 20° were observed. Tilting accompanying the block faulting produced steep dips in the "Basin Beds".

Faulting. High angle normal faults bound most of the northwest trending intermontane valleys in the area. Movement has taken place along these faults after the deposition of the "Basin Beds." It is uncertain if the folds participated in the formation of the valleys and were rejuvenated after the deposition of the "Basin Beds". As no reliable information about the age of the various "Basin Beds" in the area could be obtained, the minimum age of the block faulting is also unknown, but probably most of the faulting took place during late Tertiary time and in some places even continued into Recent times.

Along the west side of Big Sheep Creek Basin no continuous fault is indicated. The straight escarpment of the Tertiary volcanics between Meadow Creek and Coyote Creek with its well-developed triangular facets seems to represent part of a high angle fault. More to the north a fault is indicated where Belt rocks of the basin are in contact with Mississippian limestones.

High angle faulting is more evident along the eastern ridge of Big Sheep Creek Basin. Here a fairly recent fault is suggested by the escarpment and the triangular facets. The vertical displacement is assumed to be at least 1500 feet, but no accurate determination is possible because no corresponding beds on either side of the fault were found. The fault is almost continuous along the east side of the basin and its southern part trends slightly west of north. The northern part has a more northwesterly direction. In most places the actual fault traces are concealed by various Quaternary deposits.

The escarpments, which are very pronounced at several places in

Big Sheep Creek Basin, are probably composite fault scarps, which owe their height partly to differential erosion and partly to actual movement along the fault (Billings, 1946, p. 163). As the elongate basin is bound on both sides by gravity faults along which it was lowered relative to the mountains on either side, it is a graben. Tilting accompanied the faulting and dips up to 35° were produced in the "Basin Beds." These dips are much too high to be initial. According to Blackwelder (1915, p. 113) it is improbable that fine clays could be deposited at angles as high as 10°. Along another large high angle normal fault in the western part of the area, which divides the Johnson thrust in two parts, the western block has dropped relative to the eastern block. East of it a smaller fault with the same trend bounds the Johnson klippe on the east. Along this fault too the western block has dropped relative to the eastern. The ridge between Big Sheep Creek Basin and Muddy Creek Basin is a horst as it was uplifted relative to the basins along high angle faults. On the northeast side of the ridge two distinct high angle faults are between the ridge and Muddy Creek Basin. In both faults the upthrown block is to the southwest. The more western fault, which overlaps the second one, forms a distinctive scarp of Mission Canyon limestone.

Muddy Creek Basin is a graben comparable to Big Sheep Creek Basin. It is bounded on the west side by two faults as mentioned above. The east side of Muddy Creek Basin is the northwest trending Muddy Creek fault, a high angle normal fault which is very distinct and can be traced southward for more than two miles beyond the limits of the Tendoy-Beaverhead area. Along the Muddy Creek fault the "Basin Beds" were tilted

about 15° east (Krusekopf, 1948, p. 42). The fault dies out at the north end of the basin.

The Tendoy Mountains represent another horst block. Their west side is formed by the Muddy Creek fault. The eastern front is marked by the Red Rock fault, which trends northwest and can be followed discontinuously along the west side of Red Rock valley from the Idaho-Montana border to beyond the northern limit of the Tendoy-Beaverhead area. Along this fault the upthrown block is to the southwest and forms the steep mountain front with its distinct triangular facets near the mouth of Little and Big Sheep Creeks. The fault cuts the Tendoy fault and the underlying Beaverhead formation. The downthrown block is covered with a veneer of unknown thickness of Quaternary gravels mainly in the form of alluvial fans. The vertical throw has been estimated to be at least 1000 feet (Wallace, 1948, p. 41). The escarpment of the Tendoy Mountains is a composite fault scarp.

Movement along the Red Rock fault in Recent time is indicated by earthquakes and the distinct scarplets in the alluvial fans covering the actual fault trace. The scarplets of Recent age are visible from U. S. Highway 91 and have been mentioned by Pardee (1939, p. 355). The earthquake of November 4, 1897, which had its epicenter 12 miles south of Bannock, took place probably along the Red Rock fault (Scott, 1936, p. 3). This earthquake of the Lima-Bannock area was felt throughout southwestern Montana. In Dillon it lasted 40 seconds and was particularly marked during the first 10 seconds. Cracks were formed in many houses, indicating an intensity of 6 on the Rossi-Forel scale.

Regional features

The Paleozoic and Mesozoic sediments of the Tendoy-Beaverhead area were deposited in a general way in the transition zone from the eastern part of the Cordilleran geosyncline to the eastern shelf zone (Eardley, 1949). The aggregate thickness of sediments deposited prior to the first phase of Laramide orogeny seems to be greater to the west than to the east (Ross, 1947, p. 1126).

During the Laramide deformation a great belt of thrust faults was formed along the eastern margin of the Cordilleran geosyncline extending from Wyoming across Idaho into Montana (figure 42). The thrust faults of this belt are overthrust to the east, are generally parallel, and trend northward in south and central Wyoming, then swing to a northwesterly direction in Idaho and Montana. The thrusts described in this report belong to this belt. More to the west the Lemhi-Hawley Mountain and Lost River overthrusts were mapped in Idaho by Kirkham (1927, p. 27), who believes these faults to be overthrust to the west, but Ross (1947, p. 1137) opposes this view and assumes an overthrust to the east. The northern part of this belt of thrust faults is not continuous with the southern part of south central Idaho and Wyoming, but is separated by the Snake River lava plains. The lavas fill a younger downwarp where the belt of thrusts is concealed (Kirkham, 1931). In southwestern Montana the eastern boundary of the thrust belt lies approximately along Red Rock valley. East of Red Rock valley only few thrust faults are reported in a belt extending from this valley to the Madison River east of which is another belt of intensive thrusting.

This eastern belt of thrusts is roughly parallel to the western belt, but shows generally an overthrusting to the southwest. A probable exception is the Heart Mountain overthrust, which by some is believed to have overridded eastward.

The topography of the thrust belts is strikingly different from that of the intermediate belt. In the western thrust belt and to a lesser degree in the eastern one, parallel ranges are dominant, trending north in the southern part and northwest in the northern part. In the intermediate belt diverse trends occur in the parts not covered by younger volcanic rocks.

The topographic expression of the western belt is mainly due to the post Laramide block faulting which is superimposed on the Laramide thrusting and folding. The block faulting trends more or less parallel to the older Laramide thrusts. High angle faults attributed to the post Laramide disturbance occur also in the intermediate belt, but they do not show any strong parallelism and seem to be less numerous. The belt of trenches which approximately coincides with the western thrust belt, can be followed for 2000 miles from British Columbia, all through western Montana into north central Arizona and may represent a rift zone (Kardley, 1947b, p. 1176).

PHYSIOGRAPHY

Regional features

On the physiographic map of the U.S. by Fenneman (1930) the region of the Lost River, Lemhi, and Beaverhead Ranges, in which the Tendoy-Beaverhead area lies is classified as part of the Northern Rocky Mountains Province. As this region is characterized by long, parallel ranges, separated by broad, arid valleys it differs from the dissected upland of the northern Rocky Mountains in central Idaho and can therefore better be regarded as part of the Basin and Range Province. Also Anderson and Wagner (1944, p. 4), and Ross (1947, p. 1140) consider it part of the Basin and Range Province. Ross notes that it has been placed by Fenneman in the Northern Rocky Mountains Province largely because the Snake River Plain separates it from the Basin and Range Province of southeastern Idaho. The eastern boundary of the Tendoy-Beaverhead area seems to be the eastern boundary of the Basin and Range Province for a great diversity of mountain trends prevails east of Red Rock Valley.

Intermontane valleys

Mode of origin. Many of the intermontane valleys in east central Idaho and southwestern Montana are bounded by high angle normal faults (Anderson, 1934). Red Rock Valley, Muddy Creek Basin and Big Sheep Creek Basin belong to this type. At several places fresh scarplets indicate that movements have taken place along the fault planes in Recent time. It is not know, however, if faulting was responsible for the origin of the basins. It is equally possible that erosion or downwarping initiated the basins, and that later faults developed along their

margins. In the Tendoy-Beaverhead area no evidence was obtained to date the faulting with respect to the basin formation.

Umpleby (1913a, p. 17 and 1917, p. 22) assumes that the valleys were formed by stream erosion. Atwood (1916, p. 708) stresses faulting and warping before the "Basin Beds" were laid down. Shenon (1928, p. 5) thinks that the faulting has been recurrent: the first adjustment defined the valleys, later movements brought the "Basin Beds" into fault contact with older rocks. Blackwelder (1915, p. 543) favors the theory that the "Basin Beds" covered a much larger area when they were deposited, that they were downfaulted and subsequently eroded to the broad valleys because they were weak beds between masses of harder rock. The present writer believes that erosion, faulting and warping may have contributed to the formation of the intermontane valleys.

Time of origin. The time at which the basins were formed is also a matter of controversy. Atwood (1916, p. 706) and Umpleby (1917, p. 22) both assume that the intermontane valleys were formed prior to the deposition of the oldest "Basin Beds", presumably during the lower Eocene. Blackwelder (1917, p. 542) does not reject this assumption, but he favors an alternative hypothesis. In this view the "Basin Beds" were first deposited over a wide area without any well-defined basins and later down faulted into the modern narrow troughs. The basins would then be younger than the youngest "Basin Beds" and would therefore be of Pliocene age. The writer believes that the basins of the Tendoy-Beaverhead area attained approximately their present form when they received the "Basin Beds" and that not all had developed by high angle faulting

as required by Blackwelder's theory. It is concluded that the intermontane valleys most probably originated during the interval between the last phases of the Laramide orogeny and the deposition of the Sage Creek beds, which means during the lower part of the Eocene.

Physiographic surfaces

General remarks. In the Tendoy-Beaverhead area three distinct surfaces can be observed. These surfaces have been provisionally called A, B, and C surfaces. Beard (1949, p. 37) correlates them with three physiographic surfaces in the Blacktail Mountains.

A surface. The name A surface is used to designate the erosion surface whose remnants lie at 8000 - 9000 feet above sea level, which is at or a little below the highest altitudes of the area. Most of it is covered by High-level gravel. In the Tendoy-Beaverhead area the A surface is the highest and oldest. Its age and relationship to the other surfaces will be discussed later. The A surface is well preserved in the northern part of the Tendoy Mountains where the summit is flat or gently sloping. The ridge west of Muddy Creek Basin exhibits it where extensive areas are covered by gravel. In the Beaverhead Range the A surface is in part destroyed by glacial action, or shows the effects of later faulting or warping, but in other parts it is clearly indicated and little dissected.

In the Beaverhead Range the A surface has been previously designated as the "summit erosion surface" (Anderson, 1947, p. 65) or as the "summit peneplain" (Atwood, 1916, p. 707). In Idaho it has been called "post-Challis surface" by Ross (1937, p. 89) and "Idaho peneplain" by Mansfield

(1927, p. 354). The A surface can be correlated with the well-developed summit surface of the Salmon River Mountains which stands 8000 to 10,000 feet above sea level (Anderson, 1947, p. 63). The same surface can be recognized over large areas of central Idaho and forms part of the crest of the Lost River and Lemhi ranges.

B surface. Remnants of a second erosion surface at an altitude of 6500 - 7500 feet are parts of a former more extensive pediment beveling the "Basin Beds". This B surface is readily apparent on the west side of the Tendoy Mountains in North Medicine Lodge Valley. In places it is dissected as much as 75 feet. It is particularly prominent in Muddy Creek Basin. Remnants of the B surface also are found in Big Sheep Creek Basin, but in the northern part of this basin it was completely removed by later dissection. On the west side of Red Rock Valley the pediment is covered by younger Quaternary gravels mostly as alluvial fans.

The B surface is probably to be correlated with the Donkey Hills surface described by Ross (1947, p. 1145-1146) from the Borah Peak Quadrangle in Idaho.

C surface. The name C surface is used here to designate the alluvial terraces and floodplains of the modern rivers at a general elevation of 6000 - 6500 feet. It is hence not one surface, but a composite of several surfaces. At many places three levels can be distinguished: two terraces and the present valley flat. All three are lower than the pediment surface. The C surface is depositional as well as erosional.

and can be observed along all major creeks in the area. In the basins it is represented by alluvial terraces, but where the creeks cut the mountains only the flood plain is developed. River terraces occupy the northern and major part of Big Sheep Creek Basin. Two sets are present, but they were mapped as one unit (plate I). The younger is of much lesser extent than the older. Two sets of terraces also were observed along North Medicine Lodge Creek, Muddy Creek, and Red Rock River.

Age relationships. The age of the A surface, which was found over a wide region in Idaho and Montana, has been much discussed in the literature. A summary of these discussions was given by Mansfield (1927, p. 354). The following two opposing views have been advocated:

1. The A surface ("summit peneplain") is older than the "Basin Beds" and probably of Eocene age. This is the older view and it was advocated by Umpleby (1912; 1913a), Atwood (1916, p. 706; 1917), Pardee (1913, p. 235), Lindgren (1918), Livingston (1918), Mansfield (1924; 1927, p. 359), and Perry (1943, p. 6). According to this theory the main events during the Tertiary can be summarized as follows:

   a. Development of A surface (peneplain) during Eocene.
   b. Rejuvenation and formation of intermontane valleys by erosion, faulting, warping.
   c. Deposition of "Basin Beds".
   d. Rejuvenation and differential erosion. Pediment (B surface) was formed beveling the weak "Basin Beds" and the older rocks were maturely dissected with some remnants of the A surface.

2. The A surface is younger than the "Basin Beds" and probably of Pliocene age. Supporters of this view are Blackwelder (1912; 1915, p. 310; 1917), Rich (1918), Ross (1937, p. 88-89), and Anderson (1947, p. 73). The sequence of major events during the Tertiary is according to this theory:

a. Development of an Eocene (?) (pre-Challis) surface having a mature topography with intermontane valleys formed by erosion, warping or faulting.

b. Deposition of "Basin Beds" in the intermontane valleys.

c. Development of the A surface during Pliocene across all rocks, strong and weak.

d. Rejuvenation and differential erosion. The weak "Basin Beds" were reduced to a new plain (B surface), the harder, older rocks maturely dissected with remnants of the A surface.

A modification of the above sequence of events is given by Blackwelder (1917, p. 542). The A surface is assumed to be younger than the "Basin Beds", but the intermontane valleys are accounted for by faulting and warping only. As faulting is not everywhere prominent along the basins and as some of the basins branch in an arborescent fashion suggestive of a drainage system rather than a fault pattern, this sequence of events is not applicable at all places:

a. Development of an Eocene surface with a mature topography.

b. Deposition of "Basin Beds" not in the present well-defined, intermontane basins but spread over the Eocene surface.

c. Formation of ancient intermontane valleys by faulting or down warping.

d. Development of A surface (peneplain) during Pliocene across all rocks, strong and weak.

e. Rejuvenation and differential erosion. Pediment (B surface) formed on the weak "Basin Beds" in the basins. In the mountains a mature topography developed, leaving remnants of the A surface.

The Tendoy-Beaverhead area does not afford conclusive evidence concerning the age of the highest erosion surface. However, the history of the drainage system which will be given below strongly suggests the existence of a peneplain (or at least an erosion surface of low relief) after the deposition of the "Basin Beds" and prior to the development of the pediment surface. The writer therefore prefers the second hypothesis and assumes that the A surface is younger than the "Basin Beds" and probably of Pliocene age. This view is supported by observations in the Blacktail area, which also suggest that the A surface is of Pliocene age (Keenmon, personal communication).

The pediment surface bevels the "Basin Beds" and is therefore younger than these sediments. Glacial deposits overlie the B surface, which is probably of late Tertiary to early Pleistocene age.

The C surface is of Pleistocene and Recent age. The two sets of terraces probably can be correlated with two periods of glaciation: The higher and more extensive one with the Older glaciation and the lower one with the Younger glaciation. The floodplain of the creeks is of Recent age.

Drainage

Modern drainage system. In southwestern Montana and adjacent parts of Idaho many of the major streams follow the broad intermontane valleys

for the most part, but in places cut through the mountains in narrow canyons.

In the Tendoy-Beaverhead area the same feature is evident (figure 2). Nicholia Creek in its upper course follows a narrow valley and crosses Big Sheep Creek Basin. At the east side of the basin it enters a gorge cut in the high ridge of resistant Madison Limestone instead of flowing south across the low and soft "Basin Beds" of Bannock Pass. Cabin Creek follows the east side of Big Sheep Creek Basin, but in its lower course the creek leaves the basin and cuts through the limestone to empty into Nicholia Creek instead of following the basin and to unite there. Beyond the point where Cabin Creek enters Nicholia Creek the two streams together are called Big Sheep Creek which is at first in a narrow gorge and then flows into Muddy Creek Basin. The creek does not leave the basin across the low and easily erodable divide at the head of Little Water Canyon, but instead Big Sheep Creek cuts a canyon through the high and very resistant Quadrant mountains.

History of drainage system. The characteristics of the modern drainage system cannot be explained by normal headward erosion as Umpleby (1913a. p. 29-30) did. Little Water Creek will erode much faster in the softer Mesozoic strata than Big Sheep Creek in the harder Quadrant quartzites, which are of greater areal extent. It would therefore be expected that Muddy Creek Basin would drain across the divide at the head of Little Water Canyon if headward erosion alone were responsible for the present drainage.

Other possible explanations are superposition and antecedency. Both processes probably took place, and the most likely development was as follows. The modern drainage system was preceded in the Eocene by a drainage system which was partly responsible for the formation of the intermontane valleys. It has been assumed by Umpleby (1913a, p.30), Atwood (1916, p. 706-721), and others that this old river system drained to the southeast. After alluviation of the intermontane valleys had taken place the A surface developed across "Basin Beds" and older rocks. On this surface the drainage was to the northeast, much like the present drainage. Trail Creek, the basin part of Nicholia Creek and Big Sheep Creek probably represent the lower course of the ancient Arco River (Anderson, 1947, p. 70) which was part of this system. At the head of Trail Creek is a windgap which is a channel in the A surface containing gravel of the High-level erosion surface. This windgap is in line with two other windgaps in the Lemhi Range and in the Lost River Range through which the course of the Pleistocene Arco River was postulated by Anderson (1947, p. 70-71). This ancient river can be followed across the ridge between Big Sheep Creek Basin and Muddy Creek Basin, where the A surface is very well developed and the older river gravels are preserved. In the Tendoy Mountains gravels composed of water-rounded boulders of Belt and Kinnikinic (?) quartzites lie on a flat-topped hill one mile north of the junction of Muddy Creek and Big Sheep Creek (Kruskopf, 1948, p. 46). As the Belt and Kinnikinic (?) are known only from the Beaverhead Mountains and not from areas to the east of the Tendoy Mountains this is further support for the northeast drainage.

After the development of the A surface the region was subject to a general uplift and differential movements along high angle faults. The Beaverhead Range apparently rose so fast that the Arco River was unable to maintain its course across the range. Its lower, cut-off part consisting of Trail Creek, Nicholia Creek, and Big Sheep Creek was able to keep pace with the block faulting in the eastern part of the area and it cut canyons through the ridges, thereby essentially following its old course. The general uplift of the area caused the pedimentation of the "Basin Beds" in the intermontane valleys.

Glaciation

General remarks. Glacial features are abundant in the Beaverhead Mountains. The Tendoy Mountains on the other hand do not exhibit any signs of glaciation. In the mountains west of Muddy Creek one moraine occurs along McMinch Creek, but this is the only indication of glaciation outside the Beaverhead Mountains, which were probably higher than the rest of the area, and therefore caught most of the precipitation during Pleistocene time.

During two episodes of glaciation the Beaverhead Range had several mountain glaciers which sculptured the rugged parts of the Continental Divide and deposited material in the valleys and along the western part of Big Sheep Creek Basin.

Erosional features. Glacial cirques are at the heads of most major streams in the Beaverhead Mountains. Especially well developed are those of Nicholia Creek and Meadow Creek. Extensive talus slopes now cover the oversteepened cirque walls.

U-shaped valleys were formed below the cirques. Nicholia Creek Valley is a good example. The bottom of the valley is covered by glacial deposits. The tributaries are all at grade and apparently the main valley was not deepened much by the glacier.

An arete forms the Continental Divide at the head of Nicholia Creek. The divide which consists of rugged cliffs and pinnacles is so narrow here that it is almost impassable.

At some places Matterhorn peaks are developed along the Continental Divide. Eighteenmile Peak was surrounded on three sides by valley glaciers which carved the peak into a horn. Two of the glaciers flowed westward down to Leahi Valley and one eastward down Cottonwood Creek.

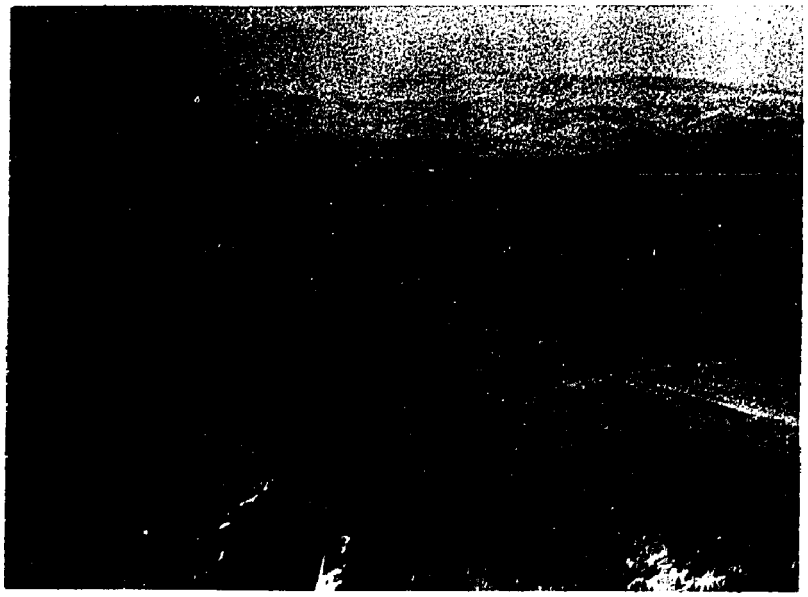
Depositional features. The depositional features indicate two different episodes of glaciation, which are provisionally named Older glaciation and Younger glaciation. The distinction between the two is based largely on topographic expression of their depositional features. The Older glaciation can probably be correlated with the Bull Lake stage and the Younger glaciation with the Pinedale stage as recognized in Wyoming (table 6). The deposits of the two episodes of glaciation are differentiated on the geologic map (plate I).

The morainic material deposited by the Older glaciation has a topography consisting of a series of low, rolling hills. The typical hummocky surface is absent. Glacial lakes that once existed in the old moraines have been completely filled. The till occurs along the mountain front and blends into the highest, most extensive terrace. No large boulders lie on the surface. The Older glaciation was larger in extent than the Younger glaciation.

The glacial deposits of the Younger glaciation are fresh and almost untouched by erosion. Large boulders are still at the surface. A good example are the moraines at the junction of Trail and Nicholia creeks (figure 43). Inside the curved walls of the terminal and recessional moraine a distinct hummocky topography represents the ground moraine. This topography is well preserved at several other places along the west side of Big Sheep Creek Basin and is clearly shown on aerial photographs. Between the knobs and kettles many only partly filled glacial lakes still exist. The moraines belonging to the Younger glaciation are closely related to the present mountain valleys. The valleys of the major creeks in the Beaverhead Mountains all contain valley trains of morainal material deposited by the glaciers of the Younger glaciation.

FIGURE 43.- Younger glacial deposit

Well-preserved terminal and recessional moraine and hummocks of ground moraine along Trail Creek. Rounded hills to the left belong to Older glacial deposits. Terraces in basin.
View looking east across Big Sheep Creek Basin.



GEOLOGIC HISTORY

The oldest rocks in the Tendoy-Beaverhead area are of igneous origin and belong to the Precambrian Pony series. They were subjected to orogenic movements and accompanying intense regional metamorphism before the deposition of sediments which now are represented by the Cherry Creek series. At the end of pre-Beltian time the intrusion of a large pluton of granitic composition (Blacktail granite) took place. Both Pony and Cherry Creek rocks were intruded and contemporaneously diastrophism and metamorphism affected all pre-Beltian rocks. This complex of gneisses, schists, marbles, and quartzites was eroded. The Belt series is composed of material derived from the denudation of the pre-Beltian mountains and contains almost entirely sandy beds with small amounts of clayey layers in places. The series was deposited in shallow water. At the end of Precambrian time a regional uplift without any significant folding formed a landmass consisting mainly of Belt rocks. During these diastrophic movements the Belt was slightly metamorphosed.

The conglomeratic and sandy material of the Flathead formation of Middle Cambrian age was eroded from the Belt landmass and islands. The thickness of the Flathead decreases greatly from the northern to the central part of the Tendoy-Beaverhead area, and there is no Flathead in the southern part. The younger Albertan formations, the Wolsey and Meagher, consist of shales and limestones respectively and have the same areal distribution as the Flathead. The deposition of the Flathead formation marks the inception of the eastern Cordilleran or Rocky Mountain trough. During the late Cambrian, the Silurian and the early Ordovician, the area was probably a positive element as no deposits of these periods have been found anywhere in this general region.

It is possible that marine sedimentation started again in the Middle Ordovician. In neighboring areas quartzites of that age have been described (Anderson and Wagner, 1944, p. 7). In the Tendoy-Beaverhead area a white quartzite has been assigned to the Kinnikinic (?) formation of Upper Ordovician age. The seas probably withdrew temporarily at the end of Ordovician time, but invaded again during Upper Devonian when the dolomitic limestones of the Jefferson and the shales of the Threeforks formation were deposited.

No break is evident between the Devonian and the Mississippian and the shales of the Threeforks are overlain by thin limestone beds and shales of the Lodgepole formation. Above these are the massive limestones of the Mission Canyon formation, the younger member of the Madison group. The Mission Canyon crops out mainly in the eastern part of the area. More to the west the shales of the Milligen (?) formation were deposited. The well-bedded dark limestones of the Upper Mississippian Brazer (?) formation overlie the Milligen shales and are also confined to the western part of the Tendoy-Beaverhead area. The Amsden formation may be in part of Mississippian age and represents a transition to the Pennsylvanian.

Sedimentation went on uninterrupted from the Mississippian into the Pennsylvanian. The amount of clastic material increased slightly, as the Amsden contains some sandy limestones and sandstones. The Quadrant formation of Lower Pennsylvanian age is almost completely composed of clastic material, which suggests some crustal unrest in this general region. During the Permian the Phosphoria was laid down in the sea. The formation consists mainly of limestone, chert, mudstone, and phosphate. It was deposited probably over a long span of time and under foul conditions on

the bottom of the sea.

The Dinwoody, Woodside, and Thaynes formations compose the Triassic system of the Tendoy-Beaverhead area and all belong to the lower part of the period. Sedimentation was predominantly marine, but some Woodside beds may represent sediments of continental origin. No physical evidence of a stratigraphic break was found between the Lower Triassic strata and the overlying Middle and Upper Jurassic Ellis group, although a considerable span of time separates the two. The Ellis group comprises the Sawtooth, Rierdon, and Swift formations and contains limestones and shales of undoubtedly marine origin. At the end of Middle Jurassic time a general uplift started and the sea finally retreated from this part of the country. The latest Jurassic is represented by the Morrison formation which consists of sediments deposited on land.

The uplift which started during the Jurassic went on during Lower Cretaceous time. It brought about the deposition of the Kootenai formation made up of clastic material derived from the rising Cordilleran geanticline to the west. Ephemeral fresh-water lakes covered part of the land. Upper Cretaceous continental beds are in neighboring areas, but none were detected in the Tendoy-Beaverhead area, which was probably subject to erosion.

At the end of the Cretaceous or the beginning of the Tertiary the first phase of the Laramide orogeny affected the area and formed east to northeast trending folds. During the Paleocene the folded mountains were eroded. The resulting coarse-grained clastics with some fine sands and fresh-water limestone formed the Beaverhead. This formation and the older rocks were folded during the second phase of the Laramide orogeny, late in the Paleocene. Again folds were produced having an easterly to north-

easterly trend. Probably at the end of the Paleocene the third phase of the Laramide orogeny took place. Northerly and northwesterly trending thrusts and folds having the same trend came into being. In several places the older northeastern structures were thrust over the Beaverhead conglomerate. The third Laramide phase was followed or in part accompanied by the intrusion of granite in the western part of the area. The episode of lower and middle Eocene was one of erosion and the Laramide mountains were reduced to a mature topography. Broad intermontane valleys were formed by a northeast drainage system interrupted possibly in places by high angle faulting and warping.

In late Eocene time volcanism broke out in adjacent regions and also in the Tendoy-Beaverhead area. Rhyolitic lava flows poured out, and these possibly caused the damming of the drainage ways in the intermontane valleys. From then on alluviation instead of erosion took place in the basins. Abundant ash and dust falls resulted in the formation of tuffs of acidic composition. East of Red Rock Valley the lowest unit of the "Basin Beds," the Sage Creek formation was deposited. It contains late Eocene vertebrate remains.

The late Eocene and early Oligocene episode of acid extrusives was followed by the extrusion of basic flows and ashes during the upper part of the Oligocene and all of the Miocene. At the same time sedimentation went on in the intermontane valleys and more "Basin Beds" were deposited. Block faulting and accompanying local gentle deformation may have occurred several times during the Tertiary, but the record is not very legible in the Tendoy-Beaverhead area. During the Pliocene, after the extrusion of rhyolitic lav as at the southern end of the Beaverhead Range, the area was

eroded to a surface with little relief or even a true peneplain (A surface or summit peneplain).

On the A surface a northeast drainage system developed. The ancient Arco River may have been the major stream. Gravels brought from the west were deposited by the rivers on the A surface. This episode of quiescence was interrupted at the end of the Tertiary by regional uplift and rejuvenation of the block faulting. Several northwest trending horsts and grabens were formed. The Arco River was cut in two but maintained its lower course across the rising block of the Tendoy Mountains and the block west of Muddy Creek. The general uplift caused rejuvenation also in the basins and the downfaulted A surface in the graben valleys became dissected and ultimately leveled off to the B surface. The raised blocks became maturely dissected and only remnants of the A surface were left.

Pedimentation of the "Basin Beds" was probably finished in the early Pleistocene. It was followed by a gentle uplift in places, causing the dissection of the pediments. In the Beaverhead Range mountain glaciation occurred during the Pleistocene in two distinct episodes. In the basins terraces were formed during this time. The block faulting at the front of the Tendoy Range continued into Recent times. Large alluvial fans are being built along the scarp.

ECONOMIC GEOLOGY

Metals

Gold, silver. The localities of the natural resources are indicated on the map of figure 44. South of the upper course of Meadow Creek near quarter section marker 30:31, T. 15 S., R. 11 W., are several prospect pits. The unaltered rock here is a shattered brown basalt tuff and andesite. The color of the altered zone which is about 50 feet wide, has been changed to green. This discoloration decreases in intensity toward the contact zone with the brown rock. The green zone contains white and bluish quartz, as well as brown banded chalcedony. Microscopic investigation (6647, 6847, 6947) revealed that hydrothermal alteration of the propylitic type has taken place. Chlorite, sericite, limonite, carbonate, and quartz are the most important secondary minerals. No ore was observed. Umpleby (1913a, p. 54-57) describes similar mineralizations from Lemhi County, Idaho, where the altered zone carries microscopic gold and silver. The deposits belong to the epithermal group.

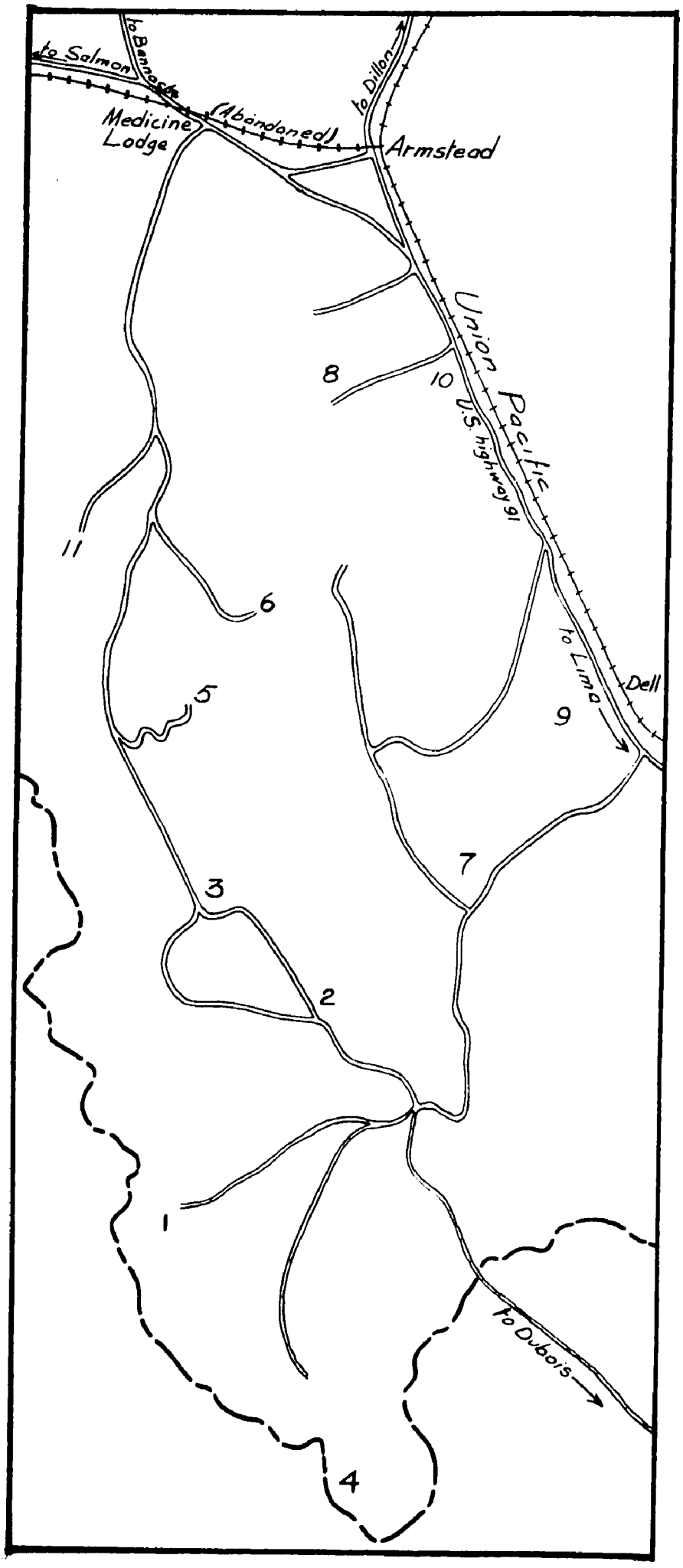
No substantial amount of placer gold has been recovered from the Tendoy-Beaverhead area.[4] Trauerman and Waldron (1940, plate 1) place the Chinatown district southwest of Armstead and east of North Medicine Lodge Creek. However, this district is the same as the Horse Prairie district which is outside the Tendoy-Beaverhead area, west of Medicine Lodge Creek and along Jeff Davis Creek and Colorado Creek (Woodward and Luff, 1942, p. 403; U. S. Forest Service, map Beaverhead National Forest; Collins, personal communication). These creeks are tributary to Horse Prairie

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4) The localities of known placer deposits in the general region are given by Lyden, Ch. J. (1948) The gold placers of Montana, Montana Bur. Mines and Geol. Mem. 26, 152 pp.

FIGURE 44.- Economic geology index map

1- Headwaters of Meadow Creek. Gold-silver prospects.
2- Grace no. 3. Copper prospect.
3- Headwaters of Medicine Lodge Creek. Copper prospect.
4- Nicholia district. Lead-zinc prospects.
5- Bonanza II Mine. Oxidized lead-zinc ore.
6- Kate Creek. Graphite prospects.
7- Dell phosphate field. See outcrop of Phosphoria formation on geologic map (plate I) .
8- North Limekiln Canyon. Abandoned limekilns.
9- Big Sheep Creek. Gypsum prospects.
10- Red Rock Valley. Gravel deposits.
11- Keystone Gulch. Coal mine.


to Salmon
to Bannock
to Dillon
Medicine Lodge
(Abandoned)
Armstead
Union Pacific
U.S. highway 91
to Lima
Dell
to Dubois
1
2
3
4
5
6
7
8
9
10
11

Creek and the possibility exists that small amounts of gold can be recovered from the gravels along Horse Prairie Creek.

Copper. In the pre-Beltian complex east of Big Sheep Creek Basin are at least two quartz veins which have attracted the attention of prospectors because of their copper content. The veins are believed to belong to the group of quartz veins intruded during the Tertiary time because similar veins cut the pre-Beltian-Madison fault contact.

One quartz vein is in NE 1/4 sec. 14, T. 14 S., R. 11 W. and within a mineral claim called Grace no. 3, dated May 21, 1948. Except for a small pit no work has been done on the prospect. The vein is exposed at the surface and forms a low ridge. Radial fibers of malachite are conspicuous although the mineral occurs only locally as a thin crust on quartz. Magnetite in small amounts is the only other metallic mineral.

The second quartz vein is in sec. 32, T. 13 S., R. 11 W. Here too the quartz carries incrustations of light green malachite. A small adit was dug but the prospect was apparently abandoned years ago.

Lead, zinc. Several prospect pits are about 1000 feet north of the Montana-Idaho boundary marker no. 574 in sec. 36, T. 16 S., R. 11 W. The pits are three feet deep and occur in gray Mississippian limestone with a gossan of quartz and limonite. The oxidized outcrop is close to the Kinnikinic (?) quartzite, which is here faulted against Mississippian limestone and shale. Anderson and Wagner (1944, p. 15-16) mention similar conditions in the Birch Creek district, Idaho. There the deposits are in limestone within a few hundred feet of the quartzite. The ore of the district is mainly oxidized and the chief metallic minerals are secondary carbonates of lead, zinc, and copper. The mineralization belongs to the mesothermal type.

An operating lead-zinc mine is south of Ellis Peak in sec. 1, T. 12 S., R. 12 W. The claim is called Bonanza II and is owned by Pete Sweeney of Lima, Montana. During the summer of 1948 two miners were employed. A road branching from Medicine Lodge road has been constructed up to the mine, and the ore is transported by truck to the railroad station at Armstead. About 14 carloads were shipped during 1948. The mine has two levels at a 50 foot interval. The lower level consists of an adit of approximately 200 feet and one stope. The higher level has a short adit, a drift and several stopes. Open stoping has been practiced and parts of the stopes have caved in. The wall-rock is rather weak, because it is much shattered, especially near the surface. The main vein is a tabular body striking N 60° E and dipping 40° S. Its width varies greatly from a maximum of about five feet. Several smaller veins parallel to the main body, which has been followed for about 175 feet. The ore is oxidized and occurs in Mississippian limestone close to the fault contact with the pre-Beltian complex. It is probably of Tertiary age. The main ore minerals are carbonates of lead and zinc.

In the Tendoy Mountains east of the southern part of Muddy Creek Basin another lead-zinc claim is said to be located (Collins, personal communication).

Nonmetals

Graphite. The graphite deposits at the headwaters of Kate Creek have drawn much attention. The deposits were mentioned by Brink (1931, p. 13). More recently they were described extensively by Perry (1948, pp. 18-20). Many prospect pits and several adits were made, mainly in sec. 21 and 22, T. 12 S., R. 11 W. Most of the claims seem to be in the possession of the National Carbon Company of New York. Much prospecting was done around

1918, but no graphite has ever been shipped. Samples of ore show an average carbon content of about 12 percent (Perry, 1948, p. 18). Although this compares favorably with other deposits, the Kate Creek graphite is of no apparent commercial value at present, because it is too finely grained and contains much iron oxide. It is so called "amorphous graphite."

The graphite occurs in a zone about a mile long, 200 feet wide, and at least 200 feet deep along the fault contact between the pre-Beltian and the Paleozoic. The amount of graphite in this zone varies considerably and no dependable reserve estimate has ever been made.

The graphite flakes lie in the schist belonging to the Cherry Creek series and in the gouges and breccias of the fault. It has also been brought into the Jefferson and Threeforks along the fault. In the schist the graphite might be of primary origin, but outside of the Cherry Creek it was deposited by hydrothermal waters after the faulting had taken place, and is probably post-Laramide in age.[5]

Phosphate. The Dell phosphate field was investigated several times by the U. S. Geological Survey and it is mentioned in the following reports: Bowen, 1917; Condit, 1919; Winchester, 1923; Condit and others, 1928; McKelvey, 1949. Phosphate occurs in two horizons in the Phosphoria. Besides phosphorus, elements such as fluorine, vanadium, nickel, and molybdenum have been detected. The phosphatic shales (Gustafson, 1949, p. 116, 119). Phosphoria shales also are noted for their kerogen content.

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5) A post-Laramide graphite deposit of somewhat different origin lies 11 miles southeast of Dillon, and has been mentioned by various writers. The most recent description of this deposit is by Heinrich, E. Wm. (1949), Pegmatites of Montana, Econ. Geol., vol. 44, p. 307,335.

Although the total phosphorous content of the phosphatic beds in the Phosphoria is high in the Dell area as compared with other fields in Montana, the deposit does not seem suitable for mining as the phosphorus is too much disseminated. In Idaho 18 feet thick beds containing more than 31% P_2O_5 are mined. In the Dell area there are no beds containing more than 31% P_2O_5. The total thickness of rocks containing more than 25% P_2O_5 in the Dell area is 2.5 feet. These containing more than 18% amount to 7.7 feet (McKelvey, 1949, p. 274-277).

Lime, gypsum, gravel. The limekilns which gave the name to North and South Limekiln Canyon were abandoned years ago. The Mission Canyon member of the Madison group was quarried here.

Gypsum prospects are located at the front of the Tendoy Mountains near Big Sheep Creek. The gypsum occurs in Mississippian strata, but has not been mined.[6]

Gravel is abundant in the Red Rock Valley and is extensively used as a road material. Smaller gravel pits are in Big Sheep Creek Basin.

Coal. Thin coal beds make up part of the "Basin Beds" at several places. The coal is of mineable thickness along Keystone Gulch, a tributary to North Medicine Lodge Creek, where Peterson's coal mine is located. The mine was operated during the winter of 1948, but no work is done during the summer months. The product is sold to consumers at the mine. The coal is lignite and of low grade. Analyses of samples taken at this locality are given by Dobbin (1932, p. 36).

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6) Gypsum has been mined from a deposit on the South Fork of Little Sheep Creek a few miles more to the south, where the same gypsum horizon is found. A description of this deposit is given by Perry, E. S. (1949) Gypsum, lime and limestone in Montana. Montana Bur. Mines and Geol. Mem. 29, 45 pages.

Oil. Around 1915 an oil well was drilled in the "Basin Beds" of Muddy Creek Basin, but the work was unsuccessful and abandoned.

The oil content of the Phosphoria shales is not readily available as the hydrocarbons occur in solid form in the shale and can be freed only by distillation (Winchester, 1923, pp. 7-8). The possibilities of finding petroleum in commercial quantities in the Tendoy-Beaverhead area are not very promising.

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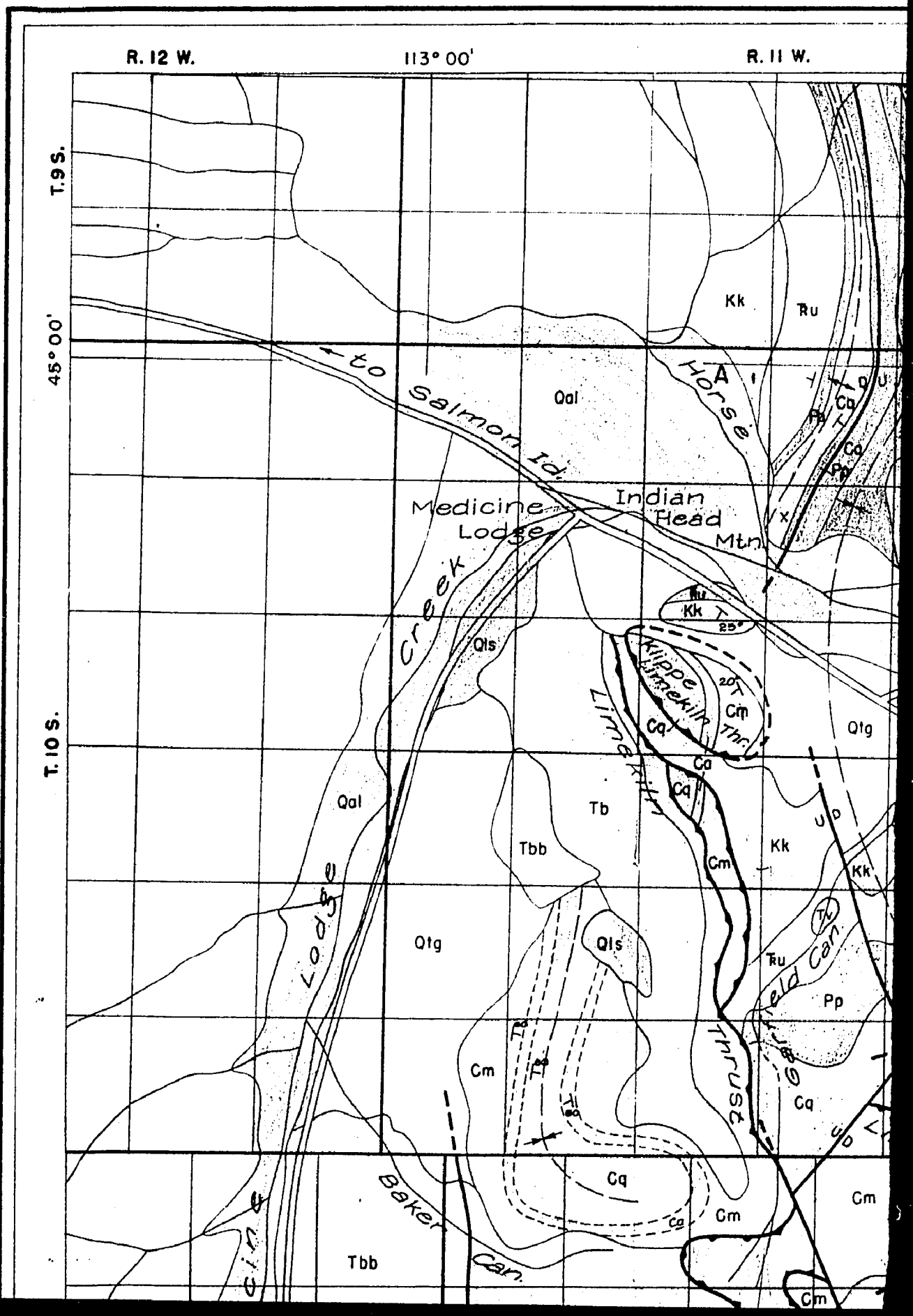
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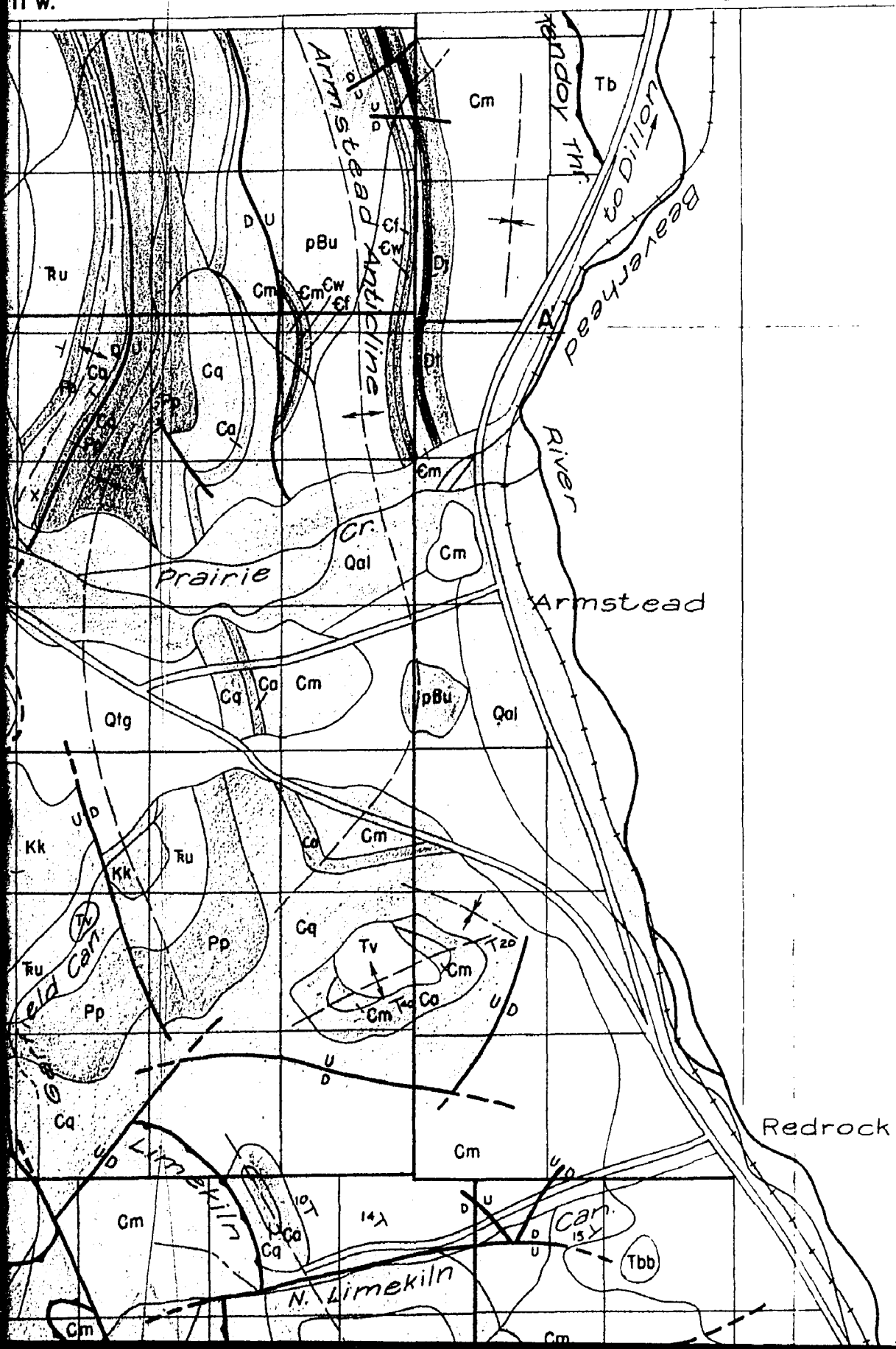
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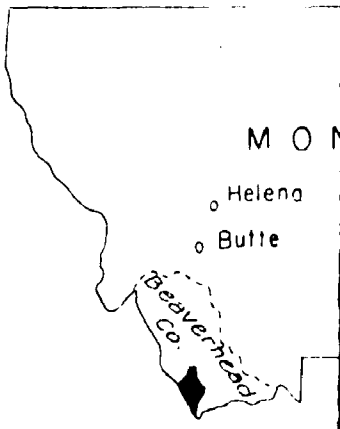

R. 12 W.
113° 00'
R. 11 W.
T. 9 S.
45° 00'
T. 10 S.
to Salmon Id.
Horse
Medicine Lodge Creek
Indian Head Mtn.
Lodge
Limekiln
Klippe
Thrust
Baker Can.
Kk
Tru
Qal
Qls
Qtg
Tb
Tbb
Cm
Cq
Pp
25°
20°

11 W.

112° 50'

R. 10 W.





MAP SHOWING L

Plate I

R. 9 W.

T. 9 S.

45° 00'

T. 10 S.

MONTANA

Helena

Butte

Beaverhead Co.

SHOWING LOCATION OF AREA

EXP

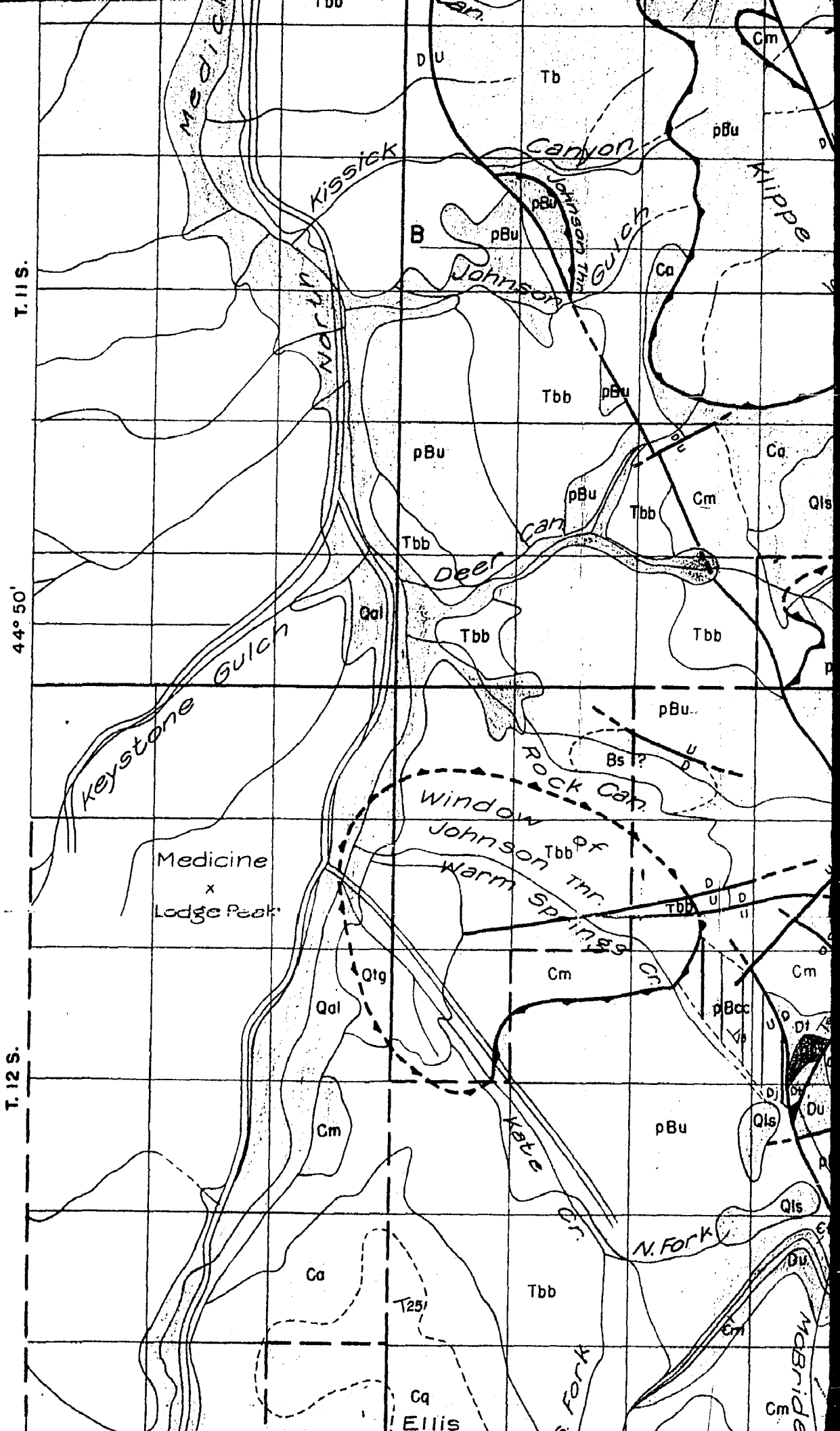
SEDI

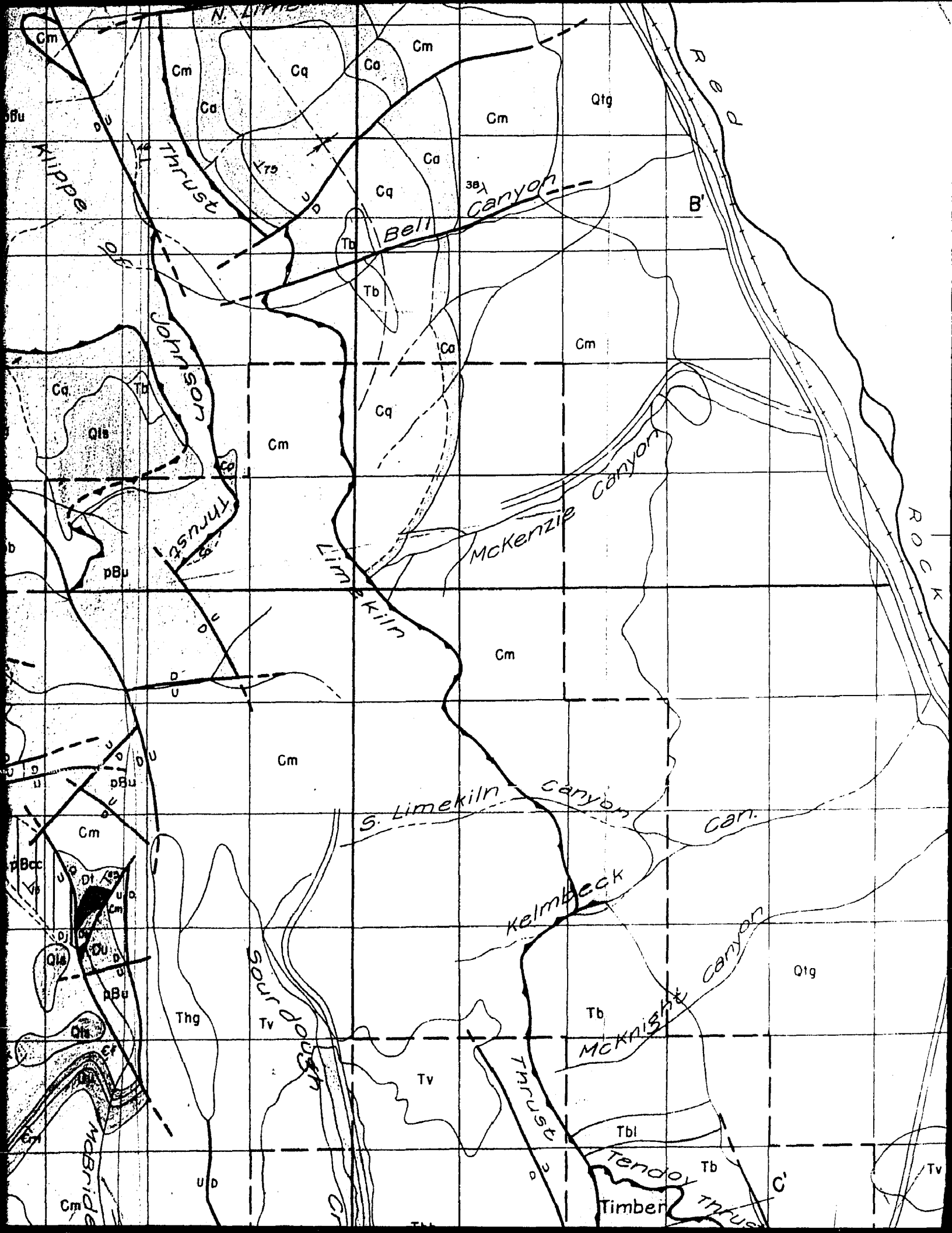
RECENT	Qal	Alluvium
	Qtg	Terrace g
PLEISTOCENE	Qygd	Younger g
	Qogd	Older gla
PLIOCENE	Thg	High-level
- PLIOCENE (?)	Tbb	"Basin be
EOCENE -	Tb	Beaverhea
PALEOCENE	Kk	Kootenai f
		Morrison f

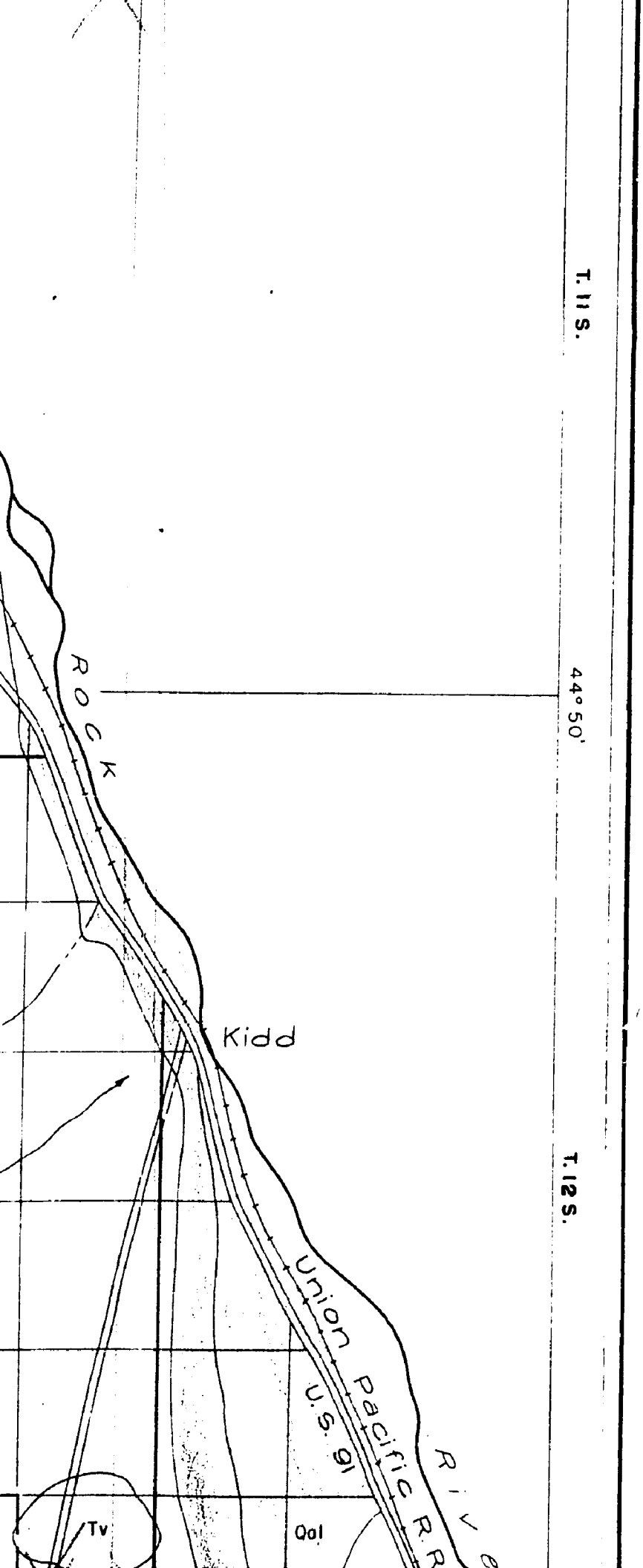
EXPLANATION

SEDIMENTARY ROCKS

Qal — Alluvium	Qls — Landslide material	QUATERNARY
Qtg — Terrace gravel		QUATERNARY
Qygd — Younger glacial deposits		QUATERNARY
Qogd — Older glacial deposits		QUATERNARY
Thg — High-level gravel		TERTIARY
Tbb — "Basin beds"		TERTIARY
Tb — Beaverhead formation	Tbl — Limestone member of Beaverhead fm.	TERTIARY
Kk — Kootenai formation		CRETACEOUS
Morrison formation		CRETACEOUS


T. 11 S.
T. 12 S.
44° 50'
Medicine Canyon
Kissick Canyon
Johnson Thr.
Johnson Gulch
Klippe
North Fork
Deer Can.
Keystone Gulch
Rock Can.
Window
Johnson Thr.
Warm Springs Cr.
Medicine Lodge Peak
Kate Cr.
N. Fork
McBride
Ellis
Tbb
Tb
pBu
Cm
Ca
Qls
Qal
Qtg
Bs ?
pBcc
T25
B


N. Limekiln
Klippe of Thrust
Johnson
Thrust
Bell Canyon
B'
Reed
Rock
McKenzie Canyon
Limekiln
S. Limekiln Canyon
can.
Kelmbeck
McKnight canyon
Sourdough
Thrust
Tendoy Thrust
Timber
C'
McBride
Cm
Cq
Ca
Qtg
Tb
Tbl
Tv
Thg
Qls
pBu
pBcc
Dl
Dj
Du
Et



PENNSYLVANIAN

MISSISSIPPIAN

Morrison forr

Jsw

Swift formati

Jr

Rierdon form

Js

Sawtooth forr

Trt

Thaynes form

Trw

Woodside form

Trd

Dinwoody form

Pp

Phosphoria fo

Cq

Quadrant form

Ca

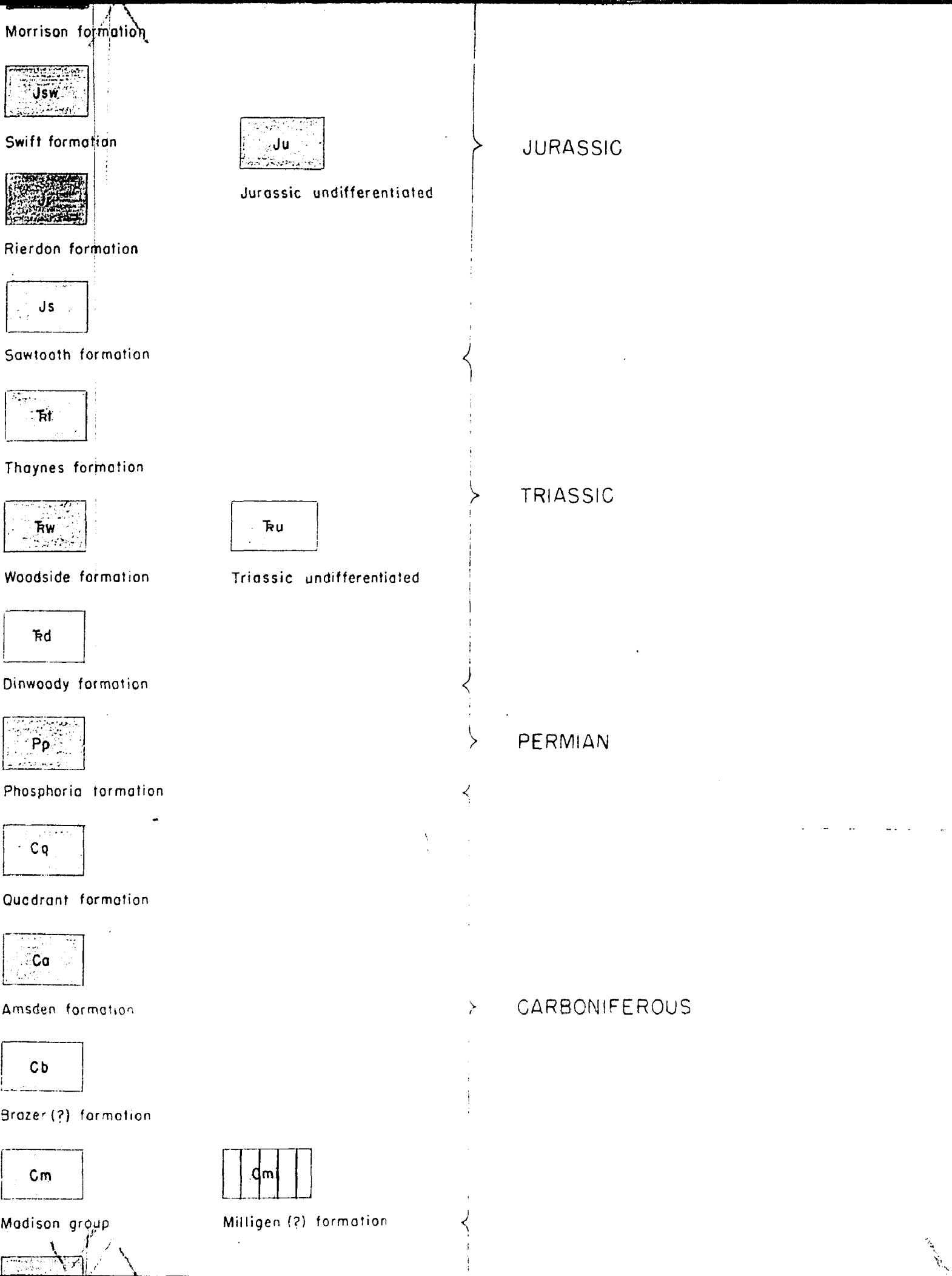
Amsden format

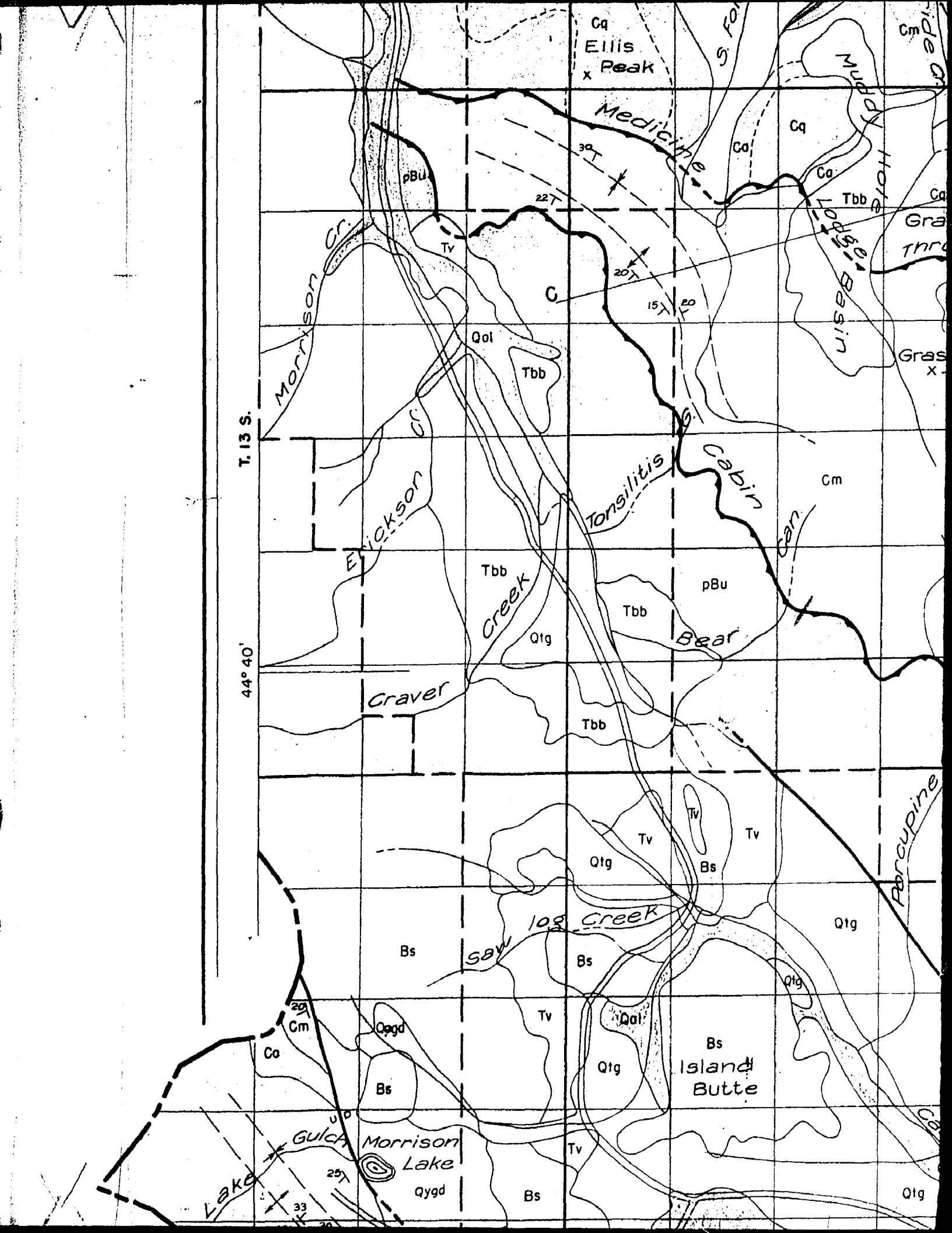
Cb

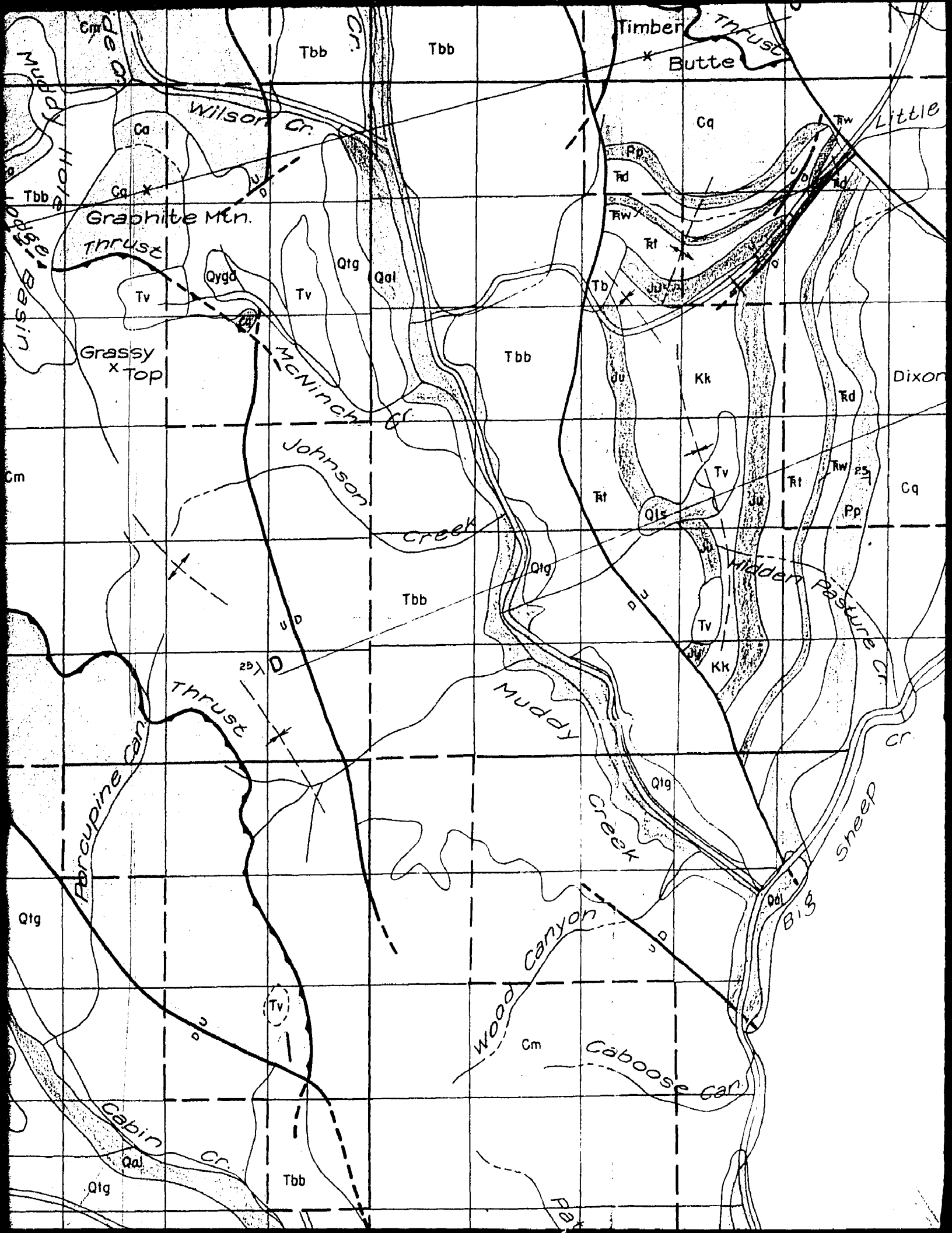
Brazer (?) form

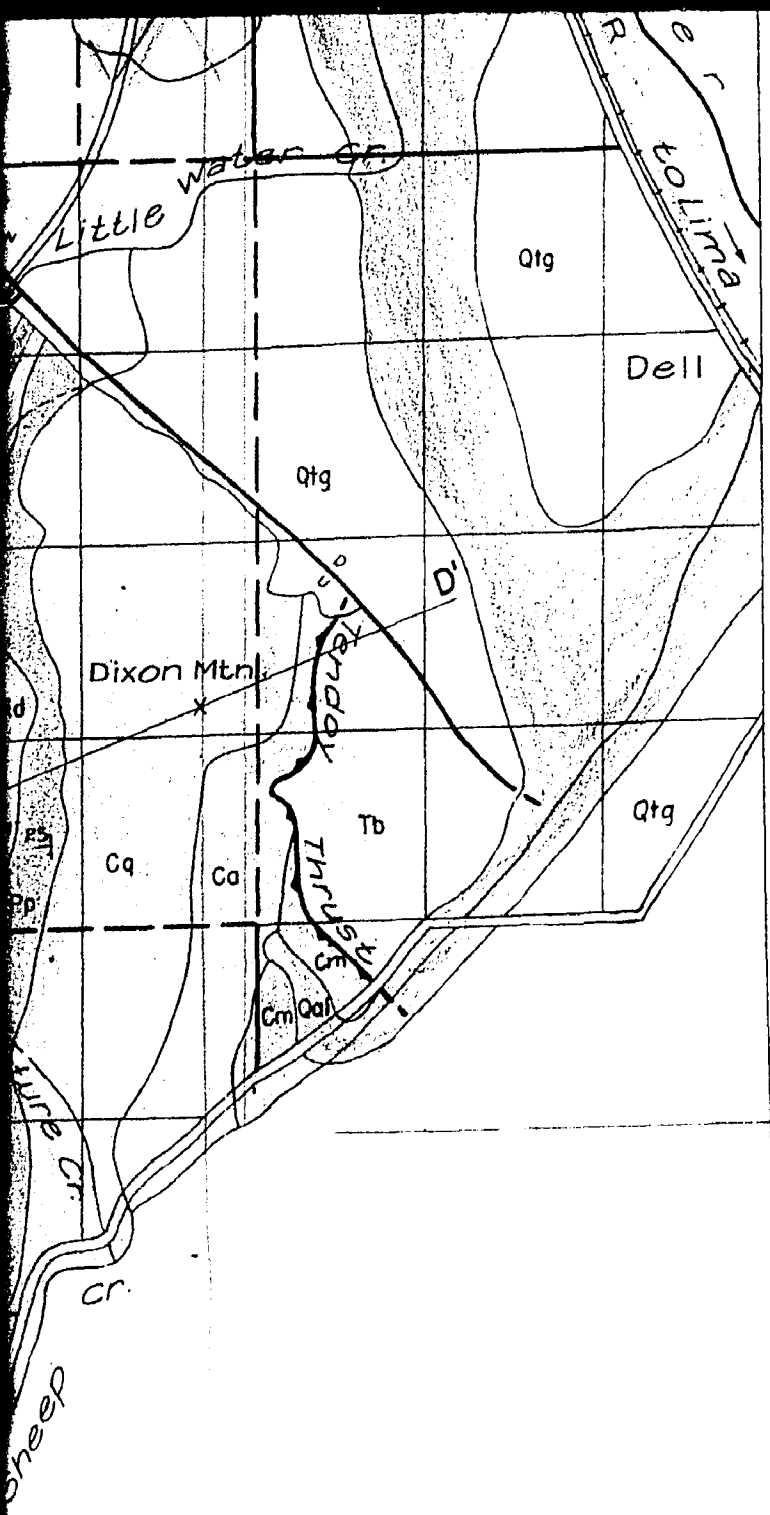
Cm

Madison group


Morrison formation
Jsw
Swift formation
Ju
Jurassic undifferentiated
JURASSIC
Rierdon formation
Js
Sawtooth formation
Trt
Thaynes formation
TRIASSIC
Trw
Woodside formation
Tru
Triassic undifferentiated
Trd
Dinwoody formation
Pp
Phosphoria formation
PERMIAN
Cq
Quadrant formation
Ca
Amsden formation
CARBONIFEROUS
Cb
Brazer (?) formation
Cm
Madison group
Cmi
Milligen (?) formation


Ellis Peak
Medicine
Mud Lake
Morrison Cr.
Erickson Cr.
Tonsillitis Cr.
Cabin Cr.
Bear Creek
Craver
Porcupine
Say log Creek
Island Butte
Morrison Lake
Gulch
Lake
Basin
T. 13 S.
44° 40'
Cq
Ca
Cm
Tbb
Tv
Qal
pBu
Qtg
Bs
Qygd
Qygd
Gra
Thr
Gras


Timber Butte
Thrust
Little
Wilson Cr.
Graphite Mtn.
Thrust
Muddy Ridge Basin
Grassy Top
McNinch Cr.
Johnson Creek
Dixon
Hidden Pasture Cr.
Muddy Creek
Porcupine Cr.
Thrust
Wood Canyon
Caboose Cgr.
Big Sheep Cr.
Cabin Cr.
Tbb
Cq
Ca
Cm
Tw
Pp
Trd
Trw
Trt
Tb
Ju
Kk
Tv
Qygd
Qtg
Qal
Qls
Pz
U
D



Dt

Threeforks form

Jefferson forma

Ok

Kinnikinic (?) for

€m

Meagher formati

€w

Wolsey formatio

€f

Flathead forma

Bs

Spokane (?) fo

METAMO

pBu

Undifferentiate

IGNE

– PLIOCENE (?)

OLIGOCENE (?) –

Tv

Lava flows, b

Dk

reeforks formation

Du

Devonian undifferentiated

DEVONIAN

fferson formation

Ok

nnikinic (?) formation

ORDOVICIAN (?)

€m

eagher formation

€w

lsey formation

€f

thead formqtion

CAMBRIAN

Bs

okane (?) formation

BELTIAN

METAMORPHIC ROCKS

pBu

differentiated

pBcc

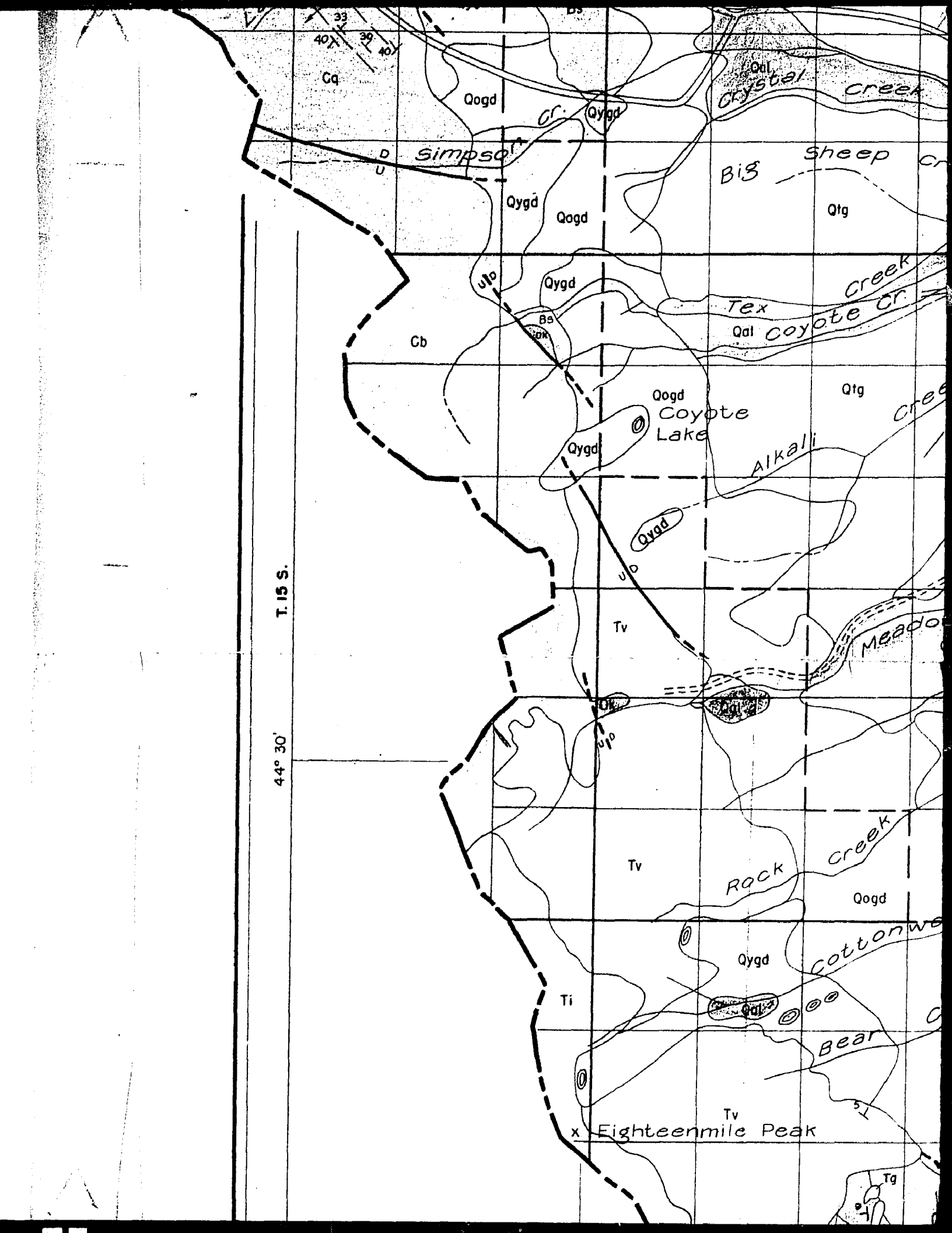
Cherry Creek series

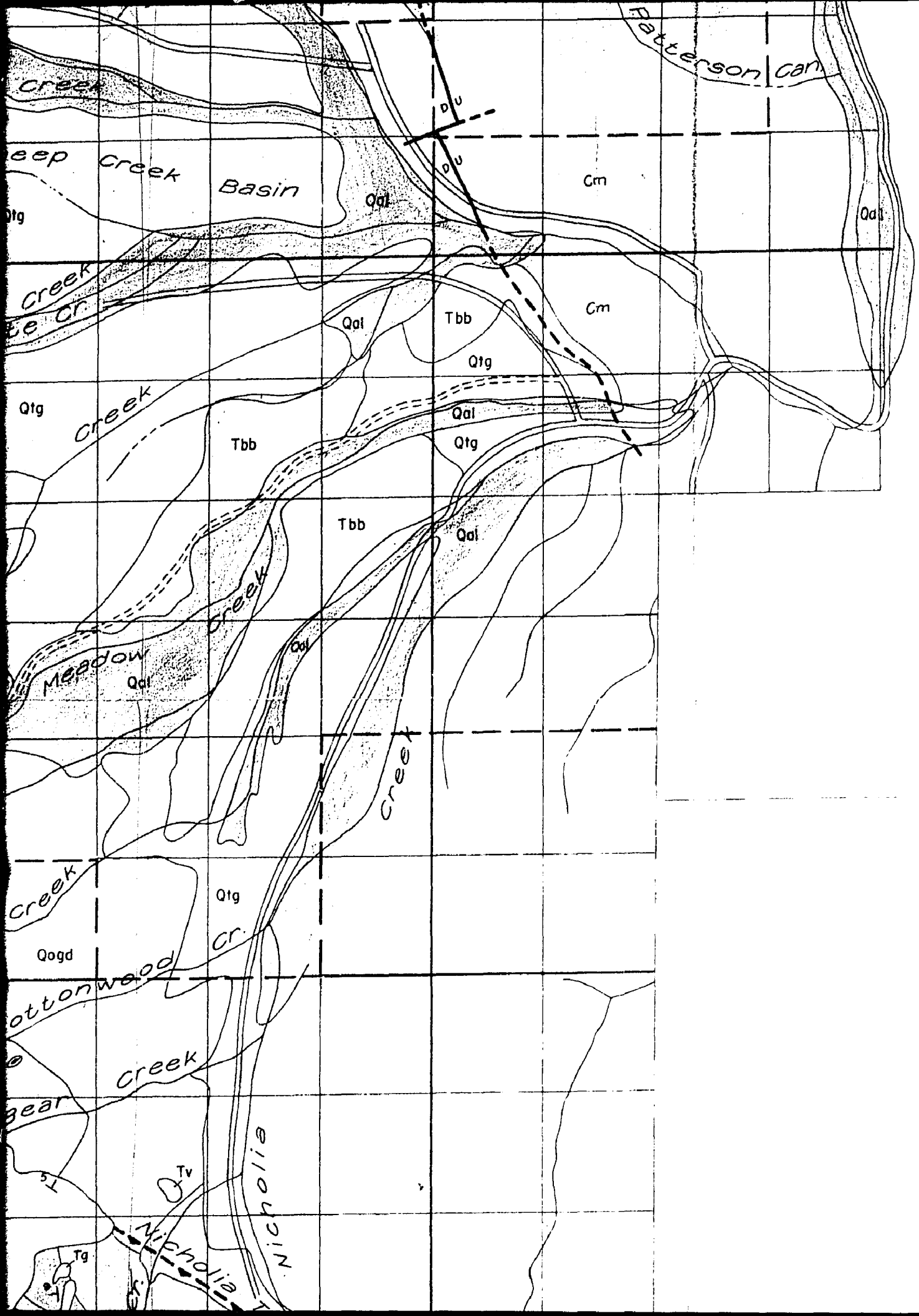
PRE-BELTIAN

IGNEOUS ROCKS

Tv

va flows, breccia etc.


T. 15 S.
44° 30'
Cq
Qogd
Qygd
Qal
Crystal
Creek
Simpson
Cr.
Big
Sheep
Qtg
Cb
Tex
Coyote Cr.
Coyote
Lake
Alkali
Tv
Meadow
Rock
Creek
Ti
Cottonwood
Bear
Eighteenmile Peak
Tg


Patterson Can.
Creek
eep Creek Basin
tg
Qal
Cm
Qal
Creek
e Cr.
Qal
Tbb
Cm
Qtg
Qtg
Creek
Qal
Qtg
Tbb
Tbb
Qal
Creek
Meadow
Qal
Qal
Creek
Creek
Qtg
Qogd
Cr.
ottonwood
Creek
Creek
Tv
Tg
Nicholia
Nicholia

Dikes

Ti

Granitic

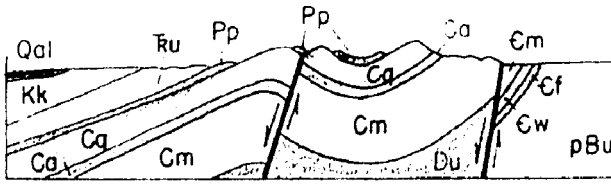
Field work done July 15 - Aug

Map compiled from aerial ph

of Beaverhead National Fore

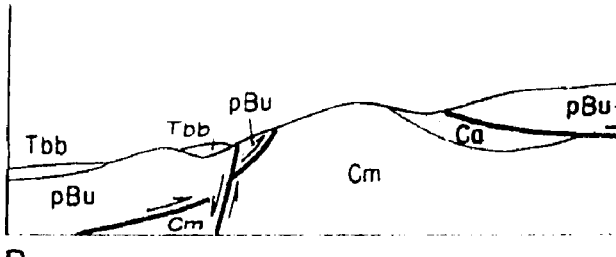
T. 15 S.

44° 30'

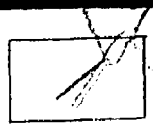


A

Armstead Ant



B



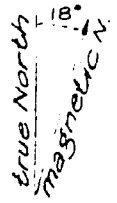
Dikes

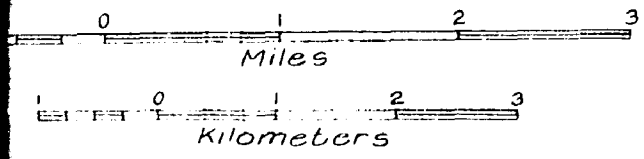
Ti

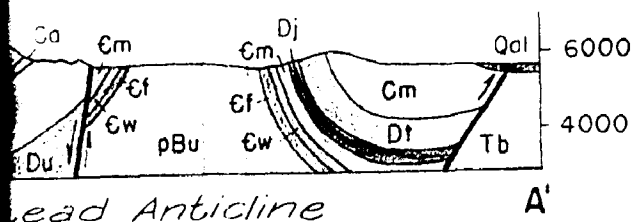
Granitic intrusive

TERTIARY

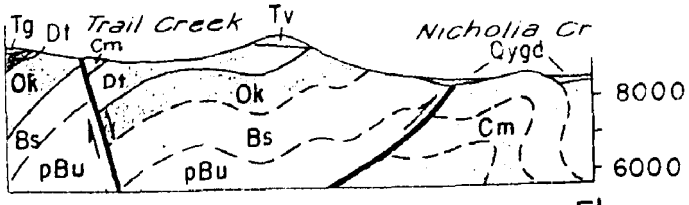
e July 15 - August 23, 1947 and June 25 - August 18, 1948.
from aerial photographs. Control: U.S. Forest Service Map
National Forest, 1947. Drafting in cooperation with D.L.Bell.



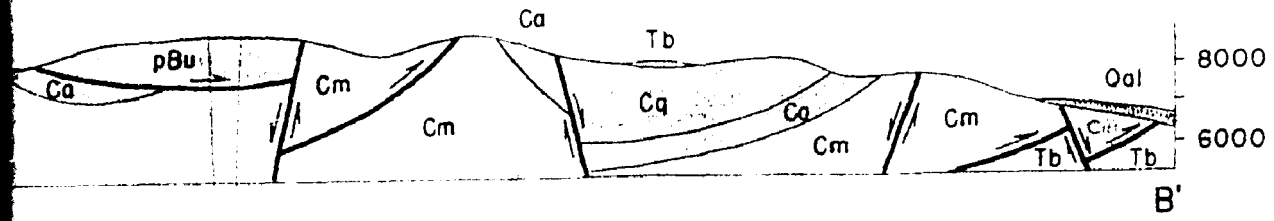




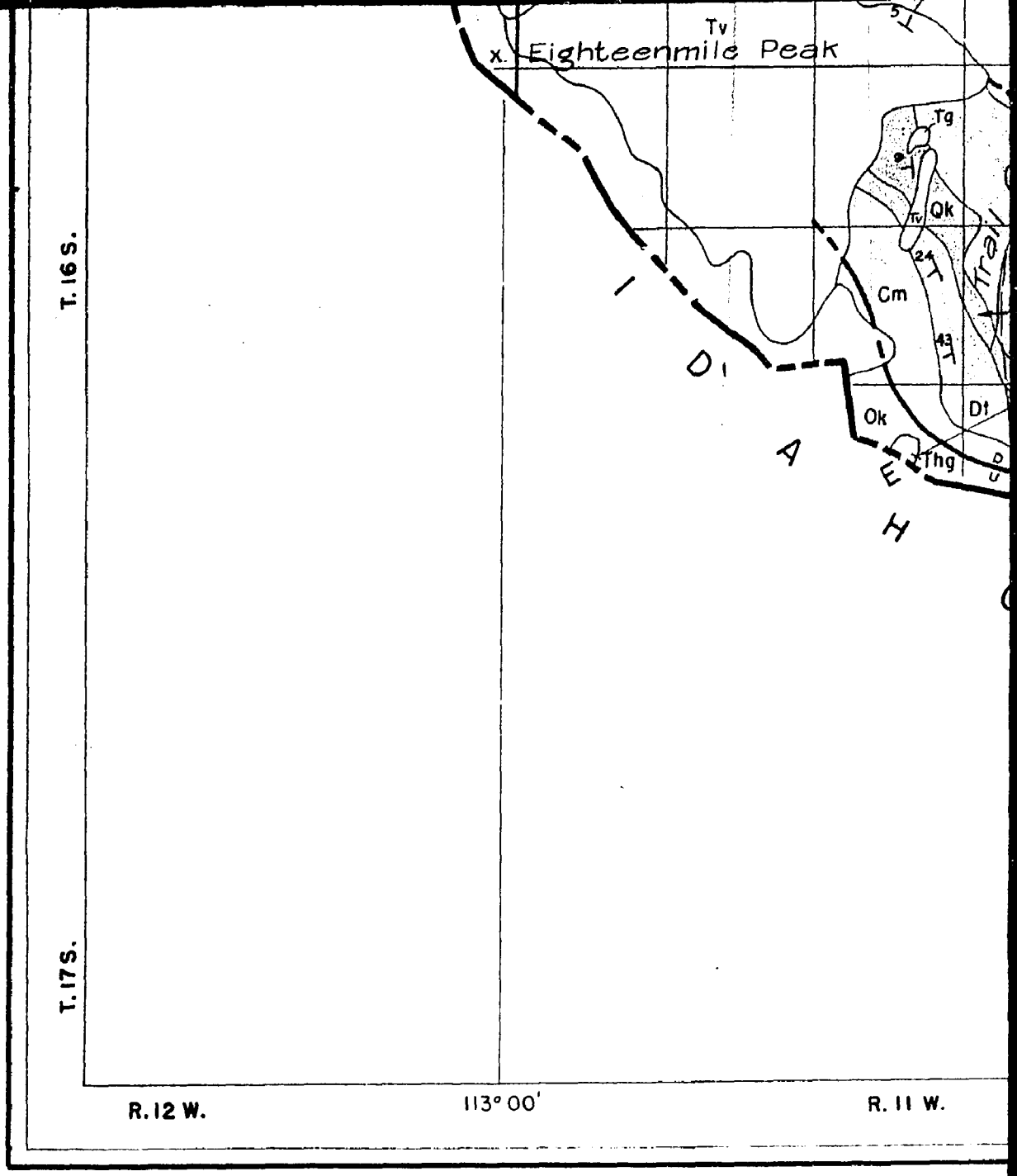
ead Anticline



Trail Creek Anticline

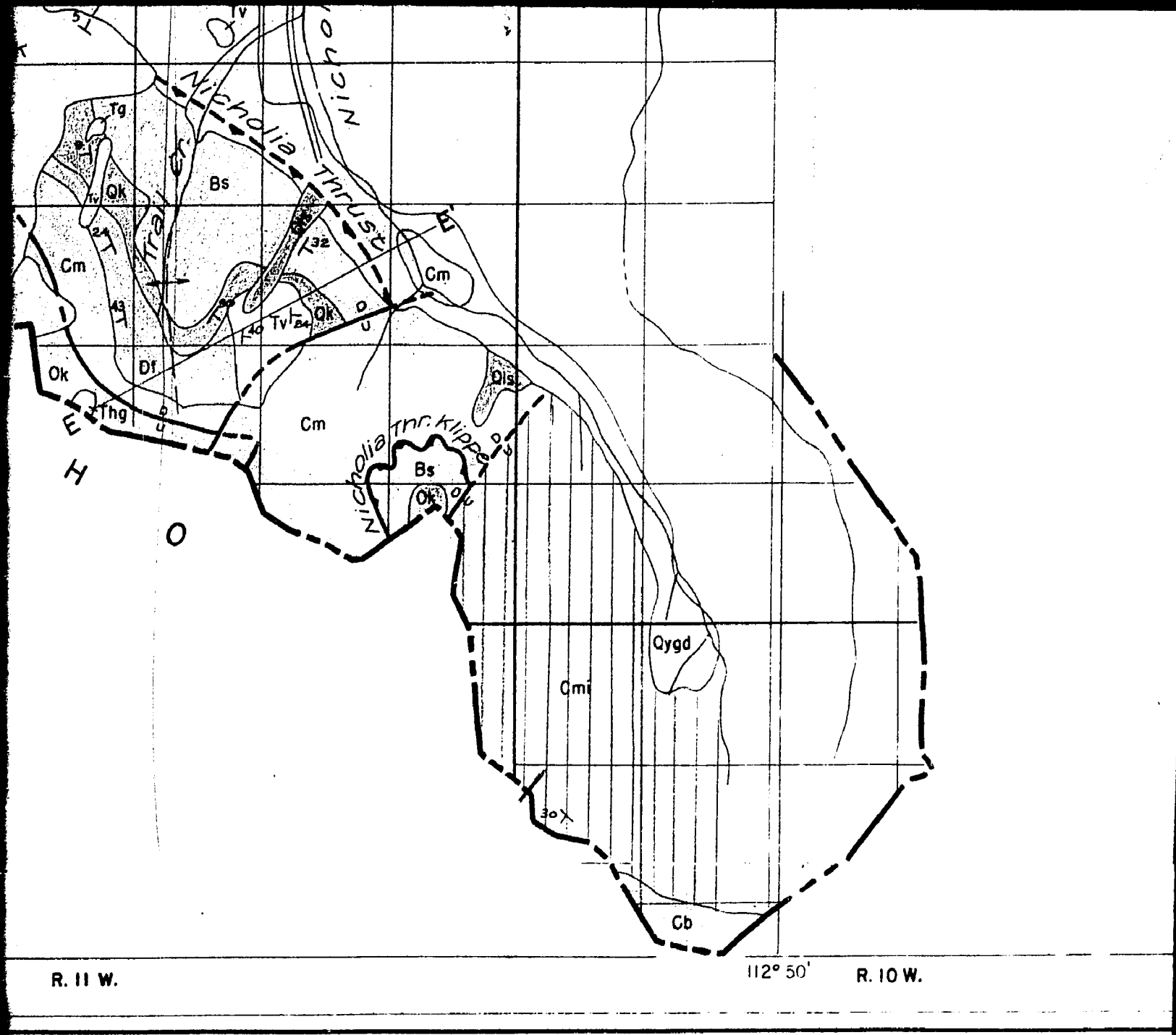


10 000



GEOLOGIC MAP AND CROSS SECT

Geology by W. O. Kupsch,



S SECTIONS OF THE TENDOY-BEAVERHEAD AREA

ogy by W.O. Kupsch, assisted by G.F. Bowers, R.A. Bronl, D.L. Cummins, R.I. Dovis, N.C. Elmer, W.A. Gillespie, H.H. Krusekopf, J.R. Peterson, R.F.

1949

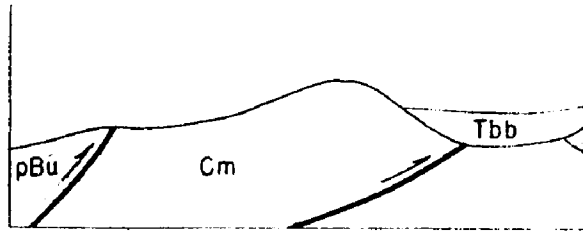
T. 16 S.

T. 17 S.

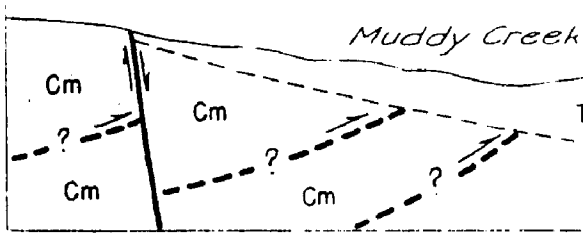
R. 9 W.



B



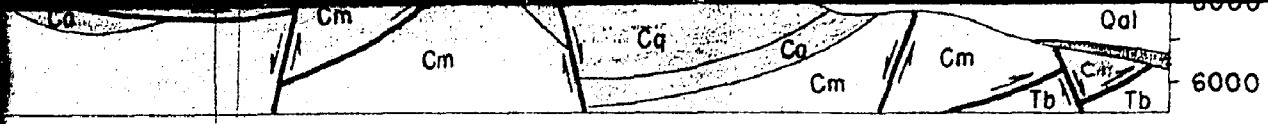
C



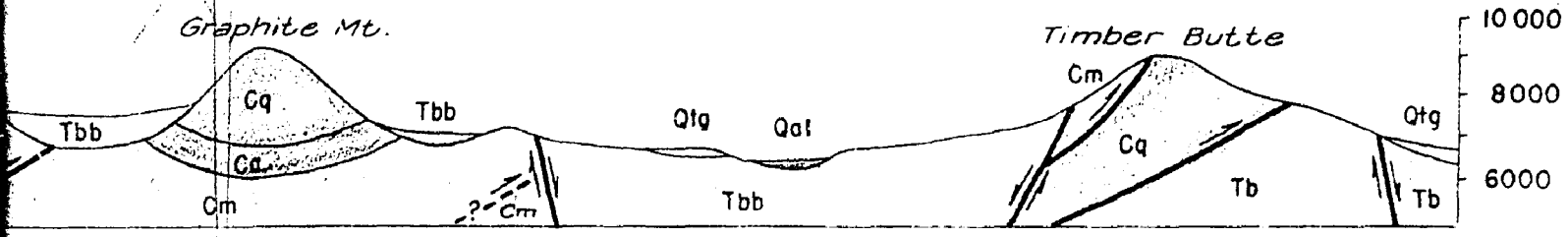
D

AREA, BEAVERHEAD COUNTY, MONTANA

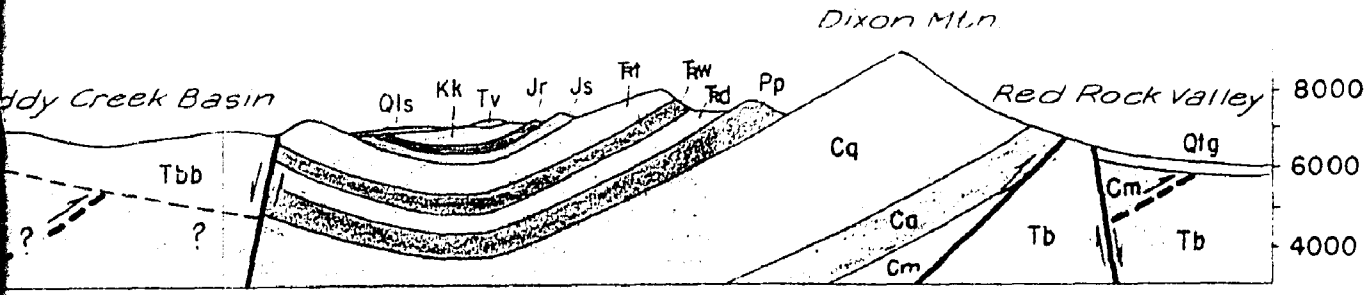
Peterson, R.F. Plank, W.T. Smith, S.R Wallace



B'



C'



Little Water Syncline

D'