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GEOLOGY OF THE CENTENNIAL REGION BEAVERHEAD COUNTY, MONTANA

*University of Michigan* PH.D. 1949

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# GEOLOGY OF THE CENTENNIAL REGION

# BEAVERHEAD COUNTY, MONTANA

by

Fred S. Honkala

A dissertation submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy in the

University of Michigan

1949

Committee In Charge

Professor Armand J. Eardley, Chairman
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# GEOLOGY OF THE CENTENNIAL REGION

## BEAVERHEAD COUNTY, MONTANA

by Fred S. Honkala

## CONTENTS

## ILLUSTRATIONS

ABSTRACT

The Centennial Valley and vicinity, about 500 square miles of southwestern Montana, mainly in Beaverhead County, was mapped in reconnaissance and the general geology of the area is described in the following report. The more pertinent conclusions made therein are reviewed.

The stratigraphy of the region was described from field observations, measured sections, hand specimens, and thin sections. The rocks range in age from Precambrian to Recent. Twenty formations of Paleozoic, Mesozoic and Cenozoic age, totaling approximately 12,560 feet in thickness are present, in addition to Precambrian metamorphics, Tertiary volcanics and basin beds (?), and Quaternary alluvium. Relations of the formations cropping out in the Centennial Region to those present in adjacent areas show that Pennsylvanian, Permian, and Triassic strata thin eastward. In the Mississippian system the Brazer limestone or equivalents, was separated from strata previously called the Madison group. An unnamed conglomerate of Cretaceous or Paleocene age is probably the equivalent of the Sphinx conglomerate in the Madison Range. Tertiary volcanic rocks show the following sequence from oldest to youngest; (1) basalt flows, (2) agglomerate or volcanic conglomerate, (3) tuff, (4) rhyolite flows, (5) dikes and sills (?). A Pliocene age is tentatively assigned to these volcanics. High level gravels were interpreted as residium of the once widespread Cretaceous (?) Paleocene conglomerate or other coarse Tertiary clastics. On the basis of vertebrate evidence the top part at least, of the beds in the Centennial Valley is termed late Pleistocene in age. It was concluded the striated (?) boulders on top of the Gravelly Range do not represent an Eocene skyline moraine as reported elsewhere, but are high level gravels.

The structure of the rocks in the Centennial Region is relatively simple, though complex thrust faulting is present outside the area in all directions. Laramide folds include the in part overturned Snowcrest Range fold, the Metzel Creek anticline, Fox Creek syncline and Peet Creek anticlinorium. Laramide and post-Laramide faults in the area are mostly normal and of high angle. The Centennial Valley is probably at least on the south, bounded by a major high angle fault.

Early and middle phases of the Laramide orogeny are evidenced in the structure and strata present, and the late Laramide orogeny probably also affected the region. Mid-Tertiary block faulting, erosion and alluviation, and Pliocene volcanism followed. Movement along block faults continued in Pleistocene time. Pliocene or Pleistocene uplift and volcanism caused major adjustments of streams and canyon cutting. Four surfaces are recognized in the Centennial Region, (1) a pre-Pliocene aggradational and degradational surface, (2) Pliocene pediments, (3, 4) and two Pleistocene levels on the Centennial Valley floor. Dunes developed in Recent times on the Centennial Valley slopes have locally diverted drainage.

Coal and placer gold have been mined in small quantities in the past, but phosphate rock and oil seem to offer the best possibilities for mineral exploitation in the future.

# INTRODUCTION

## Location and general geography

The area here called the Centennial Region is located mostly in Beaverhead County in southwestern Montana (see index map, figure 1), and extends into adjacent parts of Madison County, Montana and Clark County, Idaho. The mapped area may be reached by driving east five miles along a county road from Highway No. 93 at Monida, Montana.

The chief topographic features of the Centennial Region may be conveniently grouped into a northern, a middle, and a southern unit. The northern unit includes almost half of the Centennial Region area and may be subdivided into three sub-units; the Snowcrest Range extension on the west which trends northeast to southwest; the Long Creek - Ruby River basin in the middle which trends north to south; and the Gravelly Range extension on the east which also trends north to south. The middle unit of the Centennial Region is the Centennial Valley which trends east to west, and the southern unit is the Centennial Range which also trends east to west.

The Centennial Region is in the northern Rocky Mountain province of the Rocky Mountain system. The maximum relief is 3600 feet and the average relief is 2000 feet. It is typical of this province which was described by Fenneman (1930 - map) as one of,

> "...deeply dissected mountain uplands, not anticlinal ranges; intermont basins."

The crest of the Centennial Range marks the Idaho - Montana state line as well as the Continental Divide. The Centennial Range begins at Monida Pass, elevation 6791 feet, near Monida, Montana. From Monida

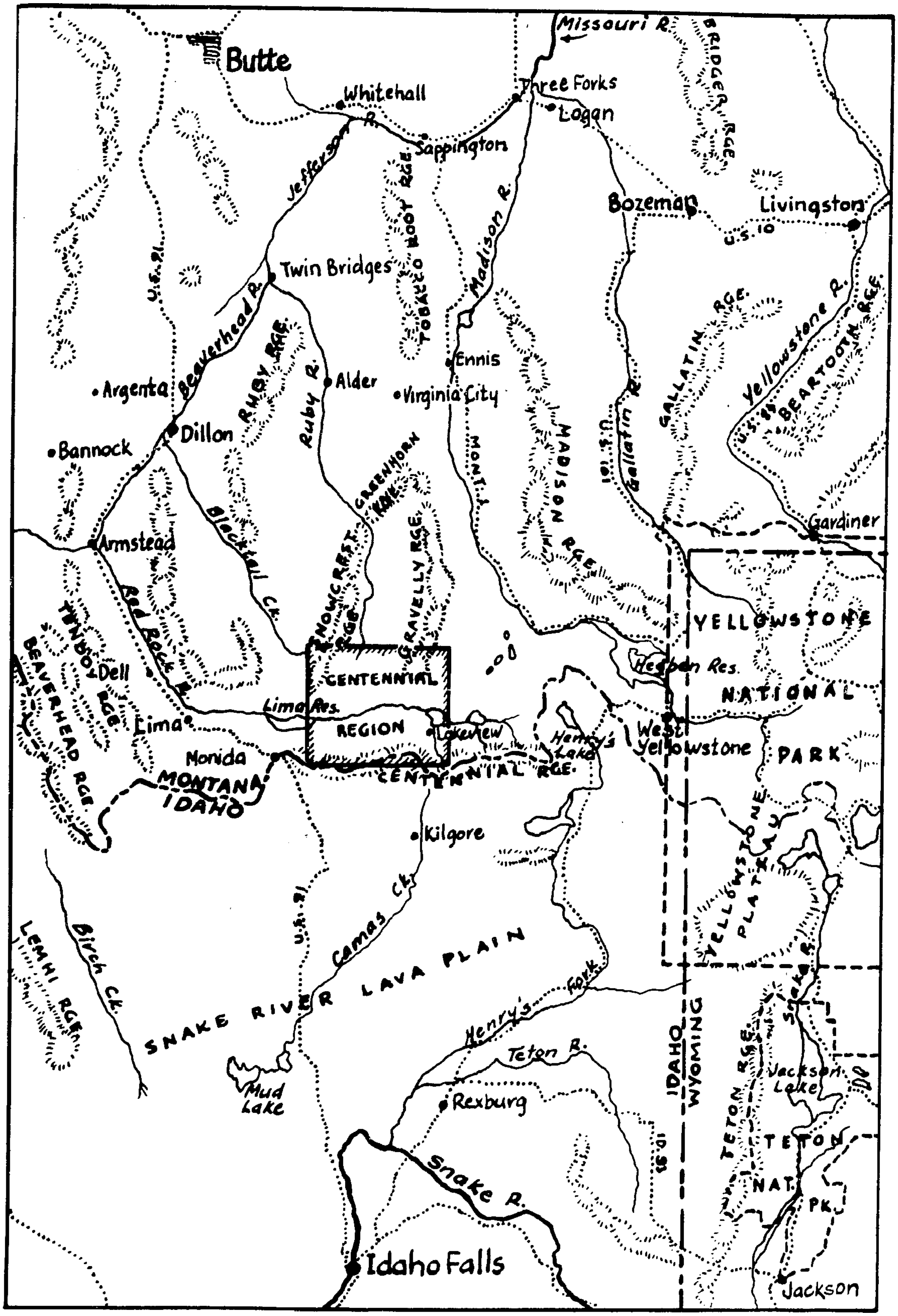


Figure 1. Index map of southwestern Montana

the elevation increases gradually eastward for 35 miles to Mt. Jefferson, elevation 10,211 feet, the highest point in the range. Six miles east of Mt. Jefferson the range ends where it is transected by Henry's Fork of the Snake River. The range has some very rugged topography, especially the eastern half has been extensively glaciated, and which forms a north-facing escarpment about 3500 feet high, (see figure 6).

The Snowcrest Range begins as low hills just north of the Lima Reservoir and trends northeastward for 30 miles to the canyon of the Ruby River. From there for 15 miles its northerly continuation is the Greenhorn Range which near Virginia City slopes away to form a low divide between the Ruby River on the west and Madison River on the east. Still farther north this divide becomes mountainous again and forms the Tobacco Root Mountains. The Snowcrest Range is a high and sharp range with a steep 3000 foot escarpment facing southeastward. The highest peak in the Range is Hogback Mountain, elevation 10,605 feet, five miles north of the limits of this report. The range includes Antone Peak, elevation 10,220 feet, the highest peak in the Centennial Region, (see figures 3, 14).

The southern extension of the Gravelly Range is included in the north-eastern part of the Centennial Region. The range is an irregular group of hills carved by stream erosion. It trends north and south and is about 35 miles long. The Gravelly Range which trends north and Greenhorn Range which trends northeast merge in the saddle separating these ranges from the Tobacco Root Mountains on the north. Black Butte, with an elevation of 10,564 feet is the highest peak in the Gravelly Range.

Many other mountain ranges are present in the vicinity. The Madison River separates the Gravelly Range from the high Madison Range farther to the east. To the east of the Centennial Region is Yellowstone Park with parts of the Gallatin and Beartooth Ranges and its dissected plateaus. The Teton Range lies to the southeast and the Snake River lava plains extend south from the Centennial Range. From Monida Pass westward the hills become higher to form the Red Conglomerate Peaks. Southwestward into Idaho is the little-known Lemhi Range. Several steep ranges to the west of the Centennial Region trend north to south, namely the Tendoy Mountains and Beaverhead Range. The Ruby Range is west of the Snowcrest Range and parallels it.

Separating one range from another are intermontane basins where most of the agriculture and industry of this section is conducted. The major streams occupy these basins for some distance and then, may cut a steep canyon through an adjacent range and enter another basin. The Centennial Valley is a typical intermontane basin drained by the Red Rock River, (see figure 4). The Long Creek - Ruby River basin is another, and the valley of the Madison River is a third example.

Most of the Centennial Region is in the Missouri River drainage basin, but the streams that flow southward from the Centennial Range flow into the Snake River and thence into the Columbia River. The main stream draining the Centennial Region is the Red Rock River, which flows westward and then northward to be joined by Horse Prairie Creek at Armstead, Montana forming the Beaverhead River, which in turn joins the Bighole and Ruby Rivers near Twin Bridges, Montana, forming the Jefferson

River. The Jefferson, Madison and Gallatin Rivers then join at Three Forks, Montana to form the Missouri River. The Red Rock River rises in the hills around Alaska Basin, the eastern end of the Centennial Valley basin. Tributaries from the Gravelly, Snowcrest and Centennial Ranges add to its volume. Chief among these tributaries are Hellroaring and Odell Creeks from the Centennial Range and Long Creek which drains parts of both of the Gravelly and Snowcrest Ranges. Other drainage of the Centennial Region includes the West Fork of the Madison River which drains much of the Gravelly Range and flows east and then north into the Madison River. The Ruby River drains part of the Gravelly and Snowcrest Ranges and flows northwest to help form the Jefferson River. Blacktail Creek drains part of the western flank of the Snowcrest Range and flows northwestward into the Beaverhead River. Some of the southward flowing streams on the west end of the Centennial Range sink into the Snake River lava plain.

Lakes are found both in the valleys and mountains. The two Red Rock Lakes occupy part of the eastern half of the Centennial Valley. Smaller lakes are present in the surrounding mountains. Many reservoirs have been constructed to store water for use in the dryer summer months. Such reservoirs include the Lima Reservoir on the Red Rock River, the Ruby Reservoir on the Ruby River, the Henry's Fork Reservoir on Henry's Fork of the Snake River, and the Ennis Reservoir and Hegben Lake on the Madison River. East of the Centennial Region is Henry's Lake, a natural lake in an intermontane basin and still further east is Yellowstone Lake.

Steep-walled canyons are a common topographic feature in southwestern Montana. Many of the smaller tributaries in the mountains such as West Fork of the Madison River and Odell Creek have cut very steep canyons, (see figures 5, 6, 3). The larger rivers may cut across mountain ranges in picturesque canyons, through which railroads and highways are routed. Examples include the Sappington Canyon of the Jefferson River near Whitehall, Montana, and the canyon of the Madison River near Hegben Lake, Montana.

The weather of the Centennial Region is rigorous. Winters are long and cold with much snow. Summers are short and hot, generally with little rain. Figure 2 shows the average temperature and precipitation for the year of 1947 recorded at Lima and Lakeview in Beaverhead County, Montana.

Agriculture is the main livelihood of the region. Cattle are raised in the valleys and sheep are driven into the mountains during the summer for grazing. In the Centennial Region much wild hay is harvested in the summer for winter stock feeding, (see figure 4). Wheat is grown near Dillon and Harrison, Montana to the north, as well as on parts of the Snake River lava plain to the south. Dry farming and irrigation are both practiced. No mineral industry has been developed in the Centennial Region, though placer gold has been mined in the past on the West Fork of the Madison River and phosphate rock and oil are future possibilities. The famous gold camps of Alder Gulch and Virginia City lie 30 miles to the north. Sheridan, Norris, and Virginia City are now the most active districts in Madison County, producing zinc, lead, silver, and gold. The Argenta district, in the famous Argenta - Bannock country west of

Dillon, Montana is the most active district in Beaverhead County, producing gold, silver, copper, lead and zinc. (Minerals Yearbook, 1946, p. 1461, 1468).

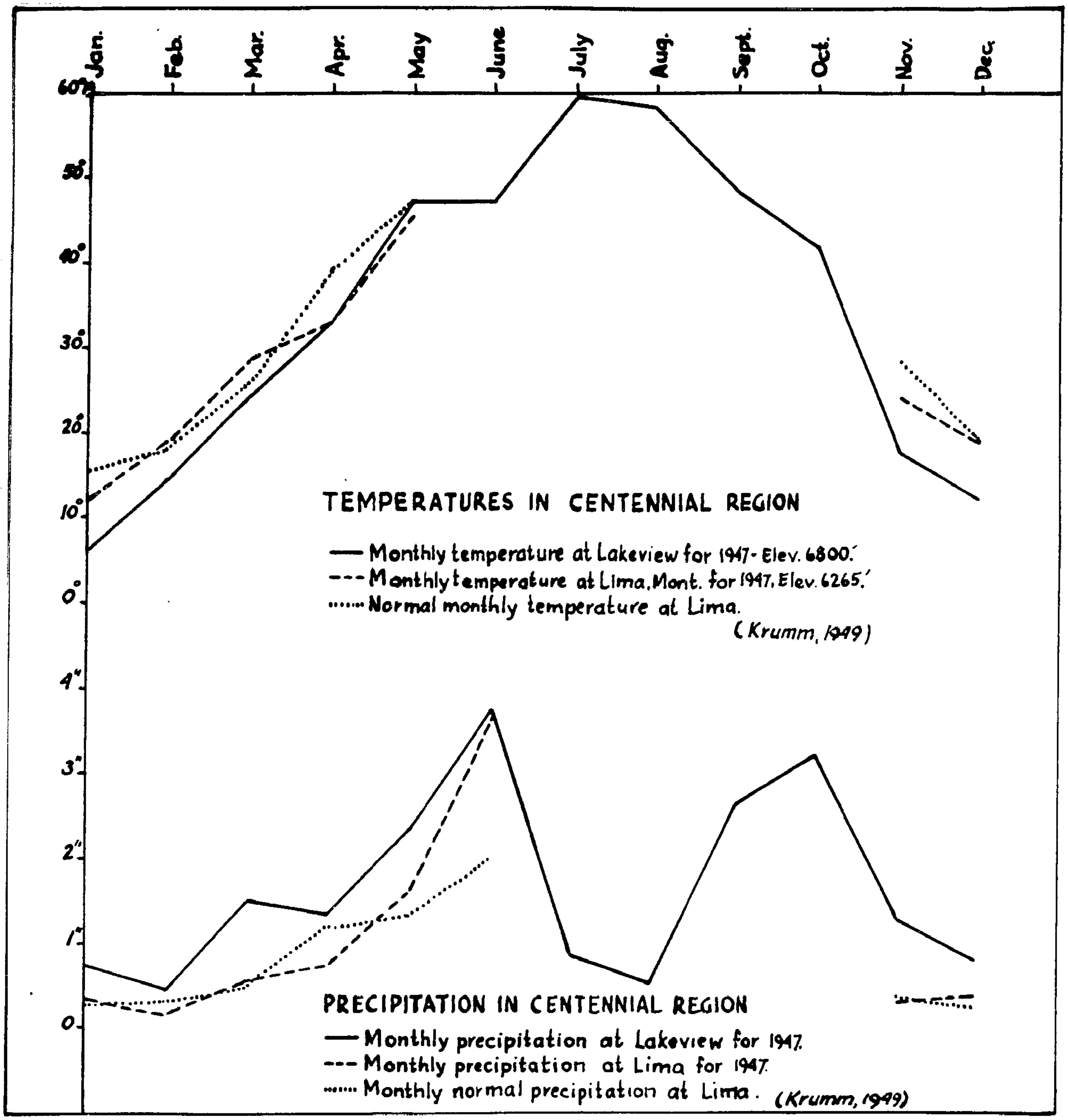


Figure 2 Temperature and precipitation in the Centennial Region

The population of the Centennial Region varies from an estimated 25 in the winter to several hundred in the summer, and most of these are engaged in ranching. The Centennial Region has no towns. The United States Government has headquarters for the Red Rock Wildfowl Refuge at the former village of Lakeview, established to protect the once nearly extinct trumpeter swan. The towns in the vicinity of the Centennial Region are few and small.

Lima, Montana, west of the Centennial Region, is a division point for the Oregon Short Line of the Union Pacific Railroad. Monida, Montana is a village located on Monida Pass south of Lima. Kilgore, Idaho, a hay and wheat-growing center, is a small village on the south side of the Centennial Range. West Yellowstone, Montana, east of the Centennial Region is a tourist center. Dillon, Montana is the Beaverhead County seat and is the largest town in the vicinity, with a population of several thousand.

## Past and present work

Little previous geologic work has been done in the region. A. C. Peale (1896) described the Three Forks area of Montana 25 miles to the north. D. D. Condit, and others, in connection with phosphate rock and oil shale surveys by the United States Geological Survey, have written several papers (1918, 1919, 1927) that deal incidentally with the area. G. R. Mansfield (1920, pp. 147-153) of the United States Geological Survey described the coal deposits of the Centennial Range in Idaho near the southern margin of the region. Mapping has recently been stimulated

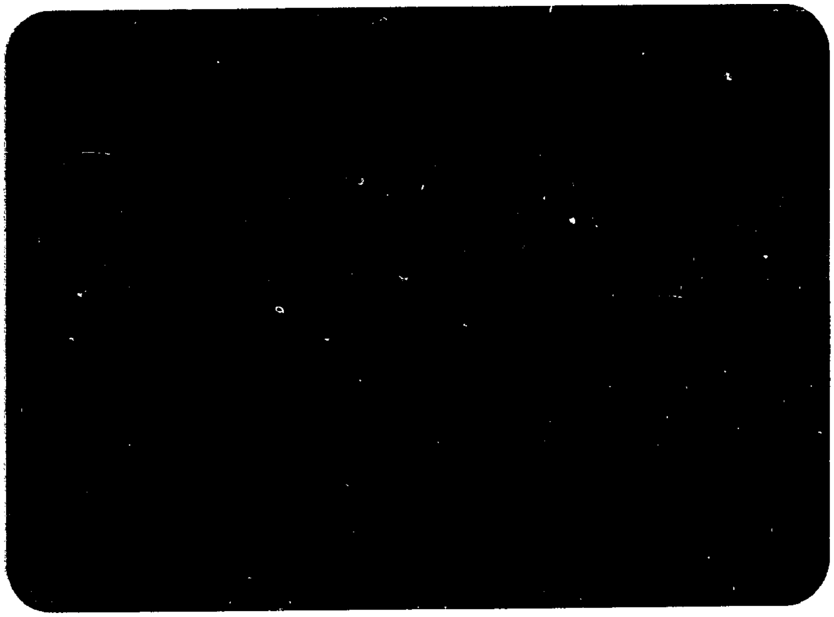

Figure 3. Snowcrest Range as seen looking northwestward across West Fork of Madison River (foreground) and Ruby River (distance) from section 19, T. 12 S., R. 2 W. in Gravelly Range.

Figure 4. Looking eastward from south side of Centennial Valley in section 20, T. 14 S., R 3 W. Note flatness of valley floor. Haystacks are for winter stock feeding. Madison Range and Yellowstone Park form distant skyline.

CENTENNIAL REGION PANORAMAS

by a new interest in oil, and renewed interest in phosphate rock. Considerable work has been done by oil company geologists near Lima, Montana, but the results have not been published to date. A.J. Eardley (1946) has mapped territory south of Lima (unpublished). Many unpublished master's and some doctoral theses have been done by students of Harvard, Princeton, and Michigan universities to the north, east, and west of the region, (Dillon, 1949, Dorr and Wheeler, 1948, Wallace, 1948). The United States Geological Survey began reconnaissance and detailed geologic mapping in southwestern Montana in 1946. M.R. Klepper (1947) mapped in reconnaissance the Snowcrest range. W.R.Lowell (1946-1948) and B. Myers (1947-1948) have been mapping in detail parts of the Willis quadrangle to the northwest. G.C. Kennedy (1947-1948) mapped part of the Lyon quadrangle to the east.

Field work for this paper was done by the author in the summers of 1947 and 1948. In 1947 field work was conducted under the supervision of the geology summer field camp of the University of Michigan at Jackson, Wyoming. A little field work was done in 1948 in the writer's spare time while working with the southwest Montana phosphate program of the United States Geological Survey.

## Acknowledgments

The author is indebted to Prof. A.J. Eardley for orientation in the field and for criticism of the manuscript. In one way or another all of the following gave assistance and their kindness is hereby acknowledged; Professors K.K. Landes, R.C. Hussey, L.B. Kellum, C.W. Hibbard, C.B. Slawson, University of Michigan; Professor W.R. Lowell, Montana State

University; Professor L.L. Sloss, Northwestern University; Dr. G.C. Kennedy, Harvard University; Dr. Helen Foster, Dr. R.W. Imlay, Mr. A.E. Weissenborn, Mr. V.E. McKelvey, Mr. and Mrs. C.T. Kennedy, Monida, Montana; Mr. J. Lamish, Mr. E.H. Meadow, Mr. W. Vaughn, geology students at University of Michigan, and Mr. O.A. Payne, geology student at University of Utah.

## STRATIGRAPHY

### General stratigraphic features

The lithologic sequence in the Centennial region includes rocks ranging in age from Precambrian to Recent. Eleven formations totaling approximately 4000 feet are of Paleozoic age. Eight formations totaling approximately 5300 feet are of Mesozoic age. An unnamed conglomerate about 3000 feet thick is of late Mesozoic or early Cenozoic age. All sediments are locally overlain by a veneer of Tertiary volcanics or Quaternary alluvium.

As might be expected, the Paleozoic rocks are predominantly marine limestone, dolomite, and other sediments. Continental sediments become increasingly important in the Mesozoic and Cenozoic formations. A stratigraphic section of the Centennial Region is portrayed in figure 29 and table 1 lists a brief summary of the formations.

### Precambrian rocks

Cherry Creek series. - The oldest rocks in this region are a series of interbedded quartzites and marbles of pre-Beltian age. (Heinrich, 1948, p. 1329). In the area studied, Precambrian rocks crop out only near Landon Ranger Station on the West Fork of the Madison River, but this

**Table 1 - Sedimentary and volcanic rocks of Centennial Region**

| Age | Formation | Thickness (feet) | Lithology |
|---|---|---|---|
| Recent | Alluvium | 35+ | Silts, marls, gravels. |
| Pleistocene | Alluvium | ? | Silts, marls, gravels. |
| Pliocene | High level gravels | | Gravels contain quartzites, schists, volcanics. |
| | Centennial Range late lavas | 600± | Basalt, agglomerate, volcanic conglomerate, tuff, alluvial beds, rhyolite in general ascending order. |
| Miocene | Bozeman lake beds | ? | Believed present at depth. |
| Middle Oligocene | Cook Ranch formation | ? | Believed present at depth. Continental clastics. |
| Upper Eocene | Sage Creek formation | ? | Believed present at depth. Continental clastics. |
| Lower Eocene or Paleocene or Upper Cretaceous | Unnamed conglomerate | 3000± | Coarse conglomerate, some coarse sandstone; also shale, silt, limestone. |
| Lower Upper Cretaceous (Colorado) | Aspen formation | 3000± | Buff sandstones, slightly consolidated tan silts and shales, some variegated. Coal and tuff sometimes present. |
| | Colorado shale | 300 | Thin-bedded, fissile, jointed, gray to black shale. |
| Lower Cretaceous | Kootenai formation | 700± | Basal conglomerate, buff to brown "salt and pepper" sandstones, red shales, silts, widespread thin fossiliferous fresh-water limestone. |
| Upper Jurassic | Morrison formation | 181 | Greenish, soft shales, interbedded sandstones, limestones and dolomites. |
| | Swift formation | 21 | Glauconitic, calcareous sandstone. |
| Lower Triassic | Thaynes formation | 138 | Cream, buff, reddish fossiliferous, calcareous sandstones. |
| | Woodside formation | 564 | Red shaly siltstone, few white, maroon siltstones, limestones near top. |

Table 1 - Sedimentary and volcanic rocks of Centennial Region (continued)

| Age | Formation | Thickness (feet) | Lithology |
|---|---|---|---|
| Lower Triassic | Dinwoody formation | 358 | Thin, flaggy, buff to brown, alternating limestone, siltstone, sandstone. Fossiliferous. |
| Middle Permian (Word) | Phosphoria formation | 229 | Black fissile shales, with interbedded limestone and sandstone. Several thick brown chert zones. Oölitic phosphatic shale and hard pisolitic phosphatic rock. |
| Lower Pennsylvanian | Quadrant formation | 402 | Mostly brown sandstone or quartzite, some limestone. |
| | Amsden formation | 73 | Soft red shales, calcareous siltstone, dolomitic or silty limestone. |
| Upper Mississippian (Meramec, Chester) | Brazer limestone | 772 | Massively bedded, coarsely crystalline gray fossiliferous limestone or dolomite. Contains chert. A cliffmaker. |
| Lower Mississippian (Kinderhook, Osage) | Mission Canyon limestone | 353 | Coarsely crystalline, gray, fossiliferous limestone, some chert present. |
| | Lodgepole limestone | 628 | Dense, dark, fossiliferous limestone. |
| Upper Devonian | Threeforks formation | 238 | Variegated soft shales, interbedded limestones. |
| | Jefferson dolomite | 229 | Massive, tan dolomite. |
| Middle Cambrian | Park shale | 30 | Soft, green micaceous shale. |
| | Meagher limestone | 1007 | Thin-bedded, hard, gray limestone with tan runic markings. A cliffmaker. |
| | Flathead quartzite | 77 | Basal conglomerate, reddish; overlying quartzite, with glauconite. |
| Precambrian (pre-Beltian) | Cherry Creek series | ? | Interbedded quartzite, marble, mica schists. |

outcrop area is part of a much larger one to the east. Precambrian rocks are also extensively exposed in the eastern extension of the Centennial Range. The Precambrian rocks crop out as rounded hills in comparison to the ridges formed by the Paleozoic and Mesozoic rocks. The Cambrian Flathead quartzite overlies the Precambrian rocks with a pronounced angular unconformity.

The Cherry Creek series was named by A. C. Peale (1896, p. 2) from outcrops on Cherry Creek, 20 miles to the north of the Centennial Region area in the Gravelly Range. Peale described them as follows,

> "— a series of marbles or crystalline limestones, and interlaminated mica schists, quartzites and gneisses — highly inclined — perfectly conformable to one another, —"

Heinrich (1948, p. 1329) describes the Cherry Creek series at Dillon, Montana, 50 miles to the northwest, as follows,

> "a group of marbles, schists, and quartzites, about two miles thick, —. Hornblende gneiss interlayered with these metasediments, represents chiefly metamorphosed mafic sills, —."

The quartzite in the Cherry Creek series is predominantly quartz, with calcite, tourmaline, and apatite noted as accessory minerals. The quartz grains are small, angular, and often crushed. Secondary quartz and calcite line vugs in the quartzite. The rock is stained by iron oxides and a typical color is weak red (10 R 4/2) of the Munsell color chart.[1] Calcite is the chief mineral of the marble, which is also stained by iron oxide and resembles the quartzite in color. The grains are angular, and average ½ mm in diameter.

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[1]The colors and color notations as listed in the Munsell color chart are used in describing all rocks studied in the laboratory. If color notations are not listed the colors were noted in the field at which time a color chart was not available.

## Cambrian system

Flathead quartzite. - The Flathead quartzite of lower Middle Cambrian (Albertan) age, (Deiss, 1939, p. 54) crops out on the extreme eastern border of the Centennial Valley area near Landon Ranger Station on the West Fork of the Madison River. As do all the succeeding formations, the Flathead quartzite also crops out in the Centennial Range to the east of the area studied. It unconformably overlies the Precambrian Cherry Creek series. If not covered by talus from the overlying Meagher formation the Flathead generally crops out in a cliff.

In the Gravelly Range the Flathead quartzite is 77 feet thick. Kennedy (1948) reports the Flathead to be 147.5 feet thick in the Centennial Range due south of Upper Red Rock Lake, and 254 feet thick 5 miles to the east on Mt. Jefferson.

The Flathead quartzite was named by A. C. Peale (1893, pp. 20-22) from Flathead Pass in the Big Belt Range near Three Forks, Montana. In the Gravelly Range it consists of a basal conglomerate and overlying quartzite. The basal conglomerate has a coarse texture with red, white or tan quartz particles ranging from subrounded to well-rounded grains 1 mm in diameter to cobbles 6 inches in diameter. Some admixed glauconite is present. An average color is weak reddish brown (10 R 6/6). The particles are from Precambrian quartzites. The conglomerate is 30 feet thick and is massive. The following sequence was measured in the Gravelly Range in section 31, T. 12 S., R. 1 W.[2]

[2]This section was measured by the author and a helper using a 100 foot steel tape and Brunton compass. Unless otherwise noted, all other sections in this report were similarly measured.

| Units | Thickness in feet |
|---|---|
| 2. Covered: Quartzitic and glauconitic sandstone float. | 47 |
| 1. Basal conglomerate (described above). | 30 |
| Total thickness of Flathead formation, | 77 feet. |

Diess (1939, p. 59) states that the Flathead quartzite represents the overlap deposit of a sea that advanced from the south. No fossils were found in the Flathead formation in the Gravelly Range, nor are they common elsewhere in the formation. (Diess, 1939, p. 56).

Meagher limestone. - The Meagher limestone of upper Middle Cambrian (Albertan) Diess, 1939, p. 54) age crops out along the West Fork of the Madison River in the Gravelly Range, and in the Centennial Range, east of Odell Creek. It is apparently conformable to the underlying Flathead quartzite and the overlying Park shale. The formation generally crops out in massive cliffs, as those forming the Portal Creek Canyon (section 25, T. 12 S., R. 2 W.) shown in figure 5. A thickness of 1007 feet was measured in the Gravelly Range. Kennedy (1948) reports a thickness of 585.5 feet for the Meagher limestone ten miles to the southeast on the north face of the Centennial Range, and 637.5 feet on Mt. Jefferson near the eastern end of the same range.

The Meagher limestone was named by Weed and Pirsson (1899, p. 2) in the Little Belt Mountains, Montana, and described (1899 a, p. 2) as,

> " — a thin-bedded limestone, often formed mainly of flat limestone pebbles. The rocks carry fossil remains — of Middle Cambrian Age."

The Meagher limestone in the Gravelly Range is a hard, dense, cliff-forming limestone, dolomitic limestone, or dolomite. It is finely crystalline and is gray (N-6) to tan (10 YR 6/6) in color. Runic markings

Figure 5. Outcrops of Meagher limestone in section 25, T. 12 S., R. 2 W. on Portal Creek in Gravelly Range. Note canyon which forms the "portal." (Photo by John Lemish).

which superficially look like an edgewise conglomerate, are common in the Meagher limestone, a common characteristic of other equivalent western Cambrian carbonate rocks. Kennedy (1948) says these markings are due to irregular blebs of dolomite which weather out as tan markings on exposures. The author notes a concentration of weathered iron oxide into these "blebs", but how the iron oxide relates to the dolomite is not known. The following sequence was measured in the Gravelly Range in sections 30 and 31, T. 12 S., R. 1 W., and section 25, T. 12 S., R. 2 W.

| Units | Thickness in feet |
|---|---|
| 7. Limestone, dolomitic in places small quartz and calcite seams, calcareous and ferruginous oölites form up to 30% of rock. Color, | |

| | | |
|---|---|---|
| | dusky yellowish orange (10 YR 6/6). Moderately crystalline, crystal diameters 1/2 to 2 mm, oölites 1/2 to 1 mm in diameter. | 50 |
| 6. | Dolomite, much of it calcareous enough to be a limestone, may contain carbonaceous material which forms indefinite color bands. Color of rock, medium gray (N-5), color bands range from medium dark gray (N-4) to pale brown (5 YR 5/2). Finely to moderately crystalline, crystal diameters 1/16 to 1/2 mm. Rock is hard, with pitted weathered surface, and runic markings, here a surface development of weathering. | 527 |
| 5. | Covered: limestone float, massive pitted. | 34 |
| 4. | Limestone, some parts argillaceous and ferruginous. Color, medium light gray (N-7) on fresh rock, weathered rock, light brown (5 YR 6/4). Finely crystalline, crystal diameters 1/16 to 1/4 mm. Rock is alternating thin-bedded, shaly limestone and slabby limestone, hard and dense, with random spots of iron oxide stain, averaging 1 to 2 mm in diameter. | 61 |
| 3. | Limestone, color, medium gray (N-6), moderately crystalline, crystal diameters 1/2 to 2 mm. Bedding thin to moderately thick, from 1 to 6 in. | 212 |
| 2. | Limestone, color, medium gray (N-6), moderately crystalline, crystal diameters 1/2 to 2 mm. Bedding thin, 1/4 to 1 in., weathers to crumbly fragments. | 25 |
| 1. | Covered: limestone float here described. Color light brownish gray (10 YR 6/2). Finely crystalline, crystal diameters 1/16 to 1/4 mm. Rock is massive and hard. | 103 |
| | Total thickness of Meagher limestone, | 1007 feet. |

The Meagher limestone was deposited in the Cordilleran trough during the upper Middle Cambrian when Cascadia was low. Relatively little clastic material was being supplied to the sea and considerable thicknesses of limestone were deposited in Montana, (Diess, 1939, p. 60). Eardley says (1947, p. 310, 334-335) that southwestern Montana was part of the eastern shelf of the Cordilleran geosyncline which was to the west. No fossils were found in the Meagher limestone of the Centennial Region, but Diess (1936, p. 1314) reports a varied trilobite fauna from the formation at Nixon Gulch near Manhatten in central western Montana.

Park shale. - The Park shale of upper Middle Cambrian (Albertan) (Diess, 1939, p. 54) age is present in the Gravelly Range along the West Fork of the Madison River. It is also present in the north-facing scarp of the Centennial Range east of Odell Creek. The Park shale is apparently conformable on the Meagher limestone and is unconformably overlain by the Jefferson formation of Devonian age.

Outcrops of the Park shale are generally obscured because it has no resistant members. A thickness of 30 feet was measured in the Gravelly Range. Kennedy (1948) measured 125 feet of Park shale on Mt. Jefferson in the eastern part of the Centennial Range about twenty miles to the southeast of the Gravelly Range. Near Mt. Jefferson several hundred feet of fossiliferous upper Cambrian limestone (Pilgrim formation ?) overlie the Park shale, but the same beds could not be found in the Gravelly Range. The Park shale was described by Weed and Pirsson (1899, p. 2) as follows,

> "-- a very thin bedded, soft, and crumbly rock, often containing glistening grains of mica, which is mostly greenish gray in color, but also shows various shades of red and purple."

In the Gravelly Range the Park shale contains thin alternating bands of siltstone and shale. The siltstone is about 40% glauconite and 60% angular to subangular bright quartz grains of silt size. The shale is soft and clayey, in thin laminations of less than 1/16 mm thickness a pale green color (10 GY 7/2) and contains black and purple mica flakes. The glauconite is altered to iron oxides which stain the siltstone a light brown (5 YR 6/4).

The Park shale was deposited in the eastern part of the Cordilleran geosyncline in upper Middle Cambrian time, according to Deiss, (1939, p. 60). Deiss infers from the greater proportion of clastic sediments in central Montana that the region east of the geosyncline (Laurentia) fluctuated vertically more often and stood higher than the region west of the geosyncline. However, according to Eardley, (1947, p. 310) southwestern Montana in middle Cambrian time was the eastern shelf of the Cordilleran geosyncline which was to the west.

Devonian system

Jefferson dolomite. - The Jefferson dolomite of Upper Devonian age (Senecan to late Chemung or early Cassadagan) (Sloss and Laird, 1947, p. 1427-1428) is present on the West Fork of Madison River in the Gravelly Range, as well as in the Centennial Range east of Odell Creek. It unconformably overlies the Cambrian Park shale and is conformably overlain by the Three Forks formation. No outcrops were found in the Gravelly Range, and a thickness of 229 feet was measured on the basis of float. The Jefferson dolomite is exposed ten miles to the south where Kennedy (1948) measured 216 feet of dark dolomite on the north face of the Centennial Range south of Upper Red Rock Lake, and 199 feet on Mt. Jefferson about 10 miles to the east of his first section. At Logan, Montana, at the type section of the Jefferson dolomite Sloss and Laird (1947, p. 1412) measured a thickness of 715 feet.

Peale (1893, pp. 27-48) named the Jefferson dolomite from exposures on the Jefferson River, fifty miles to the north. Sloss and Laird (1947, p. 1404) redefined the Jefferson formation in central and northwestern Montana as follows,

> " — composed of an upper dolomite member, including some anhydrite and evaporation-solution breccia, and a lower dense limestone member; and an unnamed basal unit of shale and shaly dolomite which bears a transgressive relationship to the underlying Ordovician and Cambrian".

As observed in samples collected from float, the Jefferson dolomite is a massive, dense, finely crystalline, with crystal diameters ranging from 1/16 to 1/4 mm, saccaroidal dolomite, medium light gray (N-7) on a fresh surface and typically dusky yellowish orange (10 YR 6/6) mixed with above gray on a weathered surface.

One recognizable fossil, a bryozoan, <u>Fenestrellina</u> <u>cf.</u> <u>emaciata</u> (?), was collected from the Jefferson dolomite in section 6, T. 13 S., R. 1 W. on the south side of Landon Ridge in the Gravelly Range. According to Eardley (1947, p. 311) in Devonian time, the area of which the Centennial Region is a part, represented a shelf zone of the Devonian basin of the Cordilleran geosyncline. The area sank slowly and was covered with less than 1000 feet of sediments after consolidation. The basin itself deepened to the west and southwest into Nevada. Sloss and Laird (1947,

p. 1413) note that the Devonian strata of central Montana reflect the position at that time of temporary positive east-west axis which occupied the site of the present Little Belt - Big Snowy - Porcupine Mountains trend.

Threeforks formation. - The Threeforks formation of Upper Devonian (Chautauquan) age (Sloss and Laird, 1947, p. 1428) is manifested in the Gravelly Range as a gentle grass or tree-covered slope, striking north-south. On the basis of float the following section was measured on the West Fork of the Madison River in section 25, T. 12 S., R. 2 W.

| Unit | Thickness in feet |
|---|---|
| 2. Covered: limestone float, red, moderately crystalline, soft. | 98 |
| 1. Covered: limestone float, in soil suggesting presence of silt and shale. Color, reddish gray (5 T 6/2). Finely crystalline, crystal diameters, 1/16 to 1/4 mm. Rock is dense, moderately hard. Few small vugs filled with coarsely crystalline calcite, some iron oxide stains. | 140 |
| Total thickness of Threeforks formation - | 238 feet. |

To the southeast in the Centennial Range Kennedy (1948) measured thicknesses of 162 and 172 feet in two sections.

Peale (1893, pp. 29-32) named the formation from exposures at Logan, near Three Forks, Montana. Fifty miles to the north of the Centennial Region Peale (1893, p. 2, and columnar section ) recorded it as being 150-200 feet thick and divisible into three units. Sloss and Laird (1947, p. 1411) measured 150 feet of Threeforks at the type section. They describe the formation as being predominantly shale, and conformable with beds above and below it.

The author believes that the shaly character of the Threeforks formation indicates a temporary shallowing of the Upper Devonian seas or a small nearby uplift after Jefferson dolomite deposition, and this, possibly, relates with a contemporaneous evaporite basin at the site of the Sweetgrass Arch, in which the Potlatch anhydrite was deposited. (Sloss and Laird, 1947, p. 1405).

## Mississippian system

General statement. - Over 1700 feet of Mississippian limestone and dolomite were measured in the Gravelly Range. Generally the term Madison formation has been applied to these beds, because superficially they all appear to have the same lithology. However by careful lithologic and paleontologic study they can be divided into three formations, the Lodgepole and Mission Canyon limestones of Lower Mississippian (Kinderhook, Osage) age and the Brazer limestone of Upper Mississippian (Meramec, Chester) age. The Lodgepole and Mission Canyon limestones were included in the Madison group by Collier and Cathcart (1922, p. 173).

Lodgepole limestone. - The Lodgepole limestone of Lower Mississippian (Kinderhook) (Sloss and Hamblin, 1942, pp. 312-313) age crops out in the Gravelly Range as a north-south trending cuesta. Locally it is in part well exposed, but in places it is entirely covered with talus or vegetation. It crops out along Odell Creek in the Centennial Range, (see figure 6), along the northwest flank of the Snowcrest Range, and in the valley of the West Fork of the Madison River in the Gravelly Range, where a thickness of 628 feet was measured. Kennedy (1948) reports a thickness of 609 feet several miles east of Odell Creek along the face of the Centennial Range, where it forms part of the steep north-facing scarp. The Lodgepole limestone is conformable to the underlying Threeforks formation and the overlying Mission Canyon limestone.

The Lodgepole limestone was named by Collier and Cathcart (1922, p. 173) from Lodgepole canyon in the Little Rocky Mountains of Montana. Sloss and Hamblin (1942, p. 305) describe it as follows,

> "The Lodgepole is divisible into an upper member, the Woodhurst, largely limestone with thin shale partings, and a lower member, the Paine, with a much larger percentage of shale."

Lodgepole float samples are a very dense limestone with some larger calcite crystals representing parts of fossils. Crinoid stems, bryozoa, brachiopods, and corals are common. The rock is moderately hard, has a petroliferous odor when struck with a hammer and is light brownish gray (5 YR 6/1) in color, due to high carbonaceous and argillaceous content.

The following section of the Lodgepole formation was measured along the West Fork of the Madison River in section 25, T. 12 S., R. 2 W.

| Unit | Thickness in feet |
|---|---|
| 4. Covered: limestone float, gray, dense. | 407 |
| 3. Partially covered: limestone, lower 15 feet has few scattered outcrops, 3 to 12 in. thick. Upper part covered; limestone float, gray, dense. | 65 |

2. Limestone; color, dark gray (N-4). Thinbedded, 1/2 to 6 in. average bed thickness. Some beds very finely crystalline, less than 1/50 mm diameter for crystal particles. More fossiliferous beds finely to coarsely crystalline, 1/16 to 2 mm in diameter. Petroliferous odor when struck with hammer. 63

1. Covered; limestone float, light gray fossiliferous. 93

Total thickness of Lodgepole formation 628 feet.

Mission Canyon limestone. - The Mission Canyon limestone crops out in the same areas as does the Lodgepole formation. Good exposures may be seen along Cascade Creek in the Gravelly Range. It is Lower Mississippian (Osage or partly Kinderhook, Sloss and Hamblin, 1942, p. 311) in age and conformably overlies the Lodgepole limestone and is apparently conformable with the overlying Brazer limestone. It is a massive, cliff-forming limestone but may form grassy slopes. In the Gravelly Range 353 feet were measured and Kennedy (1948) measured 531.6 feet on Odell Creek in the Centennial Range.

The Mission Canyon limestone was originally described by Collier and Cathcart (1922, p. 173) in the Little Rocky Mountains region of Montana. Sloss and Hamblin (1942, p. 318) describe it as follows,

> "The Mission Canyon appears almost invariably as a uniform succession of poorly bedded, highly massive, pure limestone which form impressive cliffs or whether into castellated shapes."

In the Gravelly Range the Mission Canyon limestone is usually a dense to coarsely crystalline, locally very fossiliferous, dark gray, moderately hard, petroliferous, limestone with chert and chert breccia.

Corals, gastropods, crinoids, brachiopods and bryozoa are common. A section of the formation measured along the West Fork of the Madison River in section 24, T. 12 S., R. 2 W. is as follows,

| Unit | Thickness in feet |
|---|---|
| 9. Covered: limestone float | 57 |
| 8. Covered: limestone float containing varied chert fragments. Color of limestone medium gray (N-6), moderately crystalline crystal diameters average 1/2 mm. Color of chert dusky red, (5 R 3/4), also other chert is dusky yellowish brown (10 YR 6/6). Red chert is 10% porous, pores are 1/4 to 1/2 mm. diameter, yellow chert, dense. | 29 |
| 7. Covered: limestone float | 30 |
| 6. Covered: chert breccia fragments. Color chert groundmass, reddish black (5R 2/2); chert fragments pinkish gray ( 5 YR 8/1). Chert groundmass is 15% porous, pores average 1/4 to 1 mm diameter. Chert fragments form 30% of rock, particles angular, dimensions 1 mm to 1 cm. | 2 |
| 5. Covered: limestone float | 52 |
| 4. Limestone; color, brownish gray (5 YR 4/1). Partly crystalline limestone, 50% scattered calcite crystals, 1/8 to 1 mm in diameter. Weathered surface looks oölitic due to differential weathering out of minute fossil particles. Bedding 1 to 2 ft. thick. | 26 |
| 3. Covered: limestone float, fossiliferous. | 130 |
| 2. Limestone; color dark gray (N-4), high carbonaceous content. Rock is 70% dense groundmass, and 30% scattered calcite grains from 1/8 to 1 mm in diameter. Petroliferous odor when struck with hammer. Fossiliferous. | 15 |

1. Limestone; color, medium gray (N-5). Moderately crystalline, 1/4 to 1/2 mm crystal diameters. Weathered fossils give surface an oolitic appearance. Bedding from 4 to 12 in. thick. Slightly fossiliferous. 12

Total thickness of Mission Canyon limestone - 353 feet.

Lower Mississippian sediments averaging 1000 feet in thickness were deposited in Montana in an elongate, irregular trough which Eardley (1947, p. 314) has described and called the Madison basin. In the Montana part of this trough the Lodgepole and Mission Canyon limestones were deposited. Limestone deposited in the Lodgepole sea contains much argillaceous and carbonaceous material but by Mission Canyon time the seas had cleared and the Mission Canyon limestone is purer than the Lodgepole. Conditions in these seas were favorable for invertebrate life. The writer collected several faunas from Mississippian rocks in the Centennial region.

The following fauna from the Madison group was collected in sections 26, 27, T. 12 S., R. 2 W., in the West Fork of the Madison River canyon, in the Gravelly Range, (locality 2, figure 10).

Brachiopoda

Athyris cf. lamellosa (?)
Camarotoechia cf. mutata
Chonetes loganensis
C. logani
Composita humilis
Dictyoclostus, sp.
Dielasmella cf. calhounensis
Echinochonchus alternatus
Linoproductus ovatus
Orbiculoidea, sp.
Schuchertella cf. desiderata
Spirifer centronatus
Spirifer, sp.

Torynifer cf. pseudolineata
Torynifer, sp.

Bryozoa

Fenestrellina, sp.
Hederella, sp.
Rhombopora, sp.
Sulcoretepora (?) sp.
Tabulipora, sp.

Anthozoa

Hapsiphyllum calcariforme

Gastropoda

Euomphalus cf. luxus (?)

A second fauna from the Madison group was collected from sections 34, 35, and 36, T. 12 S., R. 2 W., on the south side of Landon Ridge, south of the canyon of the West Fork of the Madison River in the Gravelly Range, (locality 4, figure 10). The following forms were identified.

Brachiopoda

Chonetes logani
Dictyoclostus cf. mesialis
Echinochonchus biseriatus
Schuchertella cf. desiderata
Spirifer increbescens

Anthozoa

Caninia juddi
Cyathophyllum (?), sp.
Hapsiphyllum calcariforme

Bryozoa

Fenestrellina cf. cestriensis
Fenestrellina, sp.
Sulcoretepora, sp.

Blastoidea

Schizoblastus sayi
Unidentified blastoid

Crinoidea

Unidentified crinoid
Crinoid columnals

Gastropoda

Euomphalus cf. luxus (?)

An evaluation of the fauna from the West Fork of the Madison River shows 12 forms that can be classed as Kinderhook and Osage in age, and 2 forms that may be Meramec in age. The Landon Ridge fauna contains 5 forms of Lower Mississippian affinities and 5 forms of Upper Mississippian affinities of which 3 are Meramec.

The Madison group contains a varied fauna and a careful study of it should prove valuable. The inconclusiveness of the Landon Ridge fauna is probably due to incomplete knowledge of the ranges of some of these forms, and contamination of fauna while collecting.

Sloss and Hamblin (1942, p. 305) in discussing the value of the Madison fauna say,

> "Although the Madison limestones are richly fossiliferous in certain areas or at certain horizons, experience in the field has proved that the occurence of fossils cannot be relied on to identify units of the group."

Brazer limestone. - The Brazer limestone of Upper Mississippian (Salem, Ste. Genevieve, through Chester) (Mansfield, 1927, p. 68) age crops out parallel with the other Mississippian formations in the Gravelly, Centennial and Snowcrest Ranges. It is well exposed on Cascade Creek in the Gravelly Range, and on Odell Creek in the Centennial Range, where it is a cliff-maker. A thickness of 772 feet was measured on Cascade Mountain in the Gravelly Range, and Kennedy (1948) reports a thickness of 406 feet on Odell Creek.


Figure 6. Odell Creek canyon

In Tps. 14 and 15 S., Rs. 1 and 2 W. Cut through Mississippian limestones. Dip slope in center right in Dinwoody formation. Note repetition of limestone scarp in upper right due to down-dropped fault slice. (Aerial photo by Agricultural Adjustment Agency)

The Brazer limestone was named by Richardson (1913, p. 413) from exposures in northern Utah.

In the Centennial Region the Brazer limestone is a dolomitic limestone, or a calcareous saccaroidal dolomite, in quite massive beds, gray, petroliferous, locally fossiliferous, and locally with much chert. The following section was measured in sections 23 and 24, T. 12 S., R. 2 W. in the Gravelly Range.

| Unit | Thickness in feet |
|---|---|
| 11. Covered: limestone float, cherty and hard. Color, brownish gray, stained by red color from overlying Amsden formation. | 80 |
| 10. Limestone: color, bluish gray, with chert bands, hard. | 77 |
| 9. Partially covered: limestone, color brownish gray, hard. Mostly float, few beds 1 to 12 in. thick crop out. | 20 |
| 8. Partially covered; limestone, color bluish gray. Float is hard, massive, fossiliferous. | 90 |
| 7. Limestone; and dolomite admixed, 60% limestone, 40% dolomite, estimated. Color, medium gray (N-6). Rock almost entirely composed of crinoid stems, fusilinids, and shell fragments. | 45 |
| 6. Partially covered; limestone, and cherty limestone float. Limestone gray and hard, cherty limestone buff. | 15 |
| 5. Partially covered; limestone, gray hard. | 76 |
| 4. Dolomite; with limestone admixed, forming estimated 40% of rock. Color, light brownish gray (10 YR 6/1). Coarsely crystalline calcite, 1/2 to 2 mm crystal diameters, embedded in a fine grained groundmass, 1/16 to 1/8 mm crystal diameters, of saccaroidal dolomite. Calcite is shell fragments, with a rough initial parallel orientation on the sea floor. | 109 |

| | | |
|---|---|---|
| 3. | Limestone; cherty, color gray, but float from upper 30 feet of unit weathers to a buff color. | 146 |
| 2. | Limestone; cherty, color, brownish grey 5 YR 4/1), color of chert, medium light gray (N-7). Moderately coarsely crystalline, crystal diameters, 1/2 to 1 mm. Highly fractured, has 10% secondary porosity due to exsolution of fossil materials. | 67 |
| 1. | Partially covered: limestone float, hard and cherty. | 47 |
| | Total thickness of Brazer limestone - | 772 feet. |

Brazer limestone deposition in southwestern Montana represents the northeastern corner of the Brazer basin, that existed in the eastern half of the Cordilleran geosyncline during Upper Mississippian time (Eardley, 1947, p. 311). The Brazer sea was clear and adjacent lands were low providing mainly chemical sediments as calcium carbonate and silica. The Brazer limestone contains a varied invertebrate fauna. Two collections of fossils were made and tentatively identified.

The following fauna was collected in sections 1, 2 and 3, T. 12 S., R. 2 W. in the Hellroaring Creek canyon in the Gravelly Range, in Madison County, Montana, (locality 5, figure 10).

Brachiopoda

Cleiothyridina cf. hirsuta
Composita humilis?
Dictyoclostus inflatus
Linoproductus cf. ovatus
Petrocrania (?) sp. undet.
Spirifer cf. centronatus

Anthozoa

Caninia juddi (?)
Hapsiphyllum calcariforme
Homophyllum (?) calceolum

Lithostrotionella cf. americana
Triplophyllites, aff.
Zaphrentis, aff.

Gastropoda

Euomphalus luxus
Loxonema sp. undet.

Bryozoa

Fenestrellina, sp.

A second fauna was collected slightly outside the limits of the Centennial Region in sections 18 and 19, T. 12 S., R. 5 W. on Gray's Fork of the West Fork of Blacktail Creek in the Snowcrest Range, (locality 1, figure 10). It contains the following forms,

Brachiopoda

Camarotoechia cf. mutata (?)
Chonetes logani
Chonetes, sp.
Cleiothyridina cf. hirsuta (?)
Composita humilis
C. subquadrata
Composita, sp.
Dictyoclostus cf. inflatus (?)
Dielasma, sp.
Echinochonchus alternatus
E. cf. biseriatus (?)
Eumetria cf. altirostris (?)
Linoproductus cf. ovatus (?)
Orbiculoidea, sp.
Petrocrania, sp.
Schuchertella chemungensis
S. cf. desiderata (?)
Schuchertella, sp.
Spirifer increbescens
S. keokuk
Spirifer, sp. undet.

Pelecypoda

Conocardium, sp. undet.
Cypricardella (?) subquadrata

Gastropoda

Euomphalus luxus

Annelida

Spirorbis, sp. undet.

Ostracoda

Ostracodes, gen. undet.

Bryozoa

Fenestrellina, sp.

Cephalopoda

Unidentified orthoconic nautiloid

An evaluation of these two faunas gives little conclusive evidence on the age of the Brazer limestone. The Hellroaring Creek fauna contains four Lower Mississippian forms and seven Upper Mississippian forms, of which five are of Chester affinities. The Gray's Fork fauna contains seven Lower Mississippian forms and seven Upper Mississippian forms and two that range through the Mississippian. Sloss (1947) in a brief examination of this fauna, stated that it appeared to be equivalent to the Big Snowy group fauna. The Big Snowy group is equivalent to the Brazer limestone.

The reasons given for the variance in the ages of the Madison group forms earlier in this paper may also apply to the fauna of the Brazer limestone. An additional reason is given by Blackstone (1934, pp. 91-92) in discussing the Yakinikak limestone, probably correlatable with the Brazer limestone. He says,

> "Twelve species were collected from the Yakinikak limestone. Of these, nine, or 75 percent are Meramec and Chester and three are Kinderhook and Osage. The presence of the Kinderhook and Osage species among an assemblage that is dominantly Upper Mississippian is probably an example of a recurrent fauna. The species may have originated during Waverlyan time and persisted in some unknown region until Upper Mississippian invasions of the sea allowed them to enter northwestern Montana."

## Pennsylvanian system

Amsden formation. - The Amsden formation, which is mostly Pennsylvanian in age but may include some Mississippian beds, is present on the east slope of Cascade Mountain in the Gravelly Range, where a thin unit of 73 feet was measured. Elsewhere outcrops are scarce, due either to thinning out of the formation or to cover by talus. The author has observed approximately 1 foot of red shale on Hellroaring Creek in the eastern part of the Centennial Range which may be Amsden.

Darton (1904, p. 396) named the Amsden formation from exposures in the Bighorn Mountains in Wyoming. He described it as a,

> " -- somewhat variable succession of red shales, limestones, cherty and sandy members --"

The Mississippian part of the Amsden formation was defined in Wyoming as the Sacajawea formation by C. C. Branson (1937, pp. 650-653), but this unit was not discernible in southwestern Montana.

The Amsden formation here is composed of soft red shales, very fine-grained calcareous siltstone, dolomitic limestones, which may have an admixture of red silt. A section measured in section 23, T. 12 S., R. 2 W. in the Gravelly Range is as follows;

| Unit | Thickness in feet |
|---|---|
| 3. Covered; shale, siltstone, sandstone float, color, reddish and buff. | 40 |
| 2. Limestone, dolomitic. Color, weak yellowish orange (10 YR 7/4). Very finely crystalline, crystal diameters range from 1/50 to 1/10 mm. Rock is dense, hard. | 2 |
| 1. Shale, siltstone, limestone, interbedded. General color, weak red (5 R 5/4), limestones stained moderate reddish orange (10 R 5/8) by iron oxides. Siltstone very fine grained, particle diameters 1/50 to 1/10 mm, limestone moderately finely crystalline, crystal diameters 1/8 to 1/2 mm. Rocks thinly bedded, 1 to 3 in. thick. Some calcite seams, 1/2 to 2 mm thick. Limestone very thinly bedded, 1/2 to 2 mm thick, contains up to 40% silt, siltstone has calcareous cement. Bottom contact covered. | 31 |
| Total thickness of Amsden formation - | 73 feet. |

In section 34, T. 12 S., R. 2 W. is an isolated 15 foot thick outcrop of conglomerate or breccia, or both. The outcrop is situated between outcrops of the Brazer limestone and Phosphoria formation, and the author estimates that it is stratigraphically located near or at the Brazer limestone and Amsden formation contact.

The conglomerate is composed of angular to subangular to partially rounded particles of limestone, which forms 50 percent of the particles, dolomite which forms 25 percent and sandstone which forms 25 percent of the particles. About 60% of the rock is particles and 40 percent coarsely crystalline calcareous cement. The particle diameters range from 1 mm to 1 cm. Iron oxides have stained the rock a light brown color (5 YR 6/4).

The conglomerate is interpreted as marking the Brazer limestone and Amsden formation contact. The thickness of the conglomerate here may be due to local solution and brecciation after Brazer limestone deposition. Perry and Sloss (1943, p. 1303) report from eastern Montana a slight angular unconformity between the Amsden formation and Big Snowy group, (partly equivalent to Brazer limestone), marked by a limestone conglomerate in one place. Scott (1935, p. 1021) reporting a thickness of 25 feet of Amsden at Eustis near Three Forks, Montana, states that there the Amsden is unconformable on the Madison group, which may have been slightly flexed before deposition of the Amsden.

It must be noted that the conglomerate resembles somewhat an unnamed Cretaceous or Tertiary conglomerate cropping out 12 miles to the west. The conglomerate on Landon Ridge is adjudged to be Paleozoic because conglomerates are possible at the stratigraphic horizon where it is believed to be present and its strike and dip coincides with rocks in the immediate vicinity.

Quadrant formation. - The Quadrant formation of Lower Pennsylvanian age crops out in the Gravelly range along the West Fork of the Madison River and between Fossil and Cascade Creeks. In the Centennial and Snowcrest Ranges it is near or at the crests of the ranges. The formation is mainly sandstone, locally friable, but it may also be quartzitic and generally is resistant to erosion. Its upper and lower limits were not observed, but Scott (1935, p. 1019) says that in the Three Forks, Montana region the Quadrant is conformable to the underlying Amsden, and that no unconformity has been found at the contact of the Quadrant and the overlying Phosphoria formation in this vicinity. Near the crest of the Centennial Range, 10 miles east of Odell Creek, the author observed a coarse conglomerate 2 feet thick where the Quadrant-Phosphoria contact could be drawn. This implies that locally, at least, the Phosphoria formation is unconformable on the Quadrant.

The Quadrant formation was named by Weed (1896, p. 2) from exposures on Quadrant Mountain of the Gallatin Range in the northwest corner of Yellowstone Park. Scott (1935, p. 1018) describes the Quadrant as consisting:

> "...primarily of well-bedded, white to pink, fine to medium-grained quartzite which is occasionally more sandy than quartzitic."

In the Gravelly Range the Quadrant is a well-sorted fine to medium grained rock ranging from friable sandstone to quartzite and locally with calcareous beds.

A section measured in section 27, T. 12 S., R. 2 W. between Fossil and Cascade Creeks in the Gravelly Range is as follows,

| Unit | Thickness in feet |
|---|---|
| 4. Covered: sandstone float, ferruginous | 48 |
| 3. Sandstone, color of fresh surface is light brown (5 YR 6/4), weathered surface is light brown (5YR 5/6). Cement is calcareous or siliceous, a little hematite present. Average sample is well sorted friable sandstone. Sand grains average 1/4 mm diameter, range 1/4 to 1 mm diameter. Grains angular to subangular, 30% frosted, 70% glassy. | 64 |
| 2. Talus slope; sandstone float, coarse-grained, ferruginous. | 236 |
| 1. Covered: sandstone float, reddish-yellow, friable. Quartzitic in places. | 64 |
| Total thickness of Quadrant formation - | 402 feet. |

The Quadrant formation is interbedded locally with marine limestones and is considered to be of marine origin. According to Eardley (1947, p. 316) the greater clastic content of the sedimentary sections on the eastern border of the Rocky Mountain geosyncline indicates marked uplift of the Canadian shield to the northeast and the elevation of the ancestral Rockies to the south in Pennsylvanian time.

Permian system

Phosphoria formation. - The Phosphoria formation, partly or wholly of Middle Permian (Word) age, crops out along Fossil and Metzel Creeks in the Gravelly Range, on Odell Creek and at or near the crest of the Centennial Range, and along the southeastward facing scarp of the Snowcrest Range. Typically it forms shaly, grass-covered slopes, or extensive dip slopes upheld by resistant chert beds. The formation thickens when traced from the southeast to the northwest, (see figure 7). In the Hell-roaring Creek basin in the eastern end of the Centennial Range the formation is about 80 feet thick and mainly a dark reddish chert. Eight miles to the west the Phosphoria formation is approximately 135 feet thick and 3 miles further west near Odell Creek approximately 200 feet thick. Continuing from that point 17 miles to the northwest, a thickness of 229 feet was measured on Fossil Creek in the Gravelly Range. Sixteen miles further west in the Snowcrest Range at least 600 feet of Phosphoria beds are present. Lowell (1949) reports 832 feet of Phosphoria strata near Dell, Montana, 25 miles west of the Snowcrest Range.

Because the Phosphoria formation, extending from Utah to Alberta, contains one of the world's largest reserves of high-grade phosphate rock it has been the object of much mapping and research by governmental and private agencies. Recently, attention has been focused on its minor constituents, including fluorine, vanadium, chromium, uranium and other rare and strategic elements. The formation also contains large reserves of high-grade oil shale.

The Phosphoria formation was named by Richards and Mansfield (1912, pp. 684-689) from Phosphoria Gulch in the Park City mining district in Utah. It generally is composed of interbedded carbonate rocks, chert, yellow to black shales, sandstone and phosphate rock. Its middle and upper parts are called Middle Permian in age by Miller and Cline (1934, p. 284), while recognizing E. B. Branson's (1916, p. 642) cochliodont shark tooth evidence that the lower part of the formation may be of Upper Pennsylvanian age. Lowell (1948), has recently divided the formation into five units (A to E), in the Dell, Montana district. These are in ascending order, Unit A, basal carbonate and siliceous member; Unit B, lower phosphatic shale member; Unit C, upper carbonate and siliceous member; Unit D, upper phosphatic shales; and Unit E, siliceous member. C. C. Branson (1930, pp. 5-14) also described a five unit division of the Phosphoria formation from the Wind River Range in Wyoming.

The phosphate rock occurs as soft, oölitic, friable, brownish black deposits, or in a less pure state as a phosphatic shale. In the Centennial Range phosphate rock also occurs as a bed of hard, pisolitic and nodular rock.

The following section was measured in section 21, T. 12 S., R. 2 W. on Fossil Creek in the Gravelly Range.

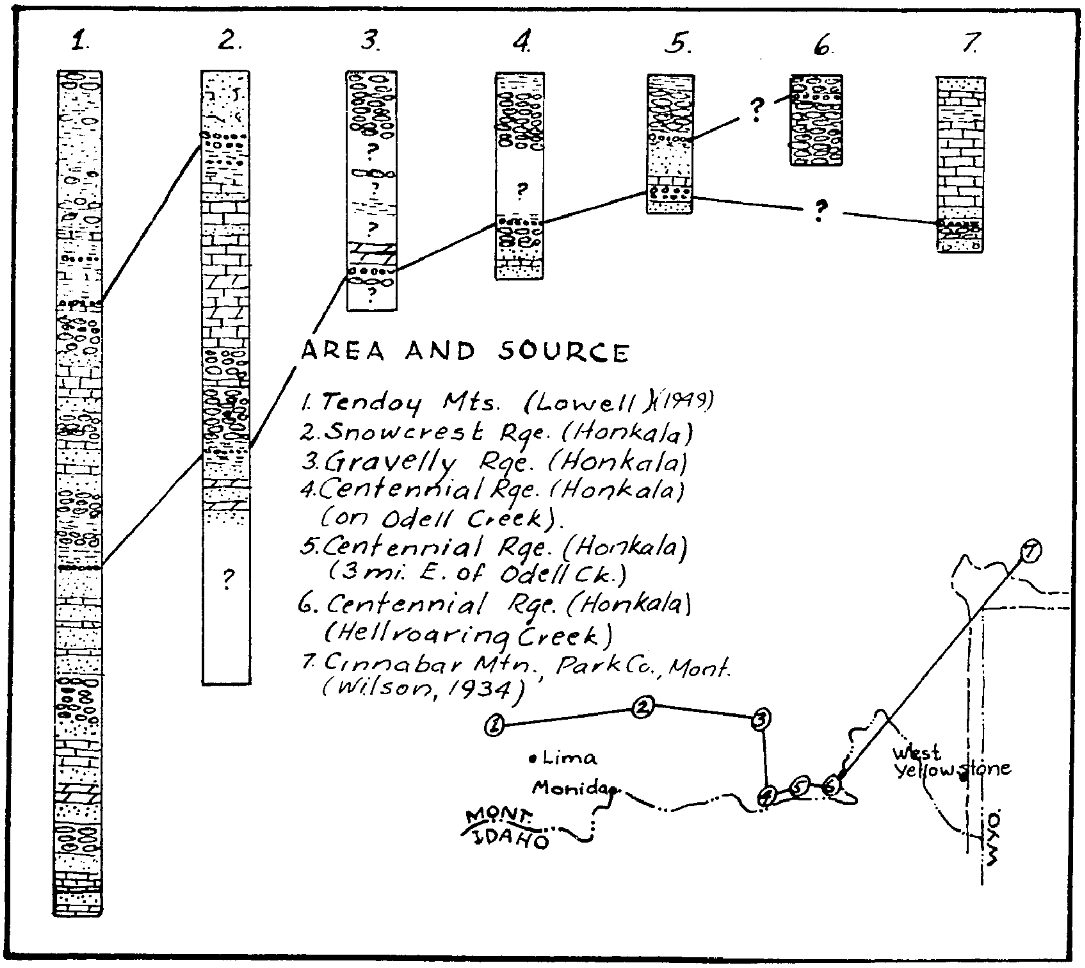



Figure 7. Variation of thickness in Phosphoria formation.

| Unit | Thickness in feet |
|---|---|
| 5. Chert, ferruginous in lower 5 feet of bed. Color, medium gray (N-5), contains small oölitic bodies throughout, forming an estimated 5 percent of rock, source unknown. | 44 |
| 4. Covered: chert float, ferruginous. Color, brownish gray (5 YR 4/1). Rock is thin bedded, beds range from 1 cm to 6 in. thick. Has oölitic appearance under microscope. "Oölites" may be unassimilated sand grains because on edge of chert bed they may be seen to merge into sandstone. | 26 |

| | |
|---|---|
| 3. Chert, slightly ferruginous, color medium light gray (N-7), dense.[3] | 15 |
| 2. Covered: chert, dolomite, shale float. Color chert, brownish gray, dolomite, yellow-white, shale, dark gray. | 64 |
| 1. Covered: shale float, dolomite float, with chert bands in upper 20 feet. Color dolomite, yellow-white, shale, dark gray. Dolomite is fine-grained, shale hard, fissile. | 80 |
| Total thickness of Phosphoria formation - | 229 feet. |

The wide variety of common and relatively uncommon sediments and sedimentary structures in the Phosphoria formation has long stimulated geologic thought. Probably the best authority on the formation is Mansfield. Of conditions in the west during the Permian time he said (1927, p. 372),

> "...The physiographic conditions of Phosphoria time were unusual. Lowlands or peneplained lands adjacent to the sea are suggested and also the abundance of sandy and quartzitic material in Pennsylvanian terranes, possibly exposed to erosion, is indicated. These conditions fit in well with Tarr's hypothesis."

Here Mansfield is discussing the origin of the chert in the Phosphoria formation and is referring to Tarr's (1917, p. 450-451) hypothesis that chert deposits are due to the accumulation of gelatinous silica at or near wave base. As noted in the stratigraphic section of the Phosphoria above there seems to be also a suggestion that the chert may in part be due to partial replacement by silica-bearing waters.

Concerning the deposition of the phosphate rock Mansfield (1931, pp. 368-369) made the following comments,

[3]Between Units 2 and 3 elsewhere on Fossil Creek a 6 to 8 inch oölitic phosphate rock unit was observed in place.

> "The mode of origin of the oölites is not clearly understood, but the presence on the sea bottom of solutions rich in phosphate or perhaps of phosphatic colloids is certainly indicated. The oölitic grains appear to have been formed directly from these, perhaps partly by chemical precipitation and partly by physical or mechanical accretion."
>
> "The water circulatory system throughout the Phosphoria sea must have been poor otherwise the conditions at the bottom would not have become so foul. Probably the inflow of sea water from the North Pacific or Arctic was impeded and the temperature contrasts between higher and lower latitudes may not have been so pronounced as they are today. At any rate, conditions were not as favorable for replenishment of oxygen in the deeper waters of the Phosphoria sea as they are in open oceans. This fact prevented the growth on the sea of ordinary organisms of the scavenger type. On the other hand, it promoted anaerobic bacterial decay, so that decomposition products such as carbon dioxide and ammonium phosphate might readily be produced."

Mansfield (1931, p. 366) also makes the following observation,

> "One of the minor constituents of phosphate rock that may shed a little light on the general conditions at its time of deposition is fluorine. Zies has shown that the fumaroles of the Valley of Ten Thousand Smokes in Alaska alone contribute annually to the sea about 135,000 metric tons of fluorine. He states that the quantity of fluorine stored in the estimated phosphate reserves of the Idaho field approximates 540,000,000 metric tons. Since volcanic emanations form the principal source of fluorine in the sea, this perhaps constitutes independent evidence of volcanic activity on a considerable scale during Phosphoria time."

Mansfield later (1940, p. 877) suggested that fluorine was active in turning phosphoric acid into phosphates. He said,

> "Two things seem to stand out as essential; first a combination of circumstances favorable to the accumulation of phosphoric acid, and, second, the presence of some agent to fix that phosphoric acid in relatively insoluble form. It is here suggested that this agent may be fluorine."

The author herein suggests another possible effect of fluorine on the formation of phosphate. Eardley, (1947, pp. 312, 316-342) has listed the evidence for extensive Permian volcanism west of Pacific trough of the Cordilleran geosyncline. Four thousand feet of Permian volcanics are present in Central Idaho. (Eardley, p. 322). It is suggested that subaerial or submarine effusions of volcanic gases such as hydrogen chloride, hydrogen fluoride and the various sulfurous gases present in volcanic emanations (Clark, pp. 260-271) may have sporadically poisoned the waters of the Phosphoria sea killing off great quantities of sea life, and thus providing phosphatic material. However, the lack of abundant fossil material in the Phosphoria formation is a deterrant to this suggestion, and some present-day workers think that phosphate beds represent concentrations of phosphate during non-deposition of other sediments, (Lowell, 1949). Dietz (1942, pp. 836-839) believes present phosphorite deposits on the coast of California are deposited in place largely by direct precipitation.

## Triassic system

Dinwoody formation. - The Dinwoody formation of Lower Triassic age was named by Blackwelder (1918, p. 425) from exposures in Dinwoody Canyon in the Wind River Range in Wyoming. It crops out in the Gravelly Range along Fossil Creek and along the West Fork of the Madison River. In the Centennial Range it lies on the dip slope that is underlain by chert beds of the Phosphoria formation, and in the Snowcrest Range it crops out on the southeastward-facing mountain scarp. The exposure is generally a grassy slope as the formation does not include resistant beds.

A thickness of 358 feet for the Dinwoody formation was measured on Fossil Creek in the Gravelly Range, and Kennedy (1948) found 471 feet of Dinwoody strata in the Centennial Range, 5 miles east of Odell Creek. The Triassic thins quickly to the northeast, for Wilson (1934, p. 372) reports 137 feet for the entire Triassic section at Cinnabar Mountain in Park County, Montana, 60 miles from the Gravelly Range.

The Dinwoody formation is fairly uniform throughout, being mainly a series of thin and flaggy, alternating, buff to brown, silty limestones and calcareous siltstones and sandstones. Fossils are fairly abundant especially the brachiopod, *Lingula borealis*. The formation is apparently conformable with the underlying Phosphoria formation and the overlying Woodside formation. A section measured in section 16, T. 12 S., R. 2 W. on Fossil Creek in the Gravelly Range is as follows,

| Unit | Thickness in feet |
|---|---|
| 5. Covered; limestone float, silty. Color, buff, weathers brown. | 211 |
| 4. Limestone, silty; color, buff; thinly and evenly bedded, beds range from 1 to 3 in. thick. | 18 |
| 3. Covered: limestone float, silty. Color, buff. | 69 |
| 2. Limestone, silty. Color buff, weathers to a chocolate brown. | 45 |
| 1. Sandstone, calcareous, glauconitic. Color bands, average 5 mm thick, medium light gray (N-7) to medium gray (N-5). Quartz is fine grained, diameters of grains range from 1/16 to 1/8 mm. Rock composed of 50% quartz, 45% calcite, 5% bright green glauconite, which under microscope shows parallelism, indicating detrital origin. Cement is calcareous. | 15 |
| Total thickness of Dinwoody formation - | 358 feet. |

Local uplifts at the close of the Permian supplied an influx of silt and clay into the Dinwoody sea, in which mud-inhabiting forms as *Lingula* were common.

The following fossils were collected from the Dinwoody formation in section 24, T. 12 S., R. 3 W. on the West Fork of the Madison River, (locality 3, figure 10).

Pelecypoda

Anadontophora fassaensis
Aviculopecten, sp.
Eumorphotis multiformis (?)
Monotis, sp.
Myalina postcarbonica

Brachiopoda

Lingula borealis

*Woodside formation.* - The Woodside formation of Lower Triassic age (Seis or lower Werfen of the Alps, Newell and Kummel, 1942, p. 938) is very well exposed along the upper reaches of Fossil Creek in the Gravelly Range (see figure 8), and less well exposed in the Centennial and Snow-crest Ranges parallel to the previously located Dinwoody formation. A thickness of 564 feet was measured on Fossil Creek in the Gravelly Range and Kennedy (1948) measured 801 feet near Odell Creek in the Centennial Range 17 miles to the south. The formation contains no resistant beds and hence good outcrops are scarce.

The Woodside shale was named by Boutwell (1907, p. 446) from exposures in Woodside Gulch in the Park City mining district, Utah, where it is a thin-bedded shale. In the Gravelly Range the Woodside formation is mainly red shaly siltstone with a few white and maroon siltstones and

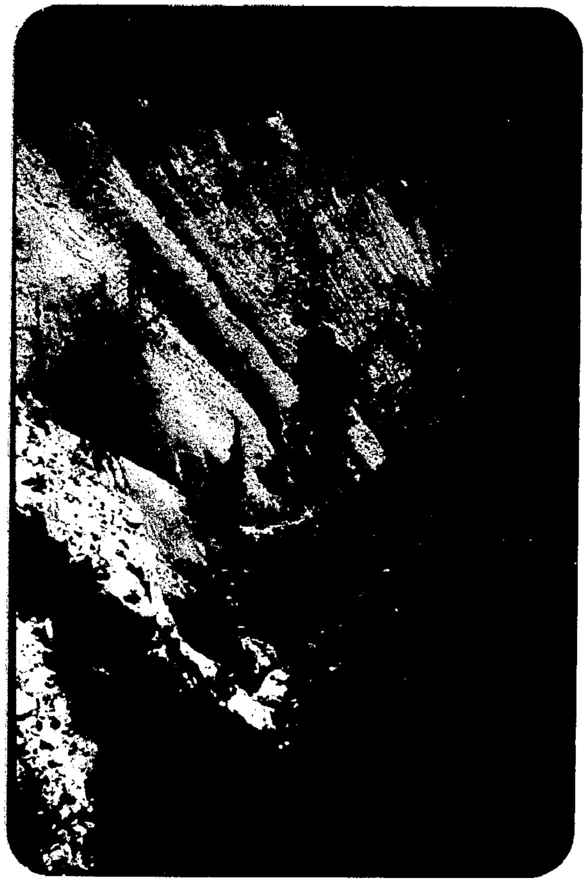


Figure 8. Woodside formation on Fossil Creek.

limestones near the top. It is conformable on the underlying Dinwoody formation and grades into the overlying Thaynes formation. The formation is apparently unfossiliferous everywhere. The northernmost extent of the Woodside formation has previously been considered as central southeastern Idaho, (see Newell and Kummel, 1942, p. 946) so this occurrence in the Gravelly Range, if truly the Woodside formation, considerably extends its outcrop area.

A section of the Woodside formation measured in section 9. T. 12 S., R. 2 W., on Fossil Creek in the Gravelly Range contains the following,

| Unit | | Thickness in feet |
|---|---|---|
| 10. | Siltstones and limestones, alternating, colors maroon and white respectively. | 30 |
| 9. | Mudstone (or shaly siltstone). Colors, red to pink. | 12 |
| 8. | Siltstone, calcareous, glauconitic. Color, reddish-gray (5 R 6/2). Well sorted quartz grain diameters average 1/25 mm. | 5 |
| 7. | Siltstone, calcareous, glauconitic, some mudstone. Color, weak orange pink (5 YR 7/2). Well sorted. | 32 |
| 6. | Covered: Mudstone float, red. | 23 |
| 5. | Mudstone, ferruginous, glauconitic, calcareous. Color "red", or pale reddish brown (10 R 5/4). Composed mainly of well sorted quartz grains, average diameter of 1/25 mm. Cement is mostly iron oxide, plus a little calcareous cement. Few glauconite grains. In outcrop shows a shaly parting. | 150 |
| 4. | Covered: Mudstone float and red soil. | 25 |
| 3. | Mudstone, red. | 23 |
| 2. | Covered: Mudstone float, red. | 252 |
| 1. | Partially covered: Mudstone float, red, and one small mudstone outcrop, 6 in. thick, in center of unit. | 42 |
| | Total thickness of Woodside formation | 564 feet |

The Woodside formation and its Wyoming correlative, the lower part of the Chugwater formation have been variously termed marine (E.B. Branson, 1915, p. 228) and continental (Reeside, 1929, p. 62) deposits. Branson believes that the "red beds" were deposited in interior seas of high salinity, inimical to marine life because of high salinity and containing no life, and unable to reduce the iron oxide among the silts that were deposited therein. He scores a valid point in asking if these "red beds" were continental, why are there no plant or animal fossil remains in them, since continental red beds do not imply necessarily arid and unfavorable conditions for life.

Thaynes formation. - The Thaynes formation of Lower Triassic age crops out in the same general areas as the other Triassic formations in this region. It is best exposed along the upper reaches of Fossil Creek in the Gravelly Range and is also exposed at the northern end of the Metzel Creek Anticline in the same range, as well as on Odell Creek in the Centennial Range and in the southeastward facing scarp of the Snowcrest Range. It conformably overlies the Woodside formation and is unconformably overlain by the Swift formation of Jurassic age. Even so, in the Fossil Creek section where the Thaynes and Swift formations are well exposed the contact could not be located and the two formations seem to grade into each other. A thickness of 138 feet was measured on Fossil Creek, and Kennedy (1948) found 82 feet near Odell Creek in the Centennial Range.

The Thaynes formation was named by Boutwell (1907, p. 448) from Thaynes Canyon in the Park City mining district in Utah where it is 1190 feet thick and consists of a limestone unit and a siltstone unit separated by a red shale. In Idaho its basal unit carries a widespread Meekoceras gracilitatis zone. This zone was located on Fossil Creek, though not right at the base of the formation. Here the formation is composed of fossiliferous cream to buff to reddish calcareous sandstones. The formation measured in section 9, T. 12 S., R. 2 W. is as follows,

| Unit | Thickness in feet |
|---|---|
| 1. Sandstone, calcareous. Color, pinkish gray (5 YR 8/1) to weak yellow (5 Y 8/4). Quartz grains angular to subangular, well sorted, average diameter 1/4 mm. Cement, calcareous. Meekoceras gracilitatis zone 50 feet above base. | 138 |
| Total thickness of Thaynes formation - | 138 feet. |

The Thaynes formation was probably deposited in seas similar to those in which the Woodside was deposited, but clearer, allowing some lime deposition and the establishment of an invertebrate fauna. The source of the sediments, as with the earlier Triassic formations, was highlands paralleling the geosyncline both on the east and west, (Mansfield, 1927, pp. 176, 189, 374).

The following fossils were collected from the "Meekoceras zone" of the Thaynes formation in section 4, T. 12 S., R. 2 W., on Fossil Creek in the Gravelly Range, (locality 6, figure 10).

Cephalopoda

Meekoceras gracilitatis

Brachiopoda

Terebratula sp.

Pelecypoda

Lima, sp.
Monotis, sp.
Myalina postcarbonica
Myalina postcarbonata
Pteria, sp.

Gastropoda

Natica (?) sp.

The following fossils were collected one quarter of a mile along the road to West Fork Ranger Station past the West Fork of the Madison River ford. The locality is in section 19, T. 12 S., R. 2 W., (locality 7, figure 10).

Pelecypoda

Monotis cf. parvulus
Monotis, sp.
Myalina postcarbonica
Myalina, sp.
Pleuromya sp.

Gastropoda, gen.

Ostracoda, gen.

Jurassic system

<u>Sawtooth formation</u>. - The Sawtooth formation of Upper Middle Jurassic age (upper Bathonian, Cobban, 1945, p. 1290) does not crop out within the limits of this report. However, it is present so near to the boundary that it is here listed. The formation crops out in section 12, T. 15 S., R. 2 W. east of Odell Creek in the Centennial Range. According to Kennedy (1948) the Sawtooth formation is 138 feet thick in the Odell Creek area and composed of gray, fine-grained, thin-bedded, brittle limestone.

The Sawtooth formation was named by Cobban (1945, p. 1270, 1277) from the Sweetgrass Arch region in northwestern Montana. The formation is unconformable on older strata beneath it and conformable with the Rierdon formation above it.

<u>Rierdon formation</u>. - Like the Sawtooth formation the Rierdon formation of lower Upper Jurassic age (upper Bathonian and lower Calovian) (Cobban, 1945, p. 1290) does not crop out within the limits of this report,

but it will be considered briefly because it is reported present so near the area. The formation crops out in section 12, T. 15 S., R. 2 W. east of Odell Creek in the Centennial Range. According to Kennedy (1948) the Rierdon formation is 43 feet thick in the Odell Creek area and is composed of calcareous glauconitic sandstone and limestone.

The Rierdon formation was named by Cobban (1945, pp. 1277-1281) in the Sweetgrass Arch region of northwestern Montana, where it is gray calcareous shale with some nodular limestone beds.

Swift formation. - The Swift formation of lower Upper Jurassic (Divesian and Argovian) (Cobban, 1945, p. 1290) age, is best exposed along Fossil Creek in the Gravelly Range, and also east of Odell Creek in the Centennial Range and probably in the Metzel Creek anticline. Elsewhere slope wash conceals its presence. The formation is soft and outcrops are unobtrusive even where exposed. Twenty-one feet of glauconitic sandstone comprise the Swift formation on Fossil Creek and Kennedy (1948) measured a section 47 feet thick, on Odell Creek. The Fossil Creek section measured in section 9, T. 12 S., R. 2 W. is as follows,

| Unit | Thickness in feet |
|---|---|
| 1. Sandstone, calcareous, glauconitic. Color, medium greenish gray (5 G 6/1). Quartz grains angular, average diameter of 1/10 mm. Rock is composed of 25 per cent quartz, 30 per cent fine grained chalcedony; part, at least, is cement, 30 per cent calcareous interstitial cement and 15 per cent glauconite. | 21 |
| Total thickness of Swift formation - | 21 feet. |

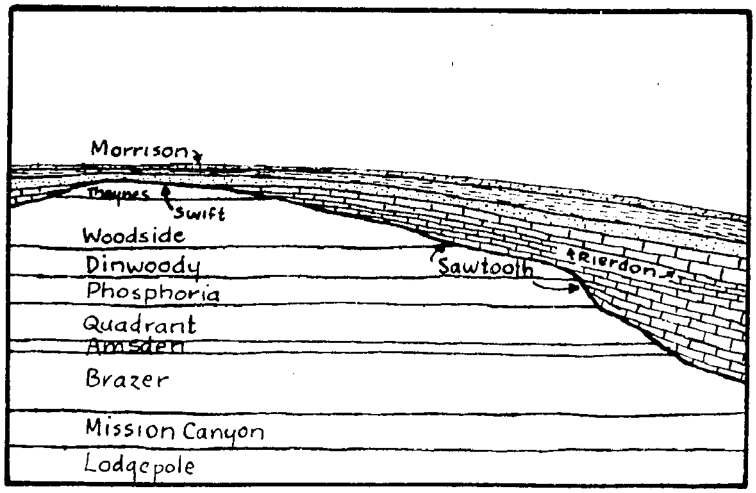


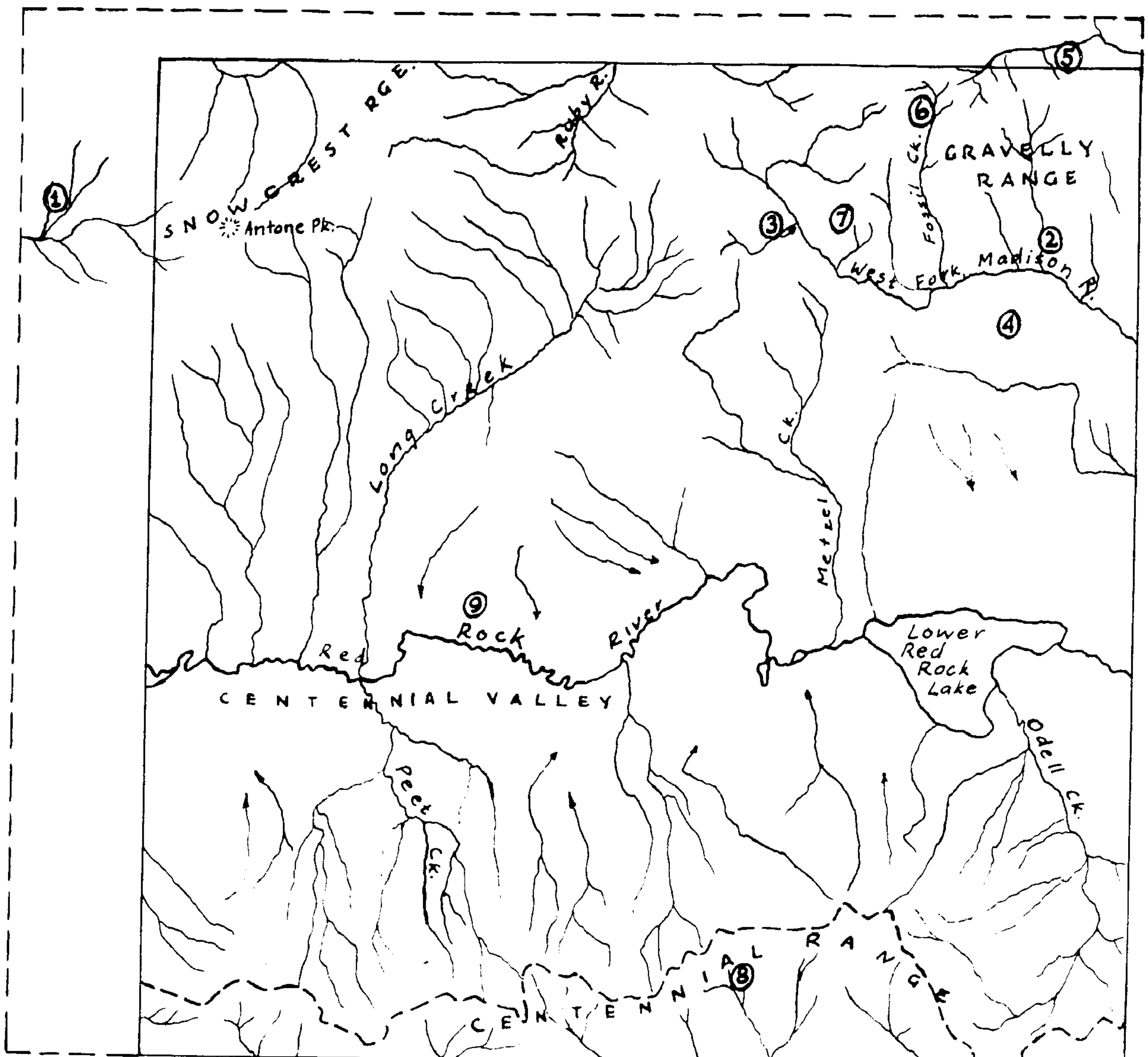

Figure 9. Relation of Jurassic strata to underlying rocks.

The Swift formation was described by Cobban (1945, pp. 1281-1286) from exposures on Sweetgrass Arch in northwestern Montana. Cobban, (1945, p. 1262) describes the Swift formation as follows:

> "The Swift formation is composed of two members. . . The lower member is dark non-calcareous shale, highly glauconitic at the base. The upper member is gray fine-grained flaggy glauconitic sandstone containing abundant black-gray micaceous shale partings."

On Fossil Creek the Swift formation unconformably overlies the Thaynes formation, though as previously stated the break could not be found, and is apparently conformably overlain by the Morrison formation.

The thickness of Jurassic sediments varies considerably over short distances in Montana. Kennedy (1948) reports the following Jurassic formations just east of Odell Creek in the Centennial Range and 18 miles southeast of Fossil Creek; Sawtooth formation (138 feet), Rierdon formation (43 feet), Swift formation (47 feet), and Morrison formation




①. Gray's Fork, W.Fk., Blacktail Ck.
②. Cascade Creek
③. Anderson Ck., W.Fk., Madison R., junction
④. Landon Ridge
⑤. Hellroaring Creek
⑥. Fossil Creek
⑦. Forest Service road cut
⑧. Scott and Bucy coal mine.
⑨. Gulch near Kennedy Ranch

**Figure 10. Index map of fossil localities**

(244 feet). Forty miles to the southwest near Snowline, Montana, the Sawtooth formation is about 1000 feet thick. Yet in the Centennial Region no Sawtooth or Rierdon strata are present, and this can be said with surety because of the excellent exposures on Fossil Creek. The situation, however, fits into the general geologic conditions for the Jurassic period throughout western Montana. Before deposition of the Jurassic formations (Ellis) in Montana there was a widespread erosional interval so that in places the Jurassic rocks lie unconformably on Mississippian rocks. The eroded surface was irregular and during deposition of the earlier Upper Jurassic rocks some regions were islands where there was no deposition. The Gravelly Range and Snowcrest Range sites were such regions, (Condit, 1917, p. 161), (see figure 9).

The sand of the Swift formation indicates a relatively near source which perhaps also supplied biotite to the sea where sedimentation occurred. Galliher (1935, pp. 1363-1364) states that glauconite forms by the alteration of biotite in areas of little agitation, anaerobic conditions and black-mud-covered sea floors. Except for much black mud covering the sea bottom, these conditions probably were present in the Swift seas.

<u>Morrison formation</u>. - The Morrison formation of Upper Jurassic age is well exposed on Fossil Creek in the Gravelly Range and also crops out east of Odell Creek in the Centennial Range. Elsewhere in the region outcrops of the Morrison formation are scarce because of its soft and easily covered lithology. A thin sandstone possibly belonging to the Morrison formation is exposed in the Metzel Creek Anticline. The Morrison formation is unconformably overlain by the Kootenai formation and

conformably overlies the Swift formation. A thickness of 181 feet of Morrison strata was measured on Fossil Creek and Kennedy (1948) found 244 feet east of Odell Creek in the Centennial Range.

The widespread Morrison formation, which crops out from Oklahoma to Alberta, was named by Eldridge (1896, pp. 60-62) from exposures near the town of Morrison, Colorado. There the Morrison formation consists of several hundred feet of alternating variegated, unconsolidated marls, silts and clays, and some sandstone and limestone beds. In the Gravelly Range the Morrison formation contains greenish shales and a few thin interbedded sandstones, limestones and dolomites. The sequence measured in section 9, T. 12 S., R. 2 W. is as follows,

| Unit | Thickness in feet |
|---|---|
| 5. Partially covered: shale and sandstone float; shale, hard; sandstone, glauconitic. | 28 |
| 4. Shale, silts, sandstone, limestone. Color, shale and silt, green and maroon, limestone, light olive gray (5 Y 6/1). Limestone moderately crystalline, contains 40 percent subangular quartz grains, average diameter 1/4 mm, some pyrite nodules and calcite seams. Shales, silts soft, interbedded with thin sandstones and limestones, bedding from 1 to 12 inches thick. | 82 |
| 3. Shales, calcareous, greenish. | 31 |
| 2. Dolomite, white to pink, hard. | 2 |
| 1. Shales, calcareous, greenish. | 38 |
| Total thickness of Morrison formation - | 181 feet. |

The Morrison formation was deposited on a broad, humid coastal plain and contains some fresh-water lake and flood-plain deposits. (Emmons, 1896, p. 23).

## Cretaceous system

<u>Kootenai formation</u>. - The Kootenai formation of Lower Cretaceous age crops out on the headwaters of the West Fork of the Madison River in the Gravelly Range, where it is best exposed. Other more obscure outcrops are found near the headwaters of Odell Creek in the Centennial Range and on Antone Pass in the Snowcrest Range. Though it has several locally resistant sandstones it does not crop out very well anywhere in the region and because its upper and lower limits could not be located accurately a complete section could not be measured. A thickness of 601 feet was measured between West Fork Ranger Station and Fossil Creek. It is estimated that the formation is approximately 700 feet thick here. Five miles to the east in Indian Creek Canyon in the Madison Range Hendricks and Hadley (1946, pp. 63-64) measured a thickness of 131 feet for the Kootenai formation, and sixty miles to the north in Sappington Canyon on the Jefferson River they found a thickness of 300 feet, (1946, p. 15).

The term, Kootenai formation, was first applied to strata near Great Falls, Montana by C. A. Fisher (1908, pp. 78-80). Previously the term had been applied as a group or series name by Canadian geologists to equivalent strata in Alberta.

In southwestern Montana the Kootenai formation includes buff to brown sandstones, red shales and silts, and a widespread thin, fossiliferous, freshwater limestone. The Kootenai formation is unconformable on the underlying Jurassic strata, with a prominent basal conglomerate from 1 to 3 feet thick generally present, and it is apparently conformable to the overlying Colorado shale. A section of the Kootenai formation measured in sections 8 and 9, T. 12 S., R. 2 W. on the ridge between Fossil Creek and West Fork Ranger Station in the Gravelly Range contains the following strata,

| Unit | Thickness in feet |
|---|---|
| 6. Covered | 100 (estimated) |
| 5. Limestone, ferruginous color, medium gray (N-6) on fresh surface, weathers to light brown (5 YR 6/4). Moderately coarsely crystalline, average crystal diameters, 1/2 mm. This is the "gastropod" limestone, characterised by abundance of small fresh-water *Nerinia*-like gastropods and the pelecypod *Elliptio hameli*, a *Unio*-like form, (Imlay, 1947). | 30 |
| 4. Covered: sandstone float, color, light brown (5 YR 6/4). Composed almost entirely of subhedral, bright quartz grains, 1/4 to 1/2 mm in diameter. Loosely cemented by silica. Few clay galls (?) present, average 1 mm by 5 mm dimensions. Unidentifiable pelecypod casts. | 118 |
| 3. Partially covered: silts, clays, also sandstone, limestone float; color clays and silts, light yellow to red. | 94 |
| 2. Covered: sandstone float, calcareous, cherty. Color, light gray (N-8) with black specks. Composed of 70 percent quartz grains, 5 percent black chert grains, 25% calcareous cement. Quartz and chert grains sub-angular to well-rounded, frosted, diameters range from 1/2 to 1 mm. Calcite coarsely crystalline, crystal diameters, 1/2 to 2 mm. Commonly called "salt and pepper" sandstone. | 174 |
| 1. Covered: conglomerate, sandstone, float. General color of conglomerate, light brownish gray (10 YR 6/2). Particles mainly quartzite, ranging in diameter from 1/2 mm to 6 inches, some black chert particles, 1/2 mm average diameter. Typical sample shows sub-angular to well-rounded particles, diameters 1/2 mm to 4 cm, "salt and pepper" sandstone matrix, | |

cement siliceous, cement in other samples, calcareous. Shows rough sorting. Conglomerate, elsewhere observed 1 to 3 feet thick, generally present at or near base of Kootenai formation. Sandstone float of "salt and pepper type". 185

Total thickness of Kootenai formation - 700 feet.

The Kootenai formation probably represents fluvial deposits spread onto a plain at the foot of the early Cretaceous ancestral Rocky Mountains, then already rising to the west of this region. Some of these sediments were deposited in widespread, albiet short-lived, fresh water lakes existing on this plain. (Bartram, 1939, p. 1146).

Colorado shale. - The Colorado shale of the lower part of Upper Cretaceous age (Benton, Niobrara) crops out along the eastern margin of the Long Creek - Ruby River basin and is best exposed on the headwaters of the West Fork of the Madison River in the Metzel Creek anticline. It is apparently conformable to the underlying Kootenai formation and to the overlying Aspen formation.

The formation is generally not well exposed because it is weak and subject to landslides. An estimated thickness of 300 feet is present in the Gravelly Range. Gardner, Hendricks and Sloss (1945, p. 14) measured a thickness of 109+ feet of Colorado shale in the Sappington Canyon of the Jefferson River 60 miles to the north. As exposed in the Gravelly Range the Colorado shale is a thin-bedded, fissile, much-jointed, gray to black shale. The shale bedding is from 1/16 inch to 1/4 inch thick, and thin sands from 1 inch to 6 inches thick, characterized by fucoidal markings are sometimes present. One thin, black, quartzitic layer contains limonite nodules up to 1 inch in diameter.

Figure 11. Metzel Creek anticline

In T. 12 S., R. 3 W. Cut by West Fork of Madison River. Strata mainly Cretaceous with Triassic in center of fold. Trees grow on rhyolite flow remnants. Note placer gold dredge tailings along stream. Fish Creek strike valley begins in lower left. (Aerial photo by Agricultural Adjustment Agency)

The term Colorado group was applied by Hayden (1876, p. 45) to include the Benton, Niobrara and Pierre formations, but present usage includes the Pierre shale in Montana group. Because the Benton and Niobrara formations are not recognizable as such in the Sweetgrass Arch region of Montana and Alberta geologists (Collier, 1929, pp. 70-73) there applied the term Colorado shale to the Colorado group equivalents, which are mainly shale. From there the term "Colorado shale" has been carried southward again. Thus the name "Colorado" spread north as a group name and now returns southward, as a formation, as well as a group name.

The Colorado shale is one of the several thick and widespread shales deposited in the Upper Cretaceous seas. The source of these sediments was the rising early Rocky Mountains to the west. (Bartram, 1939, pp. 1146-1150).

Aspen formation. - The Aspen formation of lower Upper Cretaceous (Colorado group) and possibly later Upper Cretaceous (Montana group) age crops out extensively in the area studied. It covers most of the Long Creek - Ruby River basin, and crops out along the northward facing scarp of that part of the Centennial Range west of Odell Creek. Here its southward extension is covered by Tertiary volcanics except in one place at the head of Winslow Creek where it crops out on the crest of the range. The formation is apparently conformable on the underlying Colorado shale and is overlain unconformably by younger strata including Cretaceous or Tertiary conglomerate, Tertiary volcanics and Pleistocene continental sediments. Because the formation covers miles of grassy basin country and its dip is generally slight, a section could not be measured, but a thickness of 3000 feet was estimated for it.

The Aspen formation was named by Veatch (1907, pp. 64-65) from Aspen station in Uinta County in southwestern Wyoming. In the Centennial Region the formation includes buff sandstones of variable thickness interbedded with slightly consolidated silts and shales, which may be variegated. The shales and silts are generally a tan to light brown color, and sometimes dark gray or black. In a few places the shales are siliceous. Considerable calcite is present in the shales, weathering out in crystalline masses which lie on the surface of the shale. The formation contains several beds of coal, one bed being 32 inches thick. Interbedded volcanic material is found in a few places in the upper half of the formation.

Fossils are relatively rare in the Aspen formation. The author collected a few pelecypods and gastropods from the entrance of an old coal mine in section 12, T. 14 N., R. 38 E., (locality 8, figure 10). Comparison of these forms with a fauna collected by Klepper (1948) which were identified by J. B. Reeside shows a definite similarity and suggests that they come from the same horizon. Also, Klepper's fauna which was collected on the Ruby River in section (?) T. 8 S., R. 4 W, was associated with a coal bed. Reeside says the fauna is widespread in the lower part of the Colorado group and hence is lower Upper Cretaceous in age, but he also believes that these beds contain at least equivalents of the Bear River - Aspen and the Wayan and possibly much more, (Klepper, 1948).

The author also collected a meager flora from the Aspen formation. A sandstone in section 23, T. 12 S., R. 3 W., contained plant fragments which could only be identified as conifer cones and possibly palm fronds of Mesozoic affinities. (Arnold, 1947). At the same place an overlying siliceous shale contained conifer needles which possibly came from a *Sequoia*. In section 7, T. 12 S., R. 2 W. some silicified coniferous wood was found and in section 35, T. 12 S., R. 3 W. certain siliceous shale beds contain many unidentifiable plant fragments. On Odell Creek in section 36, T. 14 S., R. 2 W., Kennedy (1948) kindly called the author's attention to plant fossils in a bank along the creek. R. A. Brown identified these for Kennedy (1948) as probably from the later part of the (Mesaverde) formation.

Correlation of Cretaceous formations. - The Cretaceous stratigraphic sequence of the middle and northern Rocky Mountains in United States has been extensively studied and many names applied to the rock units. Many of the units have several names derived from different localities, and some of the unit names have been carried far from their type localities. Because the wide expanse of the Yellowstone - Snake River lava fields separates eastern Idaho and western Wyoming from western Montana it was natural that a different set of formational names be applied to strata on each side of the lava fields, to what quite often were the same formations. As mapping has progressed the Montana names have been traced south down to the northern lava border, and the Idaho - Wyoming names north to the southern lava border. Geologists are now in the process of applying these formational names across the lava plains and it seems that more names are being carried from south to north, than from north to south.

Other factors being equal, the author has tried to apply the names established in Montana for these formations since the Centennial Region is in Montana.

| Series | Group | SWEETGRASS ARCH Romine, 1929, p. 786 | PARK CO. MONT. Wilson, 1934, p. 368 | CENTENNIAL REGION | TETON CO., WYO. Foster, 1947, p. 1538 | SE IDAHO Mansfield, 1927, p. 105 | Group | Series |
|---|---|---|---|---|---|---|---|---|
| UPPER | MONTANA | Two Medicine fm. 1900'+ | Judith R. fm. 1200'+ | | Mesaverde fm. 4075' | | MONTANA | UPPER |
| | | | Claggett sh. 650' | | Cody sh. 1365' | | | |
| | | Eagle ss. 385' | Eagle ss 410' | | Frontier fm. 2750' | | | |
| | | | Telegraph Ck. fm. 320' | ? | | | | |
| | COLORADO | Colorado sh., Blackleaf member 1850' | Niobrara, Carlile sh. 1275' | Aspen fm. 3000'± | Mowry sh. 1080' | | COLORADO | |
| | | | Frontier fm. 300' | | | | | |
| | | | Mowry sh., 210' | ? | | | | |
| | | | Thermopolis sh., 685' | Colorado sh., 300' | Thermopolis sh. 320' | Wayan fm 11800' | | |
| LOWER | | Kootenai fm. 500' | Cloverly fm. 450' | Kootenai fm. 700' | | | | LOWER |

**Figure 12. - Some Cretaceous sections in Montana, Wyoming and Idaho.**

**The Kootenai formation has been widely mapped in western Montana. The basal conglomerate ranging from 1 to 30 feet thick is a key bed in helping decipher Montana stratigraphy. The Kootenai formation as mapped by the author may contain Bear River formation equivalents. The profusion of freshwater gastropods and pelecypods in the 30 foot thick "gastropod limestone" compares with the great quantities of fresh and brackish water forms that have been described from the Bear River formation elsewhere, (Mansfield and Roundy, 1916, pp. 79-81). No other reason was found for considering Bear River equivalents in the Centennial Region, though detailed stratigraphic studies may reveal its presence. Dillon (1949, pp. 52, 58) reports Kootenai and Bear River strata as being present in the Lima Anticline, 25 miles west of the Centennial Region.**

Figure 13. Peet Creek anticlinorium

In T. 14 S., Rs. 4 and 5 W. Variously dipping strata in Aspen formation; one small fold plunges in center left. Note sharp contact of Quaternary alluvium and Aspen beds. (Aerial photo by Agricultural Adjustment Agency)

The Colorado shale is a widely recognized, though considerably misused, stratigraphic unit in Montana. In its correct usage the Colorado shale may be a Benton equivalent (Irwin, 1931, pp. 1134-1135). Because the formational name has been long used and because a mappable lithologic unit of shale of Benton affinities exists in the Centennial Region, the Colorado shale name was used. The author realizes that this unit may be equivalent to Bear River or Aspen and could possibly be mapped as a unit of either.

Strata which are termed Aspen formation in this report have also been called Mesaverde, Livingston and Bear River. The Aspen formation is a Benton equivalent and the invertebrate fossils collected in the Centennial Region (Klepper, 1948) affirm this. However, there is some doubt, because plant fossils from the same formation indicate an upper Upper Cretaceous (Montana group - Mesaverde) age for at least some beds in the sequence. It is possible that the upper part of the Aspen formation may truly be Mesaverde and the lower part Aspen. The variegated silts and shales in the upper part of the Aspen formation in the Long Creek - Ruby River basin lithologically compare with the Judith River beds of Montana age and in part equivalent to the Mesaverde formation. Dillon (1949, pp. 62-76) mapped 3436 feet of Aspen beds in the Lima Anticline 25 miles west of the Centennial Region. The term "Aspen" has recently been introduced into southwestern Montana (Dillon, 1949, p. 62) and to avoid confusion the author believes it best to accept this name, at least temporarily, for the above strata.

Figure 12 shows possible correlations of the Cretaceous strata in the Centennial Region with those nearby in Montana, Idaho and Wyoming.

Cretaceous (?) - Tertiary system

Unnamed conglomerate. - A coarse, thick conglomerate of latest Cretaceous, Paleocene, or early Eocene age, crops out on Antone Peak and northeastward along the crest of the Snowcrest Range for about 6 miles. Southwestward the formation may be traced for 20 miles somewhat discontinuously to the hills just west of Lima, Montana, and thence 35 miles north to Armstead, Montana. South of Lima on Highway 93 between Lima and Monida, Montana the formation is well exposed. Smaller exposures are found five miles east of Monida, and possibly in sections 23 and 24, T. 13 S., and section 25, T. 12 S., R. 2 W. West of Monida the formation caps the Red Conglomerate Peaks. A similar conglomerate, named the Sphinx conglomerate, crops out on Sphinx Mountain in the Madison Range, 35 miles to the northeast of the unnamed conglomerate in the Snowcrest Range.

The formation crops out in valleys, on spurs, and on mountain tops where it has been preserved as erosional remnants. Only where recent erosion has been very active does it form cliffs, elsewhere its outcrops are generally subdued and grass covered, though in the Snowcrest Range it supports a heavy timber stand.

The unnamed conglomerate unconformably overlies the Cretaceous strata west of Antone Peak with a strong angular unconformity, but on the southeast flank of Antone Peak the relationships are only disconformable. The unnamed conglomerate is gently folded in the Centennial Region and elsewhere has been tightly folded and faulted, (Lowell, 1948).

**Figure 14. Antone Peak, Snowcrest Range**

In T. 12 S., R. 5 W. Summit in center bottom, elev. 10,220 ft. Outcrops are unnamed conglomerate. From left to right, Rough and Meadow Creeks. Beds in upper left are overturned Mesozoic strata. (Aerial photo by Agricultural Adjustment Agency)

On Antone Peak the conglomerate is an estimated 3000 feet thick, but to the southwest toward Lima, Montana the conglomerate thickens, and 25 miles to the west near Dell, Montana, Lowell (1948) estimates that it may be at least a mile thick. Peale (1896, p. 3) noted a thickness of 2000 to 3000 feet for the Sphinx conglomerate in the Madison Range.

No name has been applied to the formation, but Lowell (1946-1948) has done considerable research on it and is expected to name it in the near future.

The formation near Lima, Montana is a coarse conglomerate. On Antone Peak the formation contains much conglomerate, and also coarse sandstone. The formation on the southeast facing scarp of the Snowcrest Range contains shale, silt, coarse sandstone and some conglomerate, which also describes the formation 5 miles east of Monida, Montana, (see figure 15). Lowell (1948) reports one widespread and distinctive thin layer of algae or concretionary limestone. On Sphinx Mountain in the Madison Range the Sphinx conglomerate is sandstone and coarse conglomerate.

As may be seen above, much variation is present in the unnamed conglomerate. To illustrate this the lithology and characteristics of the formation will be described from several outcrop areas.

On Highway 93 between Lima and Monida the formation is dominantly a coarse conglomerate composed of sub-angular to rounded cobbles of Mississippian limestones. The cobbles average from 3 to 5 inches in diameter, and show some sorting. The cement is sparse, and is sand and calcareous mud. Iron oxides in the cement color the rock yellow buff or orange.

A sample of conglomerate collected on Antone Peak was separated in the laboratory. A representative fraction was selected and the particles in it were counted. The sample contained 71 granules and pebbles of quartzite and 11 of limestone. The particles are angular to subangular and vary in size from 1 mm to 2 cm in diameter. The particles compose approximately 50% of the rock, and the rest is a matrix of ferruginous, calcareous sand and clay. The sand grains are angular and range in diameter from 1/4 mm to 1 mm. No sorting is present in the rock. The cement is calcareous and ferruginous. The color of the rock is pale reddish brown (10 R5/4).

An impure limestone from Antone Peak is composed of 60 percent limestone, 30 percent quartzite particles and 10 percent chert particles. One particle each of biotite schist and shale was noted. The particles are subangular to angular and often elongate. The limestone matrix is coarsely crystalline with calcite crystals ranging in diameter from 1/2 mm to 2 mm dimensions. The particles contained in the limestone have a definite orientation with their elongate axes parallel. The color of the rock is medium gray (N-6).

An impure sandstone from Antone Peak studied in thin section contains 55 percent quartz, 35 percent calcite, 5 percent chert and 5 percent accessory minerals, including hornblende tourmaline and magnetite. The quartz grains are mostly subangular to angular, but a few are rounded. The grains range in diameter from 1/4 mm to 1 mm. The calcite is moderately coarsely crystalline, crystals ranging in diameter from 1/4 mm to 1 mm. The interstitial calcite is the cement. The color is pale brown (5 YR 5/2) on a weathered surface, and light gray (N-8) on a fresh surface, (see figure 15).

An impure sandstone was collected from the unnamed conglomerate in section 16, T. 12 S., R. 4 W. on the east-facing scarp of the Snowcrest Range above the headwaters of Divide.Creek. The sandstone contains 70 percent quartz grains, 25 percent clay, and 5 percent muscovite, and no calcite. The quartz grains are angular to subangular and the muscovite flakes are irregular in shape. The quartz grains range from 1/8 to 1/4 mm in diameter, and are well sorted. The clay is the cement. The color of the rock is dusky yellowish orange (10 YR 6/6).

A sandstone collected from the unnamed conglomerate in section 16, T. 12 S., R. 4 W. on the southeast-facing scarp of the Snowcrest Range contains 80 percent quartz and 20% clay. The quartz grains are subangular and range in diameter from 1/8 to 1/2 mm. The interstitial clay is the cement. The color of the rock is moderate yellowish brown (10 YR 5/4).

A sample of conglomerate collected from the unnamed conglomerate in section 9, T. 12 S., R. 4 W. was separated in the laboratory as described above, and the particles in a representative fraction were counted. The fraction contains 42 granules and pebbles of quartzite, 14 of limestone, and one of weathered biotite schist. In addition some secondary quartz and calcite crystals, some with well developed crystal faces are present. The limestone particles are well rounded, whereas the quartzite particles are angular. The average diameter of the particles ranges from 1/2 mm to 1 cm and the quartzites generally are largest. The cement is calcareous. The color of the individual quartzite particles may be white, green, gray, or black, and the general color of the conglomerate is medium gray (N-6).

Figure 15. Thin section of unnamed conglomerate

Sandstone in unnamed conglomerate, from Antone Peak, Snowcrest Range. Note varying shapes of grains, some rounded, some angular. Some orientation present. Cement is calcite. Magnification, x 50.

No fossils were found in the unnamed conglomerate, except Mississippian fossils that were found in the limestone cobbles, and which only date the age of the rock in the cobbles and not the conglomerate.

Of interest is the relation of the unnamed conglomerate to the Sphinx conglomerate which crops out on Sphinx Mountain in the Madison Range, 35 miles to the northeast of outcrops of the unnamed conglomerate in the Snowcrest Range. Peale (1896, p. 3) named and described the Sphinx conglomerate as follows,

> "In the Sphinx Mountain, which reaches an elevation of 10,840 feet in the central part of the Madison Range, is found a group of beds which once may have spread over an extensive area of country, although at present occupying an area of about 2 square miles. This remnant is between 2000 and 3000 feet in thickness, made up of reddish sandstones and coarse conglomerates of limestone pebbles and boulders cemented with a reddish sand. The entire mass of the peak is composed of these beds, which are horizontal in position and distinctly stratified, the rugged and steep slopes of the mountain rendering evident the gigantic scale of the erosion which has left it in this district the only monument of this group of beds. So far as observed the strata are nonfossiliferous, the character of the beds precluding the preservation of fossils. They are, therefore somewhat arbitrarily referred to the Eocene, but they form a group certainly (older) than the Bozeman lake beds and (younger) than the Livingston formation."

Since the two conglomerates are fairly similar lithologically, since they both rest on latest Cretaceous, probably unconformably, and since they are both involved in mountain building processes it is possible that they were once continuous. More needs to be known about their distribution.

In a number of the Rocky Mountain ranges in Wyoming and Colorado there are similar thick, coarse conglomerates involved in the Laramide orogeny. Love (1947) describes the Pinyon conglomerate in the Jackson Hole, Wyoming region as up to 2000 feet of coarse conglomerate, unconformably overlying Mesaverde and Judith River strata, and overlain by Paleocene beds. The Pinyon, Sphinx and unnamed conglomerates were all the result of the Laramide orogeny whose pulsations extended from Cretaceous to Eocene time. They were deposited in basins or on plains by fast, aggrading streams flowing from new mountains formed by the orogeny.

From the above consideration of the conglomerate the following facts may be summarised.

1. A widespread unnamed conglomerate is discontinuously present over approximately 3000 square miles of southwestern Montana, mainly to the west of the Snowcrest Range in the Centennial Region. Another possibly equivalent conglomerate is present in the Madison Range.

2. The unnamed conglomerate overlies the latest Cretaceous with an angular unconformity in places, but the conglomerate has also been deformed.

3. The formation becomes less conglomeratic and more sandy traced eastward from Lima, Montana to the Snowcrest Range.

4. The component particles vary from place to place. Mississippian limestones and Paleozoic and Beltian quartzites dominate.

The following deductions may be made from the above facts.

1. The source of the unnamed conglomerate was west of the Centennial Region, perhaps a range in the vicinity of the Idaho - Montana state line, west of Lima.

2. The Sphinx mountain conglomerate was probably derived from a range east of its present site, and may have been deposited in separate intermontane basin from that of the unnamed conglomerate.

3. The unnamed conglomerate (and perhaps the Sphinx) probably blanketed the region since there are many widely scattered outcrops. Later uplifts and faulting have caused variations in elevation of outcrops.

4. The composition of the conglomerate reflects the rocks being eroded in the mountains, after exposure by erosion or mountain-making. The quartzites may be Precambrian as biotite schist is associated with them.

5. The unnamed conglomerate is younger than deformed Upper Cretaceous rocks but itself has been deformed by Laramide movements.

### Tertiary system

General features. - Scattered remnants of the great Tertiary lava effusions that covered extensive areas in nothwestern United States remain throughout the Centennial Valley region. Such remnants are common in the Gravelly Range where they cap hilltops and ridges. On the floor of the Centennial Valley there are several hills and ridges extending into the valley that are capped by volcanic rocks. The flows cap most of the Centennial Range west of Odell Creek and east of it cover considerable parts of the southward descending dip slope, and still further to the east form a part of the range crest in Sawtelle Peak. To the south the lavas on the flanks of the Centennial Range merge with those forming the Snake River lava fields, and to the east they tie into the

Yellowstone Plateau volcanics.

The following ascending sequence is present in the volcanic rocks of the Centennial Valley region: (1) basalt flows, (2) agglomerate or volcanic conglomerate (3) tuff beds (4) rhyolite flows (5) and dikes and sills.

Non-volcanic Tertiary rocks in the Centennial Region include high-level gravels and possibly Bozeman lake beds. The Sage Creek formation of upper Eocene age and the Cook Ranch formation of middle Oligocene age, may also be present.

Basalt.[4] - A basalt everywhere observed seems to be the oldest Tertiary volcanic rock in the region. The basalt crops out along the north-facing front of the Centennial Range and on the lower spurs of the Gravelly Range. The basalt forms irregular knobby topography and only crops out in cliffs where cut through by streams, or exposed on the mountain crest. The basalt is unconformable on the underlying Aspen formation and other older formations and is disconformably overlain by younger volcanic rocks. The observed thickness of the basalt varies from 75 to 100 feet.

A typcial specimen of basalt from section 17, T. 15 S., R. 4 W on the crest of the Centennial Range, when examined megascopically, contains 60 percent groundmass, 30 percent hornblende and 10 percent olivine as phenocrysts. The hornblende crystals are lath-like and average 1/4 mm by 1 mm

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[4] For convenience this volcanic unit will be termed a basalt. Actually the lithology varies considerably from place to place and fine grained intermediate rocks, tuffs, and basalt porphyrys and basalts are interbedded. The overall lithology is basaltic. The petrographic identifications above and on following pages were kindly checked in part by Professor W. F. Hunt and in part by Professor E. W. Heinrich of the Department of Mineralogy, University of Michigan.

in size. The olivine crystals are approximately equidimensional and are 1 mm in diameter, and may be slightly weathered to iron oxides. The basalt is dense and heavy.

A specimen of rock collected from section 12, T. 15 S., R. 5 W. on the crest of the Centennial Range was identified as a dacite porphyry or possibly a rhyolite. A thin section of the rock shows 75 percent groundmass, 10 percent quartz, 10 percent andesine, and 5 percent of accessory minerals including hornblende, relict biotite, chalcedony and sanidine. The color of the fresh rock surface is light brownish gray (5 YR 6/1). The groundmass is extremely fine-grained, and the minerals listed above form phenocrysts that have an average diameter of 1 mm.

A specimen of rock collected from section 2, T. 15 S., R. 2 W. is a scoriaceous basalt. On megascopic examination the basalt contains approximately 20 percent hornblende, 15 percent augite, 15 percent plagioclase feldspar and 50 percent calcite which filled vesicules in the lava. The color of the basalt is weak brown (5 YR 3/2) and of the calcite from white to pinkish gray (5 YR 8/1). The mineral components range from very finely crystalline to moderately coarsely crystalline. The very finely crystalline parts of the basalt are tentatively identified as plagioclase. The hornblende crystals are lath-like with average dimensions of 1/4 by 1 mm. The augite is equidimensional with an average diameter of 1 mm. The amygdules are rounded to oblong and 1 mm to 2 cm in diameter. The amygdules are filled partly or entirely with crystalline calcite or with calcareous tuff. The tuff contains small interspersed particles of the basalt.

Agglomerate and volcanic conglomerate (?).[5] - Overlying the basalt is an agglomerate, or possibly locally a volcanic conglomerate. The agglomerate crops out prominently along the north-facing scarp of the Centennial Range, and unobtrusively along the north side of the Centennial Valley, and in places in the Gravelly Range as in section 6, T. 13 S., R. 1 W, and section 25, T. 12 S., R. 3 W. In the Valley and Gravelly Range outcrops are usually represented only by large scoriaceous boulders of basalt lying on the ground. The unit disconformably (?) overlies the basalt and is disconformably (?) overlain by tuff and rhyolite. The thickness of the agglomerate is variable ranging up to an estimated 150 feet in the Centennial Range. A volcanic neck composed of agglomerate may exist in section 12, T. 14 S., R. 4 W.

A typical agglomerate outcrop is located in section 7, T. 15 S., R. 3 W. Rock types present as fragments include scoriaceous basalt, dense basalt, rhyolite, tuff, pumice and sand. Colors of the fragments include white, brownish yellow, brown, gray, and black. Most of the fragments average from 1 mm to 60 cm in diameter, but dense basalt boulders range to 120 cm in diameter and scoriaceous basalt boulders range up to 300 cm in diameter. The fragments are sub-angular to

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[5]The pyroclastic rock names used are defined as follows, (Wentworth and Williams, 1932, pp. 45-50)
(1) Tuff - composed mainly of material less than 4 mm in diameter.
(2) Volcanic breccia - composed mainly of angular pieces larger than 4 mm in diameter.
(3) Agglomerate - rounded or subangular fragments, larger than 4 mm in diameter. Rounding not due to running water.
(4) Volcanic conglomerate - resembles volcanic breccia but particles are rounded by running water.

angular, and the large scoriaceous boulders are most rounded. No stratification is evident in the cobbles and boulders but some of the sand and granules in between them show a rough stratification that is rarely consistent for 10 feet in any direction. Some of the interstitial material is tuff (see figure 16), and some of it is stream sand. The agglomerate is only slightly indurated. Underlying the rhyolite and overlying the basalt in the Gravelly Range is a unit which might be considered volcanic conglomerate rather than agglomerate. The unit is exposed in section 25, T. 12 S., R. 3 W. in a gully on the divide between Metzel Creek and the West Fork of the Madison River. The rock types present as fragments include scoriaceous basalt, dense basalt, limestone, quartzite, dolomite, and vein quartz. The variance of fragments gives the rock a wide variety of colors. The size of the fragments ranges from approximately 1 mm to 60 cm. All degrees of roundness and angularity occur, but more of the fragments are rounded than in the agglomerate. A rough stratification is present, and thin beds of granule and pebble-size fragments (2 to 64 mm in diameter) are interspersed in the conglomerate. The conglomerate is only slightly indurated.

Elsewhere in the Gravelly Range are places where no conglomerate crops out but large scoriaceous basalt and vein quartz boulders are scattered on the ground. The boulders are usually on the flanks of hills or on spurs leading down to the Centennial Valley. A rhyolite outcrop is generally present near and above the boulders. If no rhyolite is near, the boulders are located on spurs or ridges from which the rhyolite has undoubtedly been eroded. The boulders represent the agglomerate or

Figure 16. Thin section of agglomerate

From Centennial Range above Winslow Creek. Tuffaceous phase, composed almost entirely of volcanic chards. Magnification, x 50.

conglomerate which elsewhere is overlain by the rhyolite. The unit was deposited on an uneven basalt surface, and has been removed almost everywhere except where protected by rhyolite caps. The placer gold in the West Fork of the Madison River probably comes from the conglomerate since there are no quartz lodes nearby.

Streams were active during or soon after the deposition of the agglomerate. In section 17, T. 15 S., R. 4 W a stream channel was cut into the agglomerate, filled with sand, and overlain by rhyolite. The channel is well exposed on the Centennial Range scarp. The channel is semi-circular in shape, about 50 feet deep and 100 feet wide. Of the "sand" in the stream channel 90 percent is volcanic chards, 8 percent is quartz and about 2 percent is other detrital minerals as garnet, biotite and zircon. The volcanic chards are sharp-edged, triangular in cross section and elongate in shape with average dimensions of 1/2 mm by 2 mm. The other mineral grains are well-rounded, and average 1 mm in diameter. The chards are well stratified and sorted by size into layers from 1 to 2 mm thick, and oriented with their long axes parallel. The color of the sediment is a light yellowish gray. The deposit is not cemented and is as unconsolidated as beach sand.

Tuff. - Tuff beds of varying composition are present between the basalt and the rhyolite. They are interbedded with the agglomerate as described above, or interbedded with basalt, or overlain by rhyolite. Tuff beds are well exposed on a steep ridge 2 miles southwest of Lakeview, near the headwaters of Duff Creek, and on Old Baldy Mountain in the Centennial Range and in section 9, T. 13 S., R. 2 W. in the Gravelly Range.

The thickness of the tuff is variable. Several tuffs beds on Duff Creek have an estimated aggregate thickness of 200 feet.

The Duff Creek outcrop is exceptional, and shows graphically the tuff and basalt relationships. A ridge from the crest of the range trends north and south and descends to the Centennial Valley. In a cliff on its west side is exposed a vertical section of volcanic rocks, about 400 feet thick. At least three basalt layers and three tuff beds are interbedded. Figure 17 is a sketch of the outcrop. Apparently enough time elapsed between flows so that vegetation could grow on the previous surface. At one contact of basalt over tuff 1 to 12 inches of lignitic material are present. Associated with the lignite is a soft, greenish yellow mineral tentatively identified as jarosite, (Klepper, 1948).

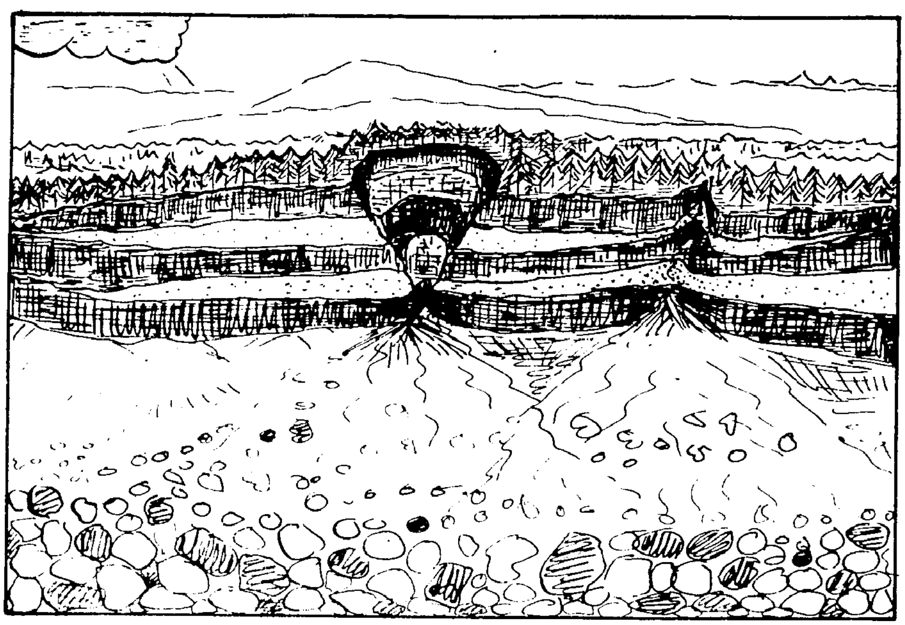

Figure 17. - Sketch of Duff Creek volcanics; dark bands are basalt, light bands are tuff.

Tuff outcrops where not concealed by vegetation form prominent landmarks. Tuff beds crop out at the top of Old Baldy Mountain in the Centennial Range and can be seen many miles away.

The tuffs show considerable variation both laterally and vertically. Typical tuff specimens are composed of small fragments of basalt, rhyolite, pumice. other tuffs, volcanic chards, and varying amounts of calcite. The color is white to cream to light gray. The volcanic glass chards are colorless to green. The size of the component particles ranges from very small chards of about 1/16 mm in diameter to fragments of volcanic rocks 4 mm in diameter. The shape of the particles is sometimes rounded, but generally angular, especially the chards. Tuffs are usually soft rocks even though some of their individual components may be hard. The fine-grained tuffs are usually indurated more than the coarser tuffs. In the fine-grained tuffs calcite is generally the cement, but silica and clay are occasionally cements. Some beds are so calcareous that they are fresh-water limestone with admixed tuff, and imperfect molds of gastropods were found in one such rock in section 9, T. 13 S., R. 2 W. Other tuff beds contain thin layers of opal. The opal results from the weathering of basic volcanic minerals which under alkaline weathering conditions break down to nontronite. According to Scheid (1948) silica is taken into solution at the same time and may be deposited at a lower level as opal. Strike and dip readings taken on tuffaceous strata do not generally agree with regional readings and indicate that the tuffs were deposited on an irregular land surface, or are cross-bedded.

Rhyolite. - Rhyolite flow remnants unconformably overlie the basalt, agglomerate or volcanic conglomerate, and the tuff beds, and may also be inter-bedded with the basalt. The rhyolite caps most of the Centennial Range west of Odell Creek and many of the higher points in the Gravelly Range, and has a maximum thickness of 50 feet.

The rhyolites are often porphyritic, and have an aphanitic groundmass with small phenocrysts of glassy feldspar which is usually sanidine, but sometimes if orthoclase (see figure 18). The phenocrysts form 5 to 35 percent of the rock. The rhyolites may be almost white, light gray, yellowish gray, purplish gray or pale red in color. The phenocrysts usually are from 1 to 2 mm in diameter. The rhyolite is hard and with-stands weathering better than the other volcanics. Flow structures may sometimes be observed in the rhyolite.

A typical specimen of rhyolite from section 25, T. 12 S., R 3 W. in the Gravelly Range, was examined in thin section. The rock contains 65 percent felspathic and quartzose groundmass, 30 percent feldspar phenocrysts which include oligoclase, and sanidine, and 5 percent accessory minerals which include diopside, hypersthene zircon and magnetite. Some pneumatolytic tridymite is present. The groundmass shows slight parallelism, due to flow structure. Megascopically examined, the rock has a medium gray color (N-5). The phenocrysts are glassy and range in diameter from 1/4 mm to 2 mm. Irregularly parallel surfaces covered with a film of iron oxides probably represent flow surfaces.

A rhyolite flow crops out on the low western end of the Centennial Range in sections 1 and 12, T. 15 S., R. 5 W. and because of its orange

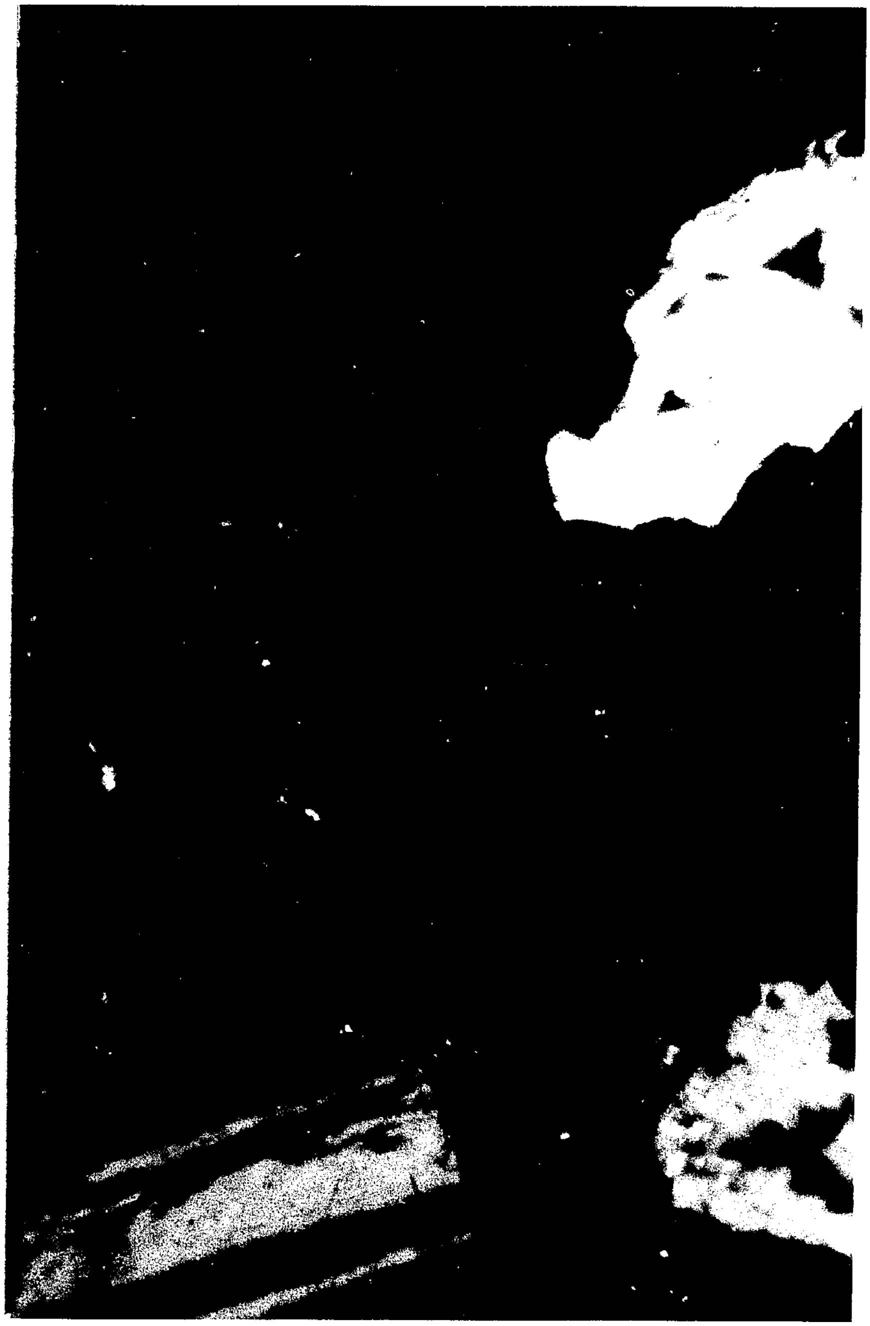

Figure 18. Thin section of rhyolite

From Gravelly Range, near West Fork of Madison River. Note very fine-grained groundmass; phenocrysts of sanidine feldspar. Magnification, x 50.

color (weak yellowish orange, 10 YR 7/4) it can be seen for a long distance. The rock contains 80 percent aphanitic groundmass, and 20 percent glassy sanidine (?) feldspar phenocrysts. The phenocrysts are from 1/2 mm to 2 mm in diameter.

Dikes and sills. - Dikes are localized in two general areas, namely, in the foothills to the immediate north of the Centennial Range crest, west of Odell Creek and in the Long Creek - Ruby River basin. The Aspen formation is host to practically all the dikes. Most of the dikes seem to weather at the same rate the Aspen formation weathers, but locally several form walls from 1 to 6 feet high. Most of the dikes are on the headwaters of Jones and Peet Creeks, and they trend approximately 90° to each other, or N. 45° E. and N. 45° W. The dikes in the Long Creek - Ruby River basin, although fewer in number, also follow two distinct directions more or less at right angles, and coincide approximately with the joints there. The correspondence of joints and dikes suggests that the joints helped localize the dikes, or were formed contemporaneously with the dikes. In general, the dikes are from 3 inches to 6 feet wide and from 100 feet to over a mile long, and have affected very little contact metamorphism. One dike in section 34, T. 13 S., R. 4 W. may be a fissure vent from which basalt flowed forming a wider outcrop than usual for the other dikes. Detailed mapping near the headwaters of Jones Creek in the Centennial Range may establish a well delineated dike swarm radiating from a volcanic vent in the vicinity.

Only one sill was mapped and it may be a dike. The sill is located in section 36, T. 14 S., R. 4 W. The sill has a high dip of 80° SW. but the enclosing strata also have the same dip (see cross-section C-C', figure 27).

The rocks that form the dikes vary considerably. Random samples collected from the dikes and studied in thin section have been identified as dacite porphyry, dorite porphyry, and olivine-basalt porphyry (see figure 19).

A sample from a dike that crops out on Jones Creek is an olivine basalt porphyry and contains 50 percent labradorite, 25 percent magnetite, 10 percent augite, 5 percent quartz (as a wall-rock contamination), 5 percent olivine, and 5 percent of accessories as apatite and biotite. The color of the rock on a fresh surface is dark gray (N-3), and on a weathered surface it is brownish gray (5 YR 4/1). The olivine basalt porphyry has a fine-grained groundmass with crystals averaging 1/8 mm in diameter. Phenocrysts of augite have maximum dimensions ranging from 1/2 mm to 1 cm. The groundmass shows some parallelism, perhaps due to flow structure.

A sample from the sill in section 36, T. 14 S., R. 4 W. is an olivine basalt porphyry. It contains 35 percent labradorite, 35 percent chlorite, which is partly altered to iddingsite (?) and montmorillonite (?), 15 percent magnetite, 10 percent olivine, and 5 percent accessory minerals, which include augite and calcite, the latter as cavity fillings. The rock is a medium dark gray (N-4) color. A groundmass which contains a high percentage of plagioclase microlites forms 70 percent of the rock and phenocrysts form 30 percent of the rock. The groundmass crystals range from 1/50 mm to 1/4 mm in diameter and the phenocrysts range from 1 mm to 1 cm in diameter. The plagioclase laths show a definite parallelism due to flow structure. The chlorite is probably an alteration product of the other iron and magnesium-rich minerals.

Figure 19. Thin section of dike rock

From a dike on Jones Creek headwaters in Centennial Range. Contains andesine, chlorite, magnetite, hornblende. Mafic minerals show alteration. Rock name, diorite porphyry. Magnification, x 50.

Of interest is an outcrop of volcanic rock which forms the curiously named Fossil Mountain in section 16, T. 12 S., R. 2 W. The outcrop is a massive knob of volcanic material rising almost precipitously about 500 feet above Fossil Creek. It is composed of a dense, hard igneous rock not resembling in any way the effusive volcanic rocks that cap the nearby hills. The rock is an olivine basalt porphyry. A megascopic examination shows the rock contains 70 percent aphanitic groundmass, probably largely labradorite, 20 percent olivine and 10 percent hornblende. The rock has a grayish-black (N-2) color. The hornblende crystals are thin laths, 1 mm or shorter, and the olivine phenocrysts range from 1/2 to 5 mm in diameter. The olivine may be partly weathered and thus stained by iron oxide, but if viewed on a fresh surface it is a very bright green. Fossil Peak is probably the vent of one of the volcanoes that were active in the Centennial Region during Tertiary time.

Age of volcanics. - Volcanic activity in almost every Tertiary epoch is recorded in southwestern Montana and southeastern Idaho. However, most workers (Kirkham, 1927, pp. 31-38; Howard, 1937, p. 78; Lowell, 1949) can differentiate two major periods of vulcanism. The writer will use Kirkham's terms of early lava and late lavas (1927, p. 31) to refer to the two periods of vulcanism. The early lavas are present 40 miles to the northwest near Armstead, Montana, and Lowell (1949) says they are of Eocene or Miocene age. Eardley (1949) says lavas of lower Miocene age are present in southwestern Montana. The writer thinks these lavas may represent the early lavas. Kirkham (1927, p. 31) found early lavas in southeastern Idaho only where preserved in erosional or structural valleys, but did not give the lavas an age designation. The writer believes that none of the volcanics of the Centennial Region belong to the early lavas.

Kirkham has described the late lavas in the Centennial Range Snake River lava plain as (1927, p. 34);

> ". . . generally made up of basal flows of basalt and andesite, with trachytes, latites and rhyolites constituting the upper flows. Interbedded with these lavas occurs ash beds, fresh water limestone, clay shale, sandstone, and conglomerate, which are called the Salt Lake formation, southeast of this area."

Kirkham, (1927, p. 13) assumes the late lavas are of Pliocene age, and that the Salt Lake formation is Pliocene in age, (1927, p. 34). The interbedded tuffs and channel sands in the volcanic flows of the Centennial Region resemble Kirkham's (1927, p. 34) description of the Salt Lake formation. The Centennial volcanics will be tentatively termed Pliocene (?) in age until more conclusive evidence is found. Howard (1937, p. 78) and Lowell (1949) have recognized Pliocene volcanics in the Armstead, Montana and Yellowstone Park regions, respectively.

Basin beds. - Almost every intermontane basin in western Montana has strata that have been called "Bozeman lake beds". Deposits called Bozeman lake beds range from Oligocene to Pleistocene in age and are both fluvial and lacustrine in origin.

The Bozeman lake beds are not exposed in the Centennial Region but they may be present in the Centennial Valley although covered by later sediments. The Centennial Valley is a structural basin and apparently no different from other basins in which Bozeman lake beds are exposed.

By the same reasoning, the author also assumes that though not present in outcrop, the older Sage Creek (upper Eocene) and Cook Ranch (middle Oligocene) formations are present in the Centennial Valley. The Sage Creek and Cook Ranch formations are continental clastics. The type localities for the Sage Creek and Cook Ranch formations are only 25 miles west of the Centennial Region.

High-level gravels. - A veneer of well-rounded pebbles or cobbles which may contain some boulders is present in the Centennial Region in varying amounts on crests and on ridges that descend from the crests. The gravels are well exposed on the flanks of the grassy hills near the mouth of Long Creek in sections 23 and 24, T. 13 S., R. 4 W. where a pavement of cobbles literally blankets the hillsides. Figure 24 shows a spur in section 26, T. 14 S., R. 3 W. that trends northward from the Centennial Range crest into the Centennial Valley, and on which gravels are spread.

At no place was more than a veneer of the gravels observed, but the gravels in places are abundant enough to hide the underlying rocks. The gravels are generally well-rounded. Precambrian schist, gneiss, quartzite and other metamorphic rocks, Paleozoic limestone and chert, and Tertiary volcanics may be found admixed. The gravels east of Long Creek are almost entirely Precambrian (?) quartzite, from 2 to 8 inches in diameter and very well rounded.

The original source of the gravels is believed to be the unnamed conglomerate, the volcanic conglomerate, or a similar unit. The conglomerate has been eroded, but a residuum of the more resistent particles or those protected from erosion, remains scattered over the landscape. Where volcanics are present nearby and at higher levels, some volcanic cobbles also may have floated down to mingle with the older gravels.

The concentration of the gravels to their present sites has been going on probably since early Tertiary time and is still continuing.

Quaternary system

General features. - Quaternary alluvium covers the floor of the Centennial Valley. Sand dunes have developed on the alluvium in Recent times. Elsewhere in the Centennial Region glacial deposits are present.

Glacial deposits. - Extensive Pleistocene mountain glaciation occurred in the higher part of the Centennial Range, east of Odell Creek. In general, however, the mountains studied in this report were too low to sustain Pleistocene mountain glaciation. Some evidence of glaciation however was observed on the headwaters of Divide Creek on the eastward facing scarp of the Snowcrest Range where several small but very symmetrical scallops in the mountain front contain tiny lakes, (see figure 20). Several miles down either side of Divide Creek are boulder ridges which may be lateral moraines. The mountain crest is only 8300 feet in elevation here so a possibility exists that the phenomena may be due to weathering, creep and slump. Small scallops in the crest of the Centennial Range near Old Baldy Mountain in section 32, T. 14 S. R. 2 W. are also believed to be due to weathering processes.

Of interest because it poses a problem, was one large sandstone boulder, about three feet in diameter, with striations (?) observed

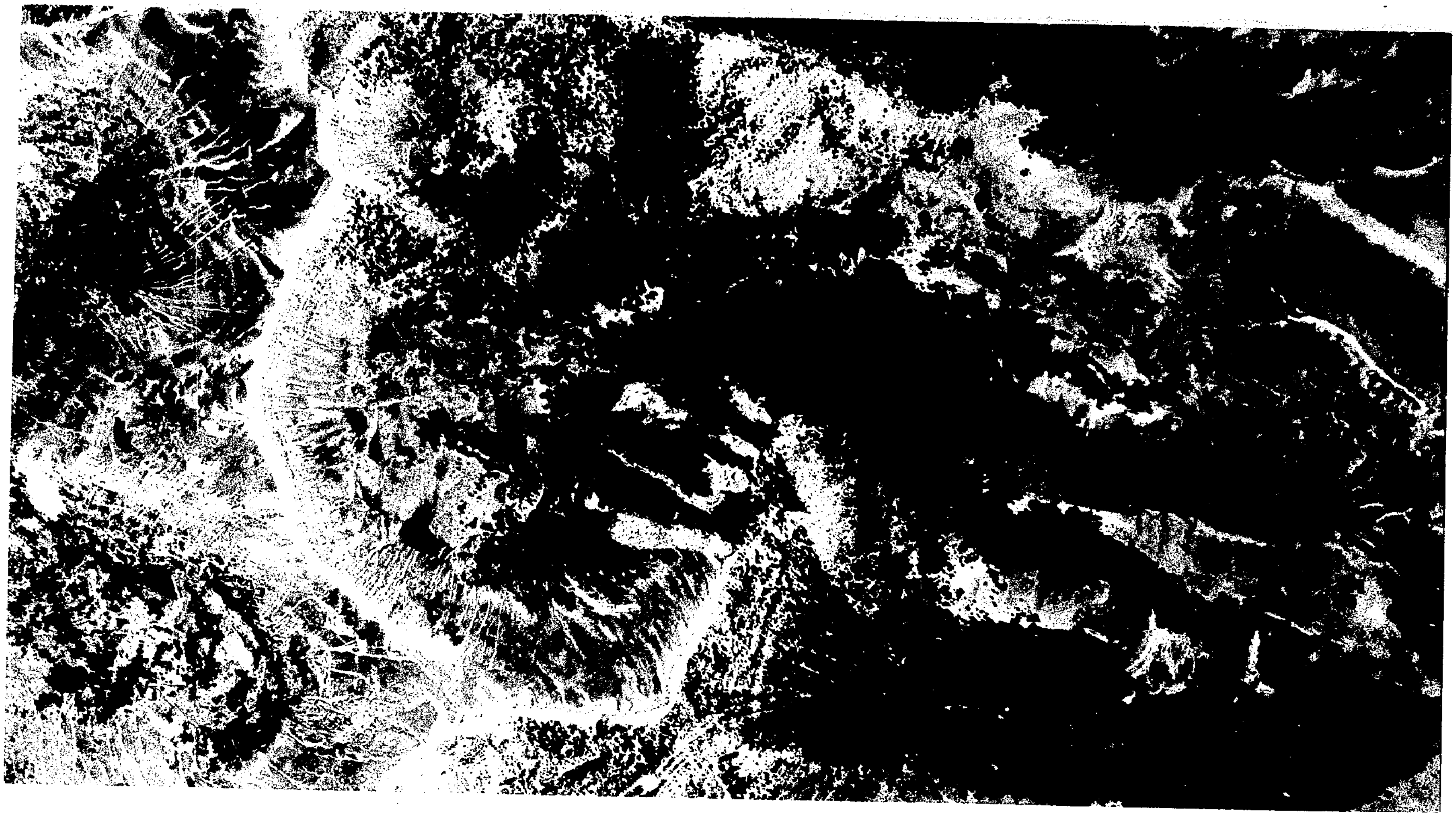

Figure 20. Glaciation (?) in Snowcrest Range

In T. 12 S., R. 4 W. Small symmetrical scallops eroded in unnamed conglomerate. Note small lakes; ridges bounding Divide Creek Valley. Note southeastward course of Divide Creek. (Aerial photo by Agricultural Adjustment Agency).

on the ridge in section 5, T. 12 S., R. 2 W, in the Gravelly Range. Other striated (?) boulders are reported present along the crest of the Gravelly Range. On the basis of these boulders Scott (1938, pp. 1011-1032) and Atwood and Atwood (1945, pp. 957-980) have postulated an Eocene glaciation in this region. The author does not agree with their conclusions for several reasons.

Scott (1938, p. 630) named the Black Butte till from some gravels near Black Butte, six miles north of the Centennial Region in the Gravelly Range. He dated the till as Eocene and tentatively correlated it with the Ridgeway and Gunnison tillites of Eocene age in Colorado. The following points in Scott's argument are weak.

1. Gravels cover much of the crest of the Gravelly Range but they are stream gravels, not glacial gravels. Scott says, (1938, p. 629),

> "The 'gravels' are, for the main part, glacial deposits of various ages. They vary in thickness from a thin veneer to as much as 200 feet. In addition to those of early Tertiary age, three distinct stages of Pleistocene glaciation are recognizable."

The "glacial" gravels are high level gravels that have been described earlier in this paper. The gravels may be found in many places as a veneer but the author doubts that a thickness of 200 feet is present. Where apparent exposures exist as in section 8. T. 12 S., R. 2 W. in the Centennial Region, Cretaceous shales underlie high level gravels floating downhill.

2. Contrary to the above statement by Scott, no stages of Pleistocene glaciation are recognizable in the Gravelly Range. The nearest

evidences are terraces in the Madison River valley and these are due to Pleistocene glaciation in the higher Madison Range to the east.

Scott also shows Pleistocene drift in his geologic map (1938, p. 631). Since Black Butte is the highest elevation in the range and is nearby it is assumed that the source of the drift would be glaciation on or near Black Butte. Except for one possible exception in the Snowcrest Range the author has not seen any record of Pleistocene glaciation in the region studied. Atwood and Atwood (1945, p. 194) themselves refute Scott's claim of Pleistocene glaciation. They say;

> "There are no cirques or canyons, — Black Butte — shows no signs of glaciation."

3. Scott describes the till as composed of fine sand and silt, pebbles, cobbles and boulders, mainly derived from Precambrian metamorphic rocks (1938, p. 633). The till, however, should contain at least as much Paleozoic rocks as Precambrian, since Paleozoic rocks undoubtedly cropped out in many places in Tertiary time as they do now. Scott says the limestones have been leached away. (1938, p. 633). If so, clay should remain and the till should be a hardpan. The till is not a hardpan, nor is it consolidated in any way.

4. According to Scott, (p. 635) the Eocene (?) till is overlain by tuff and basalt, respectively. Scott says the basalt is younger than the tuff because it overlies the tuff, (p. 633). It has been shown earlier in this paper that some tuff is contemporaneous with the basalt and some may be younger than the basalt. So many horizons of tuff or tuffaceous sediments may be found that it is impossible to correlate the tuff in the mountains with tuff in the Bozeman lake beds, as Scott does (1938,

p. 634) especially without any fossils. It has been suggested earlier that the volcanic deposits in this region are probably Pliocene in age and that the lake beds may be Oligocene to Pleistocene.

5. The correlation (1938, p. 635) of two glacial deposits, as the Black Butte till and Ridgeway tillite, 1000 miles apart, is questionable, especially when one deposit is of uncertain origin and age, and covers only about 1 square mile.

Atwood and Atwood, (1945, p. 191) said that the gravels on Gravelly Range were,

> ". . . in large part at least, — a glacial moraine. Some of the finer material may be outwash associated with glaciers. This moraine was deposited by alpine glaciers which descended from mountains that no longer exist and was placed in a valley during Eocene time. There it remained through the long periods of mid-Tertiary erosion when the widespread Rocky Mountain peneplain was developed. Today, owing to the subsequent uplift and erosion of the range, it is a high place or crest of a mountain range."

Several weak points in their argument are noted.

1. A boulder, admittedly weathered, (1945, p. 192, 193) is shown by Atwood and Atwood as an example of striations. Although the striations are transverse to the color bands, the striations may be due to weathering controlled by the rock fabric which is invisible to the naked eye. (Knopf and Ingerson, 1938, p. 15)

2. Atwood and Atwood (1945, p. 192) concede that most of the "moraine" is water-worn material. Lack of stratification is held as evidence for glacial deposition. The author points out that a residual deposit of gravels such as the high level gravels described earlier in this report, usually has no stratification.

3. A peneplain is essentially a level surface cut on all of the rocks of a region. It is hard to picture a glacial deposit remaining unconsolidated, essentially unweathered, and undisturbed through a cycle of peneplanation, as Atwood and Atwood postulate (1945, p. 196). All Wisconsin tills of the central United States are deeply weathered. Nebraskan tills which may be one million years old are almost unrecognizable due to weathering. If the Black Butte till is Eocene it would seem that even if it had not been peneplaned, some gumbotil would have formed in the 50 million years of its existence.

4. Atwood and Atwood (1945, p. 196) postulate the Gravelly Range site was a lowland when areas nearby were high. The author believes that the lines of weakness controlling the Rocky Mountain ranges have been long existent and relatively fixed. Some ranges, of course have been higher than others, but taken as a group any one range was not low while another nearby range was uplifted. It is hard to conceive the Gravelly Range being markedly low in comparison to nearby ranges at one time and elevated to an equal elevation at another time, (Eardley, 1948a). Uplift and likewise erosion, affect regions, not selected ranges.

5. Atwood and Atwood (1945, p. 196) date the moraine as Eocene apparently mainly on the basis of Scott's age determination which has been shown to be erroneous.

6. The climate in Eocene time was a warm tropical climate with local aridity (Eardley, 1948a), not conducive to glaciation except in very high mountains.

7. Atwood and Atwood (1945, p. 195) use the terms "till" and "tillite" interchangeably to refer to the Black Butte gravels and in no place mention the degree of consolidation of the gravels.

8. Striated boulders in stream deposits do not necessarily signify glaciation. Striations may be formed while rocks are encased in river ice, and then the striated rocks may be ice rafted long distances downstream. Striated boulders of this origin are commonly being formed now in Alaska and were formed in Pleistocene time in the drainage basins of the Potomac and Tennessee Rivers (Wentworth, 1928, pp. 948-953), and in rivers in southeastern Texas (Reed, 1928, pp. 520-521).

In this report the author has previously described two sources of gravels present in the Centennial Region, namely, a Cretaceous or early Tertiary conglomerate and a Pliocene (?) volcanic conglomerate. Both units have been shown to contain resistant Precambrian boulders. Both units probably covered the Gravelly Range at one time. High level gravels have been shown to represent a residuum of the weathering of either or both of the units. The questionable thickness of Scott's "till" has been reviewed, the preponderance of stream gravels in the deposits noted, the possibility of some striated boulders from extra-glacial sources in stream deposits suggested, the age determination of the "till" proved erroneous, and correlation practices questioned.

The author believes that the "Black Butte till" is a residuum of the erosion of conglomerate that once covered the Gravelly Range. He believes that no till or moraine exists in the Gravelly Range.

Alluvium. - The Centennial Valley is covered by Pleistocene alluvium which is at least 35 feet thick and perhaps several hundred feet thick.

The Red Rock River flows on the alluvium across the east-west length of the area studied. The valley floor averages 6 miles wide and includes an area of about 130 square miles. It is nearly flat, (see figure 4) except for a few sand dunes and gently sloping fans built out onto it by streams from the mountains that surround the valley. Smaller deposits of alluvium are found in sections 1, 2, and 3, T. 13 S., R. 2 W., in the Odell Creek valley and Long Creek Valley.

The sediments covering the valley floor previously have been casually termed either Bozeman lake-beds, or Tertiary lake-beds. The Bozeman lake-beds have been considered earlier in this paper. The lake beds do not crop out anywhere in the Centennial Region but may be present at depth in the Centennial Valley.

The Pleistocene alluvium is well exposed in a draw in section 2, T. 14 S., R. 4 W., where a thickness of 35 feet was measured. The strata are probably considerably thicker than the exposed section. Kirkham (1927, p. 23) reports a thickness of 400 feet of Pleistocene gravel and alluvium from Mud Lake, Idaho, 50 miles southwest of the Centennial Region. The alluvium in the Centennial Region is mainly silt and some marl. The following thickness was measured in section 2, T. 14 S., R. 4 W.,

| Unit | Thickness in feet |
|---|---|
| 2. Marl; silty, white, unconsolidated, with bone fragments of rodents (?) | 5 |
| 1. Silt, marl gravel; color of silt and gravel, gray; marl, white. Several marl zones up to 5 inches thick. Several gravel lenses, 6 inches or less thick, very irregular bedding, particles up to | |

12 mm in diameter. Gastropods found at depth of 15 feet, gopher and ground squirrel bones at 34.5 feet depth. — 30

Total thickness of alluvium — 35 feet.

The vertebrate remains were identified by Hibbard (1949) who says,

> ". . . in regard to the specimens from the (Bozeman Lake beds), Beaverhead County, Montana: your No. 8-13-14, one, the anterior part of a gopher skull (Thomomys talpoides, mus. No. 25,806); and the other a part of the right jaw of a ground squirrel (Citrellus) with $M_2$ — $M_3$, Mus. No. 25,805.
> Both of these forms are Recent in aspect. The beds cannot be older than late Pleistocene from which they were taken, provided the fossils were taken in place."

The gastropods were identified by van der Schalie (1949) who says,

> ". . . a report on the mollusks — upon examination are: Lymnaea caperata say. — very similar to our recent specimens of this species. The shells — are a group of fresh-water forms and that species tends to inhabit pools (in) lake-like regions."

Sand dunes. - Intermittently small lakes have, as they do now, occupied part of the valley, or larger temporary lakes have flooded the whole valley. The flatness of the valley floor, old beach lines on the valley slope (see figure 26) and wave (?) truncation of spurs extending into the valley (see figure 13) all attest to this. After the last flooding of the valley, and before vegetation could develop on the emergent silts, the constant winds in this region formed several areas of dunes on the valley floor, (see figure 26). The dunes will be more completely discussed under "Physiography."

# STRUCTURE

## General features

The following discussion will be made clearer by reference to the geologic map[6] and structure sections of the Centennial Region (figure 27), and to the other figures, (3, 4, 11, 13, 14, 21, 22, 28), dealing particularly with structure. The discussion of the structure of the Centennial Region will first note the general features, then describe the individual structures, and finally offer a structural history of the region.

The rocks involved in the structure of the Centennial Region are divisible into 3 broad classes; namely, (1) the Precambrian basement complex, (2) Paleozoic, Mesozoic and early Tertiary sediments, (3) and Tertiary volcanics. The above rocks, deformed in varied degree, crop out in parts of the Centennial, Gravelly or Snowcrest Ranges. These mountain ranges are characterized by general simplicity of structure including broad open folds and high angle faults. Only one overturned fold is present, and no thrust faults were noted such as exist in almost any

[6] Aerial photos flown for the Agricultural Adjustment Administration were used as a base for the field mapping of the Centennial Region. Flight strips were tied together using the radial line assembly method (Eardley, 1942, pp. 55-69). Section lines were drawn on the aerial photos using section corners located in the field, roads, ranch fences, and boundary and drift fences in national forests. Forest service maps of the Beaverhead National Forest were of great help. The center lines and wing points of the flight strips were transposed to an acetate overlay and section lines and contacts were also transposed. From the overlay a base map of desired (smaller) scale was prepared. A grid was devised for the overlay and a proportionally smaller grid for the base map of desired scale, and contacts, culture and drainage were sketched on the smaller map.

direction from the area. Several periods of crustal movement are recorded in the sediments, with some of the older sediments deformed more than the later sediments.

Parts of three mountain ranges are present in the Centennial Region area. Each of these ranges differ considerably from the others. Their gross structural features are herein reviewed.

The author believes that the Snowcrest Range and its northeastern extension, the Greenhorn Range, (north of the Ruby River Canyon), is an asymmetrical anticline, steeply overturned to the southeast. It has a trends to the northeast and may locally pass into low angle thrust faults. The southern end of the Snowcrest Range forms the headwaters of the westward flowing Blacktail Creek. A northwest-southeast section through Antone Peak in the Snowcrest Range shows three crests (see cross section B-B', figure 27). A western crest is formed by Paleozoic rocks and central and eastern crests are formed by the Cretaceous (?) Tertiary conglomerate, which unconformably overlies the older rocks and is folded but less so than the underlying rocks.

The Gravelly Range is a deeply dissected block of Paleozoic and Mesozoic sediments which trends north to south and dips to the west, resting on a Precambrian core. Several short tension (?) faults which trend east to west cut the sediments. A well-defined anticline, asymmetrical to the east, which trends northwest to southeast, and a corresponding syncline are present in the otherwise evenly dipping rocks.

The highest part of the Centennial Range which is east of Odell Creek, is a block of Paleozoic sediments, bounded on the north by a steep 3000 foot scarp of tectonic origin. The crest of the Centennial Range west of Odell Creek is capped by Tertiary volcanics on an anticlinorium which trends southeast in the Upper Cretaceous sediments. The western half also has a relatively abrupt scarp to the north, from 500 to 2500 feet high, and a high angle thrust (?) fault which trends north to south along the Odell Creek valley separates the eastern and western halves of the Centennial Range. Two large basins are found in the subject area, namely the Centennial valley and the Long Creek - Ruby River basin. The Centennial valley is a basin which trends east to west, averages 6 miles wide, and extends across the area studied. It is mainly a basin of deposition and contains an unknown depth of Pleistocene and older continental deposits. The basin is of tectonic but may be partly of erosional origin. The Long Creek-Ruby River basin trends north to south, is about 4 miles wide, and divides the northern part of the Centennial Region, and may be of tectonic origin. The soft Aspen formation, which forms the floor of the basin, is being rapidly eroded by the active Ruby River.

Laramide faults

Gravelly Range. - A high angle normal fault in sections 27 and 28, T. 12 S., R. 2 W. near Fossil Creek has an estimated length of 1.5 miles, strike of N. 70° E, and estimated throw of 500 feet, with the south side downthrown. Red siltstone float on the south side of the fault indicates that the Woodside formation moved down and rests against the Phosphoria formation. The Dinwoody formation has been considerably shattered along the fault just east of Fossil Creek. Here a hill several hundred feet high is composed of a jumble of Dinwoody fragments, ranging in diameter from 1 inch to 50 feet. Post-fault solution around the fault zone may have caused slumping, accounting for the large blocks.

A small high angle thrust fault is located nearby in section 27, T. 12 S., R. 2 W. The fault trace is about a quarter of a mile long and the strike is N. 20° E. The fault plane has an estimated dip of 60° W. The throw is about 75 feet and the heave about 35 feet. The displacement in a resistant chert member of the Phosphoria formation is well displayed on the West Fork of the Madison River.

Another small high angle fault is located in section 31, T. 12 S., R. 1 W., where it is believed to be parallel to the course of the West Fork of the Madison River. The fault is at least a half of a mile long and its strike is N. 45° W. The estimated throw is 300 feet and the southwest side has been brought into contact with Cambrian Flathead and Meagher formations on the northeast side.

Centennial Range. - Faults observed in the Centennial Range are localized near Odell Creek. A high-angle thrust fault or possibly a normal high-angle fault is located mostly west of Odell Creek in sections 1 and 12, T. 15 S., R. 2 W., section 36, T. 14 S., R. 2 W. and section 31, T. 14 S., R. 1 W. The estimated length of the fault is 3 miles, though it may extend farther in either direction. The fault trace is irregular but it has a general strike of N. 30° E. In section 1, T. 14 S., R. 2 W. where the Brazer limestone is in contact with the Aspen formation the estimated stratigraphic throw is 4500 feet and the throw perhaps 3000 feet. High northwestward dips are present in the Aspen formation suggesting a high angle thrust type of fault. The fault relations are well exposed along the course of a tributary of Odell Creek that flows from the little lake in the northwest corner of section 12, T. 15 S., R. 2 W. Much of the fault trace is in heavily forested country, but it can be recognized by Mississippian limestone and Cretaceous coarse "salt and pepper" sandstone float.

A small low angle thrust fault slice in section 1, T. 15 S., R. 2 W., near Odell Creek may have been overridden by the above described fault. The fault slice is about 1 mile long and in the southern part of section 1. It has a due north strike, turning in the northern half of section 1 to an almost due west strike where it abuts against the above fault. The fault plane has an estimated dip of 30° S, and the stratigraphic throw is about 1000 feet. At the northern end of this fault the Brazer limestone of Mississippian age overlies the Dinwoody formation of Triassic age.

Other faults are present in section 30, T. 14 S., R. 1 W. but they continue into the Lyon quadrange mapped by Kennedy (1948) and so will not be discussed here, (see figure 6).

### Laramide folds

__Gravelly Range__. - On the western flank of the south end of the Gravelly Range are two folds, the Metzel Creek anticline and the Fox Creek syncline[7], (see figure 11).

The axis of the Metzel Creek anticline may be traced from section 17, T. 13 S., R. 2 W., northward for three miles and then northwestward

[7]Fox Creek enters the West Fork of the Madison River in the northeast corner of section 13, T. 12 S., R. 3 W.

for about six miles. The anticline is from three to four miles wide. At the south end it plunges under the Quaternary alluvium with an angle of plunge estimated at 10° S. and at its north end it merges into the thick Upper Cretaceous sedimentary sequence of the Long Creek - Ruby River basin and has an angle of plunge of 15° NW. The fold is asymmetrical to the northeast, the strata on that side dipping from 18° to 55° NE., and those on the southwest dipping from 5° to 22° SW. The West Fork of the Madison River cuts across the northwestern half of the fold and exposes beds from Pennsylvanian (Quadrant) to Upper Cretaceous (Aspen) in age. The southern half of the fold is capped by resistant Phosphoria formation chert and quartzite. The anticline is nowhere faulted, but some dikes intrude its flanks, and volcanics overlie its higher points.

The For Creek syncline roughly parallels the Metzel Creek anticline. The axis has an average N. 30° W. strike and is about 8 miles long. The snycline enlarges from 1 mile wide at its southern end to 4 miles wide at its northern end. The fold closes to the south, in section 33, T. 12 S., R. 2 W., and opens to the northwest with an estimated 10° angle of plunge. The syncline is asymmetrical to the southwest where the strata dip from 18° to 55° N.E., as compared with the northeast limb where they dip an average of 11° SW. Upper Cretaceous Aspen strata lie in the center of the syncline and the oldest beds exposed in the nose of the fold belong to the Permian Phosphoria formation.

Centennial Range. - The Peet Creek anticlinorium is located in the drainage basin of Peet Creek in the northern third of T. 15 S., R. 3 and

4 W., and southern third of T. 14 S., R. 5 and 4 W., (see cross-section C-C', figure 27). The length of axis of the major fold can be followed for about 12 miles, and the length of the axis of the smaller folds are distinguishable for 2 to 9 miles. The width of the anticlinorium is about 8 miles, and the width of the separate folds ranges from half a mile to 2 miles. The general strike of the anticlinorium is N. 60° W., but its component folds may vary from N. 45° W. to N. 65° W. One of the smaller folds in section 25, T. 14 N. R. 5 W. was observed to plunge with an angle of about 30° NW., but none of the other folds was seen to plunge. The trend of the anticlinorium which at the surface is entirely in the Aspen formation is covered to the northwest by Quaternary alluvium and to the southeast by Tertiary volcanics. The anticlinorium is abnormal;[8] the folds on its southwest limb are asymmetrical to the northeast, the folds on its northeast limb are asymmetrical to the southwest. On both flanks the dips of the asymmetrical limbs range from 50° to 80°, and the dips of the opposite limbs from 31° to 40°. The central fold of the anticlinorium is slightly asymmetrical to the southwest. Several miles to the south across the Continental Divide into Idaho folding is present which may represent a continuation of the Peet Creek anticlinorium (Kirkham, 1928, p. 4). (See also figure 13, this text.)

A small fold is probably present in the Aspen formation in section 31, T. 14 S., R. 1 W. The strike of the axis is N. 30° E. and it can be traced for approximately one mile. The fold was postulated on the basis

[8]In an abnormal anticlinorium the axial planes of the minor folds converge upward. (Billings, 1946, p. 51).

of opposite directions of dip about half a mile apart, in the Aspen formation.

Snowcrest Range. - The Snowcrest Range in its southern extension has three crests as shown in cross-section B-B', on figure 27. However, about ten miles to the north the crest formed by the Paleozoic and Mesozoic strata becomes the only crest in the range. The strata are overturned and may represent the overturned limb of a large overturned anticline, 20 miles long, which trends northwest to southeast. The fold (?) axis is located in the northwest corner of section 3, T. 12 S., R. 5 W., where it strikes N. 50° E., and the axial plane is overturned and dips 45° NW. Beds in the overturned limb (?) generally dip from 30° to 65° NW. The oldest strata exposed in the fold (?) is the Madison group of Lower Mississippian age and the youngest is the Aspen formation of Upper Cretaceous age. North of the Ruby River canyon the fold (?) may pass into a thrust and southwest of Sawtooth Peak, near the west boundary of the Centennial Region the dip becomes normal. (Klepper, 1949).

The writer has shown on the geologic map (figure 27) an overturned syncline in the Cretaceous rocks under the unnamed conglomerate in T. 12 S., R. 5 W. In section 15, T. 12 S., R. 5 W. Cretaceous sandstones crop out in a draw on the west flank of Antone Peak, and the beds dip vertically. Possible interpretations of the dip include a high-angle normal fault downthrown to the southeast, a thrust fault from the southeast or northwest, or mashing and adjustment in the relatively soft Cretaceous rocks where the strata are beginning to come out of their overturned condition. No evidence of a fault was seen, so the interpretation of a syncline seems the most likely. (See figure 27, cross-section B-B', also figure 22). On the geologic map (see figure 27, also cross-section B-B') the syncline is in T. 12 S., R. 5 W. The syncline is overturned to the southeast, the fold axis strikes N. 40° E., and the axial plane dips 50° NW. Beds in the syncline dip from 30° NW to 90°, and only Cretaceous strata are exposed in the center of the fold. Klepper (1949) also interprets the structure in similar fashion.

The unnamed conglomerate of Paleocene (?) age lies unconformably on the more tightly folded Paleozoic and Mesozoic rocks. It trends as a belt roughly northeast-southwest and is about 8 miles wide. The belt is cast in a shallow syncline whose eroded upturned northwest limb forms the middle crest of the south end of the Snowcrest Range. The syncline is slightly asymmetrical to the northwest, with a dip on that limb of 30° to 56° SE. and on the southeast limb of 12° to 25° W. and SW. The syncline opens slightly to the south.

<u>Other Folds</u>. - A major fold, the Clover Creek anticline, (Eardley-1946) is present to the west of the Centennial Region. The fold is in the unnamed conglomerate and trends to the northwest. If continued under the Quaternary alluvium the projection of the fold axis would be located in sections 27, 34 of T. 13 S., R. 5 W.

In the Long Creek - Ruby River basin in the generally gently southwestward dipping Cretaceous sediments several small reversals of dip were noted (see figure 27, section A-A'). A shallow, fairly symmetrical north-south trending syncline is located in sections 12, 13, and 24, T.

13 S., R. 4 W. and a corresponding gentle anticline may be present in sections 10, 15, and 22, T. 13 S., R. 4 W. A small reversal of dip was noted on the Ruby River in T. 12 S., R. 3 W. The fold trends N. 50° W. and may possibly represent a continuation of the Metzel Creek anticline.

Laramide diastrophic history. - A tentative Laramide diastrophic history of the Centennial Region is presented in figure 21 and is compared with a history compiled by a conference of University of Michigan thesis students working in southwestern Montana in 1948, (Eardley, 1949) and a partial history abstracted from Kirkham's papers (1927, 1931).

Uplift, which was probably orogenic, heralded the Laramide orogeny in Lower Cretaceous time. The Kootenai formation was deposited as a result of the uplift and the coarseness of the Kootenai basal conglomerate attests to the sharpness of the uplift.

Uplift continued through early Upper Cretaceous (Colorado) time. The uplift was relatively gentle and finer-grained clastics were deposited forming the Colorado shale and Aspen formation. The Aspen formation also contains some tuffaceous material, signifying nearby vulcanism in Colorado time. The uplift probably continued through late Upper Cretaceous (Montana) time but, in general, erosion dominated over deposition. Vulcanism was extensive to the northeast where the Livingston formation was deposited.

A sharp orogenic uplift occurred probably in Paleocene time, although it may have started in late Upper Cretaceous, or continued to early lower Eocene. The uplift may be called the early Laramide orogeny. Metzel Creek anticline and Fox Creek syncline which trend northwest-southeast and the Snowcrest Range which trends southwest-northeast were formed in this orogeny. More field work must be done to properly define the spatial and time relations represented by these two conflicting trends. The unnamed conglomerate which may locally have a thickness of over a mile is proof of the greatly increased stream erosion caused by the orogeny. The conglomerate overlies the Aspen formation in the Snowcrest Range with angular unconformity.

The unnamed conglomerate was moderately folded in perhaps lower Eocene or upper Paleocene time. After the folding the conglomerate participated in extensive thrusting, in Middle Eocene (?) time. Lowell reports (1949) that the conglomerate has been overthrust by older rocks and also has itself been overthrust in the Dell, Montana region. The folding may represent the Middle Laramide orogeny and the faulting the Late Laramide orogeny.

The remainder of Eocene time was dominated by erosion. The development of the widespread intermontane basins of Montana perhaps began in upper Eocene time, with downwarping, (Eardley, 1949) of the basins. Relief was accentuated and the Sage Creek formation of continental clastics was deposited. As noted earlier, though the Sage Creek beds do not crop out in the Centennial Region, the type section of the beds is only a few miles to the west and it seems logical to assume that the beds are present at depth in the Centennial Region.

Post-Laramide normal faults

<u>General statement</u>. - The front of the Centennial Range and the front of the Gravelly Range facing the Madison Valley are probably

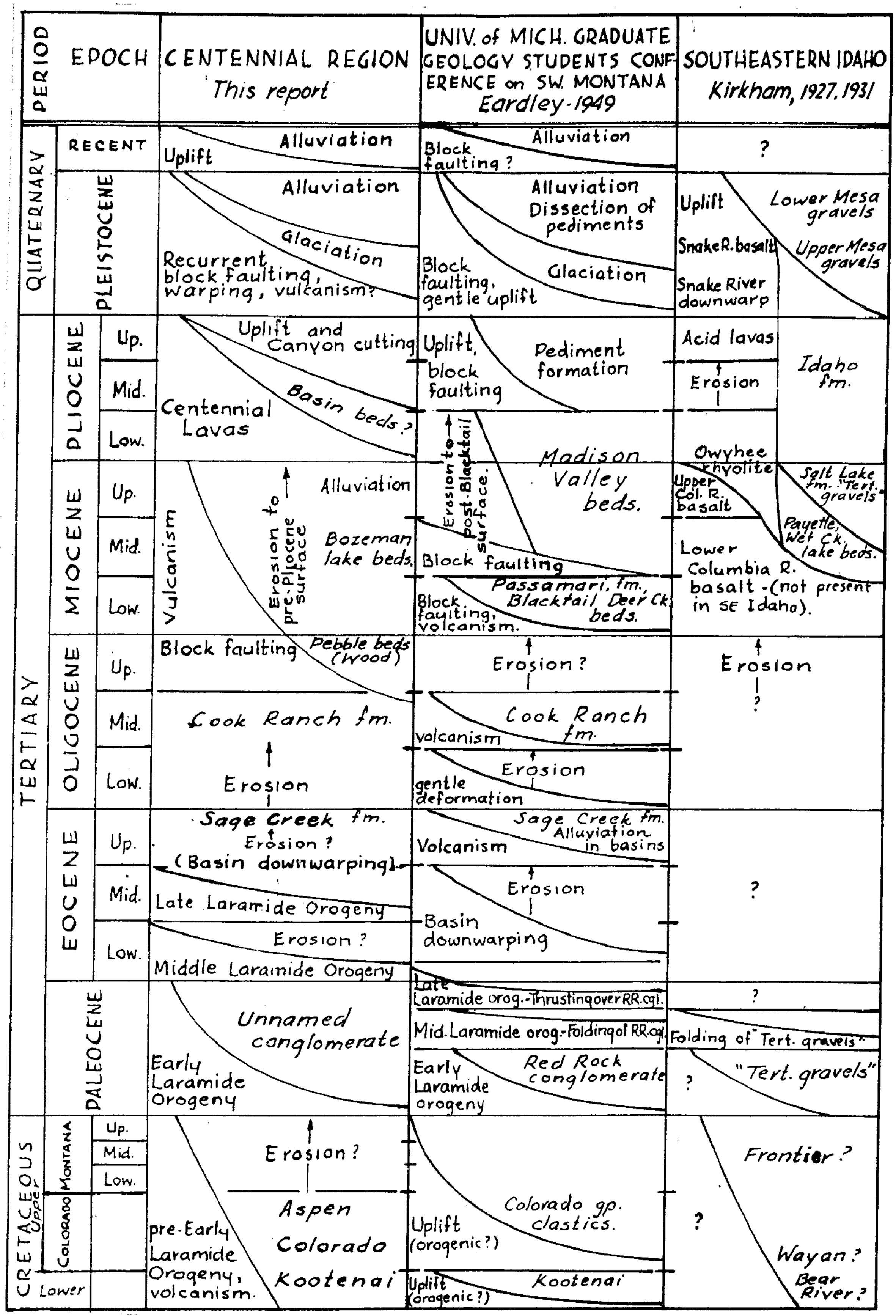


**Figure 21. Correlation chart of deformational, depositional, and erosional events in southwestern Montana and southeastern Idaho**

bounded by normal faults, and the Centennial Valley is probably downfaulted on at least one side. Little direct evidence, however, can be presented for the faults.

Centennial Valley. - The author believes that Centennial Valley is probably of tectonic origin. A postulated normal fault bounds the south of the valley (see figures 13, 22). The presence of the fault is suggested by the fairly straight front of the Centennial Range, by the lack of evidence that any of the strata in the Centennial Range dip to the north, which could make the valley a syncline, by the lack of evidence for other agencies capable of causing the valley, and by similar nearby valleys where the structural evidence more clearly indicates valleys of tectonic origin. Evidence for downtilting in the Centennial Region is reviewed in a subsequent section of this report and forms the most convincing proof for the Centennial Range fault. Downtilting of the Centennial Valley and uptilting of the Centennial Range must have hinged on a fault.

The fault is probably a high angle fault, dipping to the north and with an unknown throw. The fault trends west to east and may extend from the western border of the Centennial Region eastward for 35 miles. In other basins thicknesses of several thousand feet of Tertiary lake beds are present (Peale, 1896, p. 3), indicating probably that much accumulative downfaulting. The throw of the fault bounding the Centennial Valley may be similar.

The fault is not continuous. A north-south fault which has been described previously in this paper, cuts the east-west fault at Odell

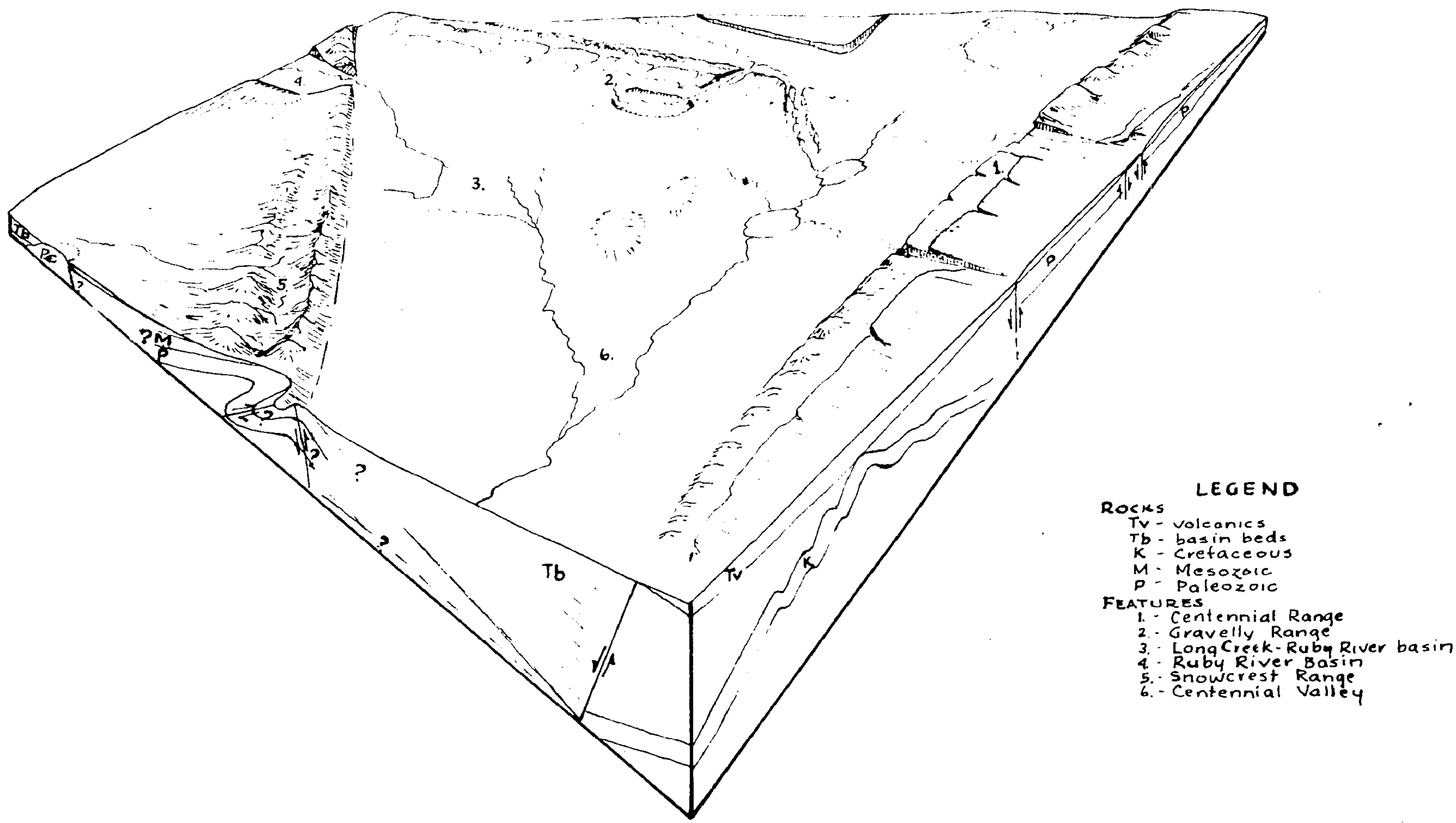


Figure 22. - Generalized physiographic and structural block diagram of the Centennial Region.

Creek. A small graben-like block of Paleozoic sediments has broken from the front of the main fault just east of Odell Creek, (see figure 6). This fault is in the Lyon quadrangle mapped by Kennedy (1948) and will be described by him. In T. 14 S., R. 1 E. in the Hellroaring Creek basin two north-south normal faults, each several miles long cut the east-west block. From Hellroaring Creek, the Centennial Range continues eastward for 10 miles as sharp, rugged scarp several thousand feet above the basin country present to the north. The range however is entirely of Precambrian rocks, and Precambrian rocks, apparently continuous, can be traced northward to the Gravelly Range, as a low ridge which separates the Centennial Valley from Alaska Basin to the east. Kennedy (1948) believes that the continuous exposure of Precambrian rocks is proof that no fault bounds the Centennial Valley. The author believes that a fault can be present just as easily in the Precambrian rocks as in the younger rocks. The Precambrian rocks have not been studied in detail, their lithologies are surficially alike and displacement is harder to prove by this line of evidence.

Long Creek - Ruby River basin. - Normal faults may bound that part of the Long Creek - Ruby River basin in the Centennial Region, but no evidence can be presented for the faults. The Aspen formation beds dip gently westward into the basin from the crest of the Gravelly Range. Within the basin minor folds may interrupt the westward dip. The western edge of the basin is delineated by the abrupt scarp of the Snowcrest Range. As observed by the author north of Antone Peak and in the Ruby River Canyon, in T. 9 S., R. 3 W., 21 miles northeast of Antone Peak, the Snowcrest Range is an overturned fold (?), though as previously noted, some thrusting may also be present. Dorr and Wheeler have presented evidence (1948, pp. 68-72) that the Ruby River occupies a down-faulted basin after it leaves the Ruby River Canyon, and date the faulting as Miocene to Recent.

Regional tilting. - Regional tilting may have occurred in the Centennial Region. The tilting uplifted the Centennial Range and the northern part of the Centennial Region as shown in figure 23. Correspondingly the southern half of the Centennial valley was downtilted as was the Snake River lava plain. Evidence for the tilting is listed as follows:

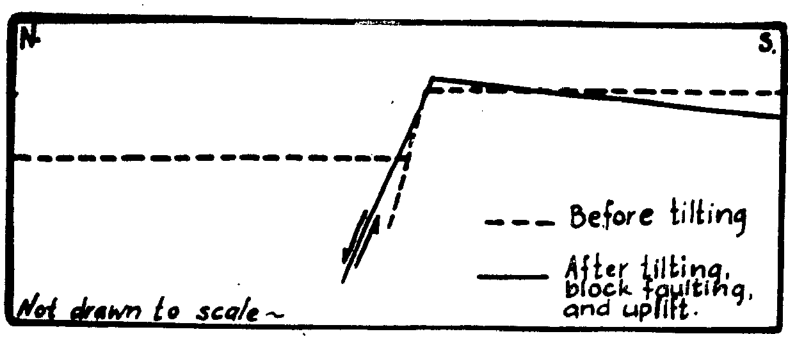


Figure 23. - Diagrammatic representation of tilting in Centennial Region.

(1) Northward flowing streams may have pirated southward flowing streams. In the headwaters of Divide Creek, which flows into Ruby River, the channel trends southeastward and is separated from the headwaters of Long Creek by a very low and narrow divide, (see figures 20, 27). Long Creek continues south-eastward but Divide Creek makes a rather abrupt turn to the northeast and eventually flows north to join the Ruby River.

Divide Creek once may have flowed southward into Long Creek but if regional tilting occurred to the south, the Ruby River would have been rejuvenated and cut back on the north side of the divide faster than Long Creek did on the south side and thus capture Divide Creek.

Another example of stream piracy may be in the Gravelly Range. All the major tributaries of the West Fork of the Madison River originate in the north and flow almost due south into the West Fork which flows from west to east. If the northern half of the Centennial had been uptilted the gradient of the West Fork, which flows eastward and then northward would have been increased. The West Fork could thus actively erode headward to the west and capture the southward flowing tributaries of the Red Rock River. It must be admitted, however, that most of the southward flowing tributaries are strike valleys and later in the report it will be shown that the West Fork may be superimposed.[9]

(2) As suggested by figure 23, downwarp has occurred on the Snake River lava plain and corresponding uplift in the Centennial Range. The presence of the Snake River downwarp has been recognized by many geologists and Kirkham has reviewed the evidence (1931, pp. 456-470) for the downwarp and added new evidence. (1931, pp. 471-482). Kirkham (1931, p. 481) believes the downwarping is of late Pliocene or Pleistocene age since late Pliocene rhyolite flows are downwarped.

The geologic map of the Centennial Region (figure 27) shows that the volcanics on the crest of the Centennial Range dip generally from 15 to

[9] Superimposition of streams in the Centennial Region is discussed under "Physiography."

25 degrees to the south. Kirkham (1927, p. 13) has shown that the Pliocene lavas were very fluid and spread over much territory. The writer has previously tentatively correlated the Centennial volcanics with Kirkham's Pliocene lavas. It does not seem that the apparently very fluid lavas could have evenly accumulated at dips of 15 to 25 degrees. Many of the interbedded tuffs also coincide in dip to the lavas. It seems that the tuffs also would accumulate generally in horizontal layers rather than in persistently-dipping beds. Post-lava extrusion and post-tuff deposition tilting is a plausible explanation.

The author believes the margins of the Snake River downwarp are delineated by normal faults which dip away from the downwarp. Beyond the immediate margin, lesser but similar downwarping was distributed. Thus, the Centennial Range front forms the northern margin of the Snake River downwarp and the Centennial Valley downtilting represents the additional extra-marginal downwarping, (see figure 23).

Post-Laramide diastrophic history. - As has previously been noted no Oligocene deposits crop out in the Centennial Region but the type locality of the middle Oligocene Cook Ranch formation is only a few miles to the west, and it is assumed that the Oligocene history recorded there may also be applied to the Centennial Region (Wood, 1935, p. 255). Lower Oligocene time was apparently one of erosion and gentle uplift may have occurred at the close. The Cook Ranch formation composed mainly of clay, with some sand lenses, may represent a time in middle Oligocene when locally, at least deposition exceeded erosion, (Wood, 1935, p. 254).

Block faulting possibly occurred in upper Oligocene or lower Miocene time as pebble beds that may be of this age overlie the Cook Ranch formation with angular unconformity (Wood, 1935, p. 255).

Erosion dominated Miocene history in southwestern Montana. The highlands that had been rejuvenated several times in early Tertiary time were eroded to a surface which has been called the post-Blacktail surface (Eardley, 1949a). Kirkham (1927, p. 13) also postulates a pre-Pliocene peneplain. Extensive basin beds were deposited including the Bozeman lake beds in the Centennial Region and elsewhere, the lower Miocene Passamari formation and upper Miocene Madison Valley formation of the lower Ruby River basin (Dorr and Wheeler, 1948, pp. 68, 69), the Muddy Creek basin beds of Miocene (?) age, west of Dell, Montana (Wallace, 1948, p. 52), the Payette formation of Middle and Upper Miocene age in Idaho, (Kirkham, 1931, p. 471), and the Salt Lake formation of Idaho and Utah (Kirkham, 1931, p. 472).

During the Miocene alluviation vulcanism continued in nearby areas, and volcanic material is found interbedded in the basin beds, (Dorr and Wheeler, 1948, pp. 8-14). Extensive lava flows were extruded in upper Miocene and Pliocene time in Idaho and in the Centennial Region, (Kirkham, 1927, p. 13; 1931, pp. 471-472) and in the Yellowstone region (Howard, 1937, p. 78). Basin beds may have been deposited in the Centennial Region in Pliocene time corresponding to the Idaho formation in Idaho, (Kirkham, 1931, p. 472). The extensive lava plains and alluviation combined to reduce the relief in late Pliocene time. Near the close of Pliocene time and perhaps in early Pleistocene time, extensive uplift rejuvenated streams and started canyon cutting. Canyons have been cut in the rhyolite, considered by the writer as perhaps late Pliocene in age.

In Pleistocene time recurrent block faulting along previously established lines accentuated the topography. Tilting and warping of the Snake River lava plain and the Centennial Region occurred as previously discussed in this report. Extensive basalt flows filled the center of the Snake River downwarp (Kirkham, 1931, p. 479), covered large parts of the Yellowstone region (Howard, 1937, pp. 7, 8), and may be present in some parts of the Centennial Region. The writer has observed canyons several hundred feet deep cut into the basalt in the center of the Snake River downwarp indicating considerable regional uplift since extrusion of the Pleistocene Snake River basalt. Pediments which may represent Pliocene alluviation have been deeply eroded (see figure24) indicating Pleistocene (?) uplift.

Uplift is continuing today along the earlier block fault surfaces. Fresh scarps are present along the fronts of the Tendoy Range and the Madison Range to the west and east respectively of the Centennial Region. Two north-south faults on Hellroaring Creek in the Centennial Range are clearly visible on aerial photos even though the country is heavily forested.

## Relation of local structures to regional structures

More data is needed to correctly place the Centennial Region structures into the regional picture. Nearby structural units include the Madison Range, Yellowstone Plateau, the Snake River downwarp and the great zone of overthrusts in western Wyoming, southeastern Idaho, and southwestern Montana. Many interesting problems are posed in the regional structural relations. Some correlations with nearby structures have been suggested in the Laramide and post-Laramide diastrophic histories which have been related previously.

## PHYSIOGRAPHY

### General statement

Four erosional or depositional surfaces are believed to be present in the Centennial Region, and these surfaces will be briefly discussed below. Stream adjustments, dune topography and beachlines will also be reviewed.

Pre-Pliocene surface. - As previously suggested, the Pliocene (?) lavas may rest on an erosion surface developed in Miocene (?) time. Kirkham (1927, p. 13) says,

> "Assuming a Pliocene age for the Late Tertiary lavas, a pre-lava peneplain-like area must have existed in order to have such a widespread relatively flat-lying series of these acid lavas which are consistently thin for their extent and notably similar in lithology over a vast region."

The writer believes that Dorr and Wheeler are referring to the same erosion surface when they say, (1948, p. 70),

> "Four surfaces have developed in the basin. All but one, the highest are post-Miocene in age as they cut the Madison Valley formation. The highest and oldest is an erosion surface remnants of which form the level tops and skyline of the Ruby and Greenhorn Ranges. The surface is probably Early Tertiary in age and formed during a long erosion interval which removed Paleozoic and Mesozoic rock and left the Precambrian exposed."

Figure 24. Pediment in Centennial Range

In T. 14 S., R. 3 W. Gravel capped Pliocene (?) alluvial surface forming divide. Headward erosion of streams removing pediment, and exhuming light-colored Aspen formation below. (Aerial photo by Agricultural Adjustment Agency).

It is believed that the volcanic rocks in the Gravelly and Centennial Ranges were extruded or deposited on the pre-Pliocene surface. Since then tilting and uplift have warped the Centennial Range portion of this surface. The surface is present at about 9000 feet elevation and is preserved where overlain by volcanics, or recently exhumed by erosion. Figure 9 shows diagrammatically the relations among the surfaces postulated as present in the Centennial Region.

__Pediments__. - Pediments capped by high-level gravels are present from elevations of 7000-8000 feet in the Centennial Region, (see figure 24). It has been suggested previously that the high level gravels, which cover many of the ridges that slope down from the range crests, represent a residuum of the unnamed conglomerate, the volcanic agglomerate or conglomerate, or other unknown coarse clastics that may have been spread over the Centennial Region at various times in the Tertiary period.

The pediments may represent the gently sloping surfaces eroded during Pliocene or earlier alluviation. Uplift at the close of the Pliocene caused rejuvenation of streams. The streams dissected the uplifted surface and today only remnants of the surface are left on the interstream divides at elevations from 7000 to 8000 feet. Figure 24 shows such a divide with rapidly downcutting streams working headward into it.

__Centennial Valley surface__. - The sediments eroded in Pleistocene time from the uplifted mountains have been spread over the floor of the Centennial Valley in broad, gently sloping alluvial fans, or deposited in lakes that from time to time have existed in the valley.

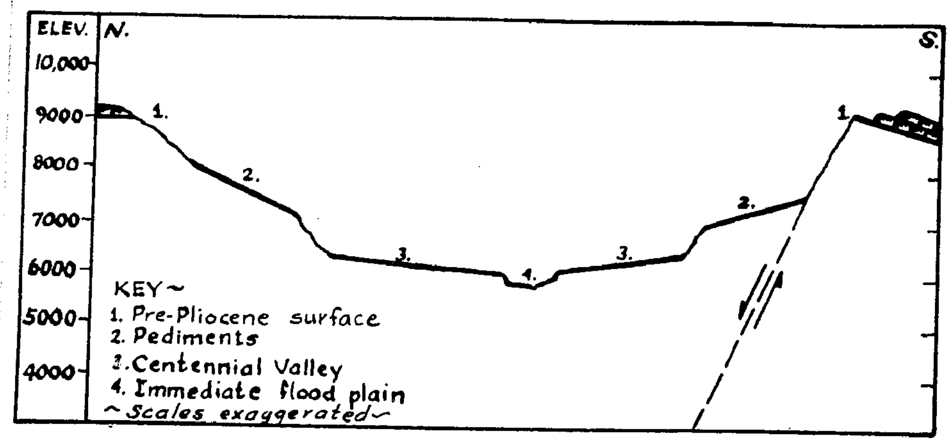


Figure 25. - Diagrammatic representation of erosional and depositional surfaces in Centennial Region.

The surface is from 4 to 10 miles wide and ranges in elevation from 6600 to 7000 feet. Fossils from the Centennial Valley previously described in this report date the uppermost part of the Centennial Valley sediments as late Pleistocene.

Immediate flood-plain surface. - The Red Rock River has entrenched its flood plain into the Centennial Valley surface up to a depth of 50 feet, and to a width of one fourth to one half of a mile. To maintain grade, all tributaries of the Red Rock River have likewise entrenched their courses in the Centennial Valley surface.

The downcutting of the Red Rock River is probably due to two causes, namely, lowering of the divide near the present site of the Lima Reservoir dam in section 32, T. 13 S., R. 6 W., and recurrent uplift along the previously established lines of block faulting. Canyons cut into the Quaternary lavas of the Snake River lava plain and the notching of the floor of the canyon of the West Fork of the Madison River, are probably both results of the same uplift and are briefly noted elsewhere in this report.

Tertiary and Quaternary stream adjustments. - The larger streams in the Centennial Region, with the possible exception of Long Creek, pass through steep canyons at certain places in their courses. Examples of such canyons include almost the entire course of the West Fork of the Madison River in the Centennial Region, the canyon of the East Fork of Blacktail Creek in section 2, T. 12 S., R. 5 W., and the canyon of Odell Creek in sections 30 and 31, T. 14 S., R. 2 W. Each canyon is at least 2000 feet deep measured from the crest of the respective ranges through which they cut. The Odell Creek and Blacktail canyons expose Mississippian rocks and the West Fork canyon is cut to Precambrian rocks. Other canyons are present nearby but outside the Centennial Region, and include the Ruby River canyon between the Snowcrest and Greenhorn Ranges, Hellroaring Creek canyon in the Centennial Range, the Elk, Hidden, Cliff and Wade group of lakes, and the Red Rock River canyon between Lima Reservoir and Lima, Montana.

The mountain tops near West Fork and Odell Creek are capped with volcanics. It has been previously suggested that the volcanics are Pliocene in age, and were widespread in the Centennial Region. By the end of Pliocene time volcanics had been extruded onto a relatively flat pre-Pliocene erosion surface, and in addition, alluviation had helped create a relatively monotonous landscape. Upon this surface of deposition the larger streams meandered in about their present courses. Uplift occurred at the end of the Pliocene and the larger streams started a canyon-cutting cycle exhuming earlier Laramide structures as they cut down deeply, sometimes to the Precambrian. In middle (?) Pleistocene time additional uplift occurred and the streams cut down still further into the relatively large valleys that had been produced up to that time. The West Fork of the Madison River in sections 27 and 28, T. 12 S., R. 2 W. has thus notched its broad main canyon with a small V-shaped youthful gorge up to 100 feet deep.

The canyons probably represent the attempts of the larger streams to maintain their courses during the many topographic changes caused by Tertiary and Quaternary downwarping, uplift, and volcanism. Superimposition of streams may have caused some canyons.

The apparent reversal of drainage in the Centennial Valley may be connected with superimposition. Five to ten miles east of the Centennial Region in Tps. 12 and 13 S., R. 1 E., is a group of elongate, deep lakes that have a definite northerly trend, and occupy a prominent and steep valley. From south to north the lakes are Elk, Hidden, Cliff and Wade Lakes. Elk and Hidden Lakes have no surface outlets but Elk Lake probably drains in the subsurface into Centennial Valley and Hidden, Cliff, and Wade Lakes drain north into the Madison River. All tributaries entering the lakes, including Limestone Creek which enters Elk Lake, point north. Undoubtedly the Centennial Valley once drained into the Madison River through the valley that the lakes now occupy. The valley is cut mainly in Tertiary rhyolite. The author suggests that the stream that once occupied this valley was superimposed onto the rhyolite at the same time that a smaller stream slightly beyond the western border of the map was superimposed on the Cretaceous (?) Tertiary unnamed conglomerate in T. 13 S., R. 6 W., near the site of the present Lima Reservoir. The Centennial Valley may have had a small divide in it, similar to or even lower than the present one between the Ruby River and Long Creek. Because the smaller stream, the ancestral Red Rock River, was superimposed on the loosely cemented and thus easily eroded conglomerate it cut down faster than the northward flowing stream which was superimposed on rhyolite and in places Precambrian crystallines which underlie the rhyolite. The westward-flowing stream soon cut back through the divide and diverted the Centennial Valley drainage. Other factors are listed below which may in part, or perhaps, wholly have been the cause of the reversal.

(1) If southward tilting occurred a lower westward outlet than the outlet to the north, may have been opened.

(2) If the West Fork of the Madison River pirated drainage that formerly flowed into Centennial Valley the water level in the lake may have been lowered below the north outlet.

(3) Pleistocene glaciation which was widespread in the Madison Range may have temporarily dammed up the northern outlet, causing the water in the Centennial Valley to back up and seek another outlet.

Other stream adjustments - Fossil Creek, Cascade Creek, and Buford Creek in the Gravelly Range are believed to be mainly strike valleys. Fish Creek in sections 26 and 35, T. 12 S., R. 3 W is a well-developed strike valley.

Portal Creek in sections 19 and 30, T. 12 S., R. 1 W. in the Gravelly Range is not a permanent stream during most of the year. Nevertheless, Portal Creek occupies a steep-walled canyon several hundred feet deep cut in the resistant Meagher limestone, (see figure 5). The present run-off seems incapable of eroding the canyon. It is suggested that in Pleistocene time a larger stream occupied the valley and part of the canyon cutting may be due to superimposition, aided by favorable jointing. The source of the stream may have been a large spring which since then has dried up or found a different orifice.

Dune topography. - In late Pleistocene or Recent times waters supplied by melting glaciers covered Centennial Valley. When the lakes receded, areas of unconsolidated silt were left exposed to wind action. The silt was soon whipped into dune areas, the largest of which makes that part of the valley now called the Sand Hills, located in T. 13 S., R. 2 W., (see figure 26). These dunes trend northeast to southwest and their individual shapes are slightly arcuate to the southeast, indicating that a wind from the northwest formed them. The dunes are from 10 to 35 feet high and may be several hundred feet long, and are mostly barchan type. The Sand Hills are about 4 square miles in area. Other smaller dune areas show the same characteristics. Beaches of the southeast side of the Sand Hills indicate that dune development in that direction was halted by water. Vegetation is still sparse on these dunes but it is not known if this condition has existed since their formation. Pre-dune drainage has been stopped or diverted by the dunes. A small stream in

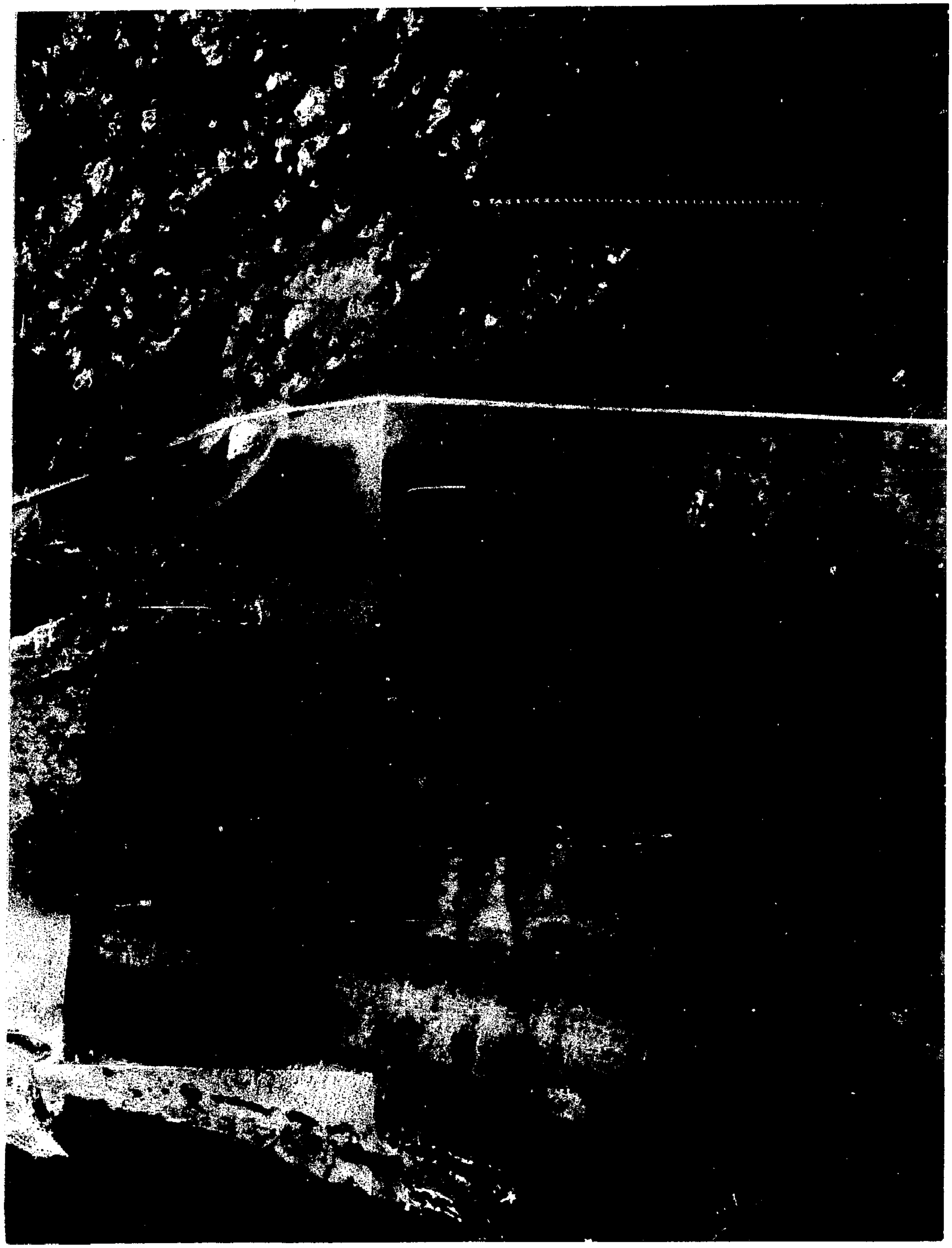

Figure 26. Sand dunes and beaches in Centennial Valley

In T. 13 S., R. 2 W. Present swampy margin of Red Rock River in lower left, beaches in lower half of picture, dunes in upper half. (Aerial photo by Agricultural Adjustment Agency) section 14, T. 13 S., R. 2 W., flows into a playa dammed by the dunes. Snowshoe Creek in section 18, T. 13 S., R. 1 W., is diverted by the dunes from its southeast direction into a due east direction.

It is believed that dune areas in the Centennial Valley have caused the sudden northward swing of the Red Rock River in section 1, T. 14 S., R. 3 W. The dunes dammed the river causing it to flow two miles to the north and then around the end of the dune area.

Beaches and shorelines. - Lakes have apparently existed in structural depression that is the Centennial Valley during parts of Tertiary and Quaternary time. Because of increased runoff in Pleistocene time, the lakes were more extensive than now. As the Pleistocene lakes in the Centennial Valley receded gradually to their present size many emerged beaches were left marking the retreat of the lakes (see figure 26). More and better developed beaches are present on the north side of the Red Rock Lakes, but beaches also are present on the south side where Kennedy (1948) has correlated some with Pleistocene glaciation. Critically measured elevations of the beaches on the north and south side of the lakes would offer valuable evidence for or against the southward tilting previously suggested in this report.

Of interest especially on the Upper Red Rock Lake is the configuration of the present northern shoreline as compared with the southern shoreline. If southward tilting is still occurring along the fault plane that probably marks the Centennial Range front, the north shore should be a shoreline of emergence and the south shore a shoreline of submergence. The present northern shoreline is exceptionally smooth and very gently arcuate, whereas the southern shoreline is relatively more irregular.

The contact between the Aspen formation and the Quaternary alluvium along the front of the Centennial Range is very sharp and may represent an evenly eroded shoreline. The contact, however, may also mark the position of the postulated normal fault along the front of the Centennial Range, (see figure 13).

## GEOLOGIC HISTORY

An outline of the depositional and orogenic history of the area is as follows;

1. Deposition of pre-Beltian sandstones and limestones; metamorphism and erosion.

2. Transgressive overlap by Middle Cambrian seas. Deposition of conglomerate, sandstone, limestone and dolomite in deepening seas. Slight uplift and deposition of shale.

3. Emergence and erosion during Ordovician and Silurian time. Possible deposition and subsequent erosion in Upper Silurian or Lower Devonian.

4. Submergence in Upper Devonian by seas in which dolomite was deposited. Seas later fluctuated with the resulting deposition of limestones and shales.

5. Continued reduction of borderlands, predominance of chemical sediments in Mississippian Madison basin.

6. Moderate uplifts of borderlands, causing alternation of sandstone, shale and limestone beds in Upper Mississippian,

Pennsylvanian and Permian formations in the Rocky Mountain geosyncline. Occasional extraordinary conditions of sedimentation resulting in chert and phosphate rock deposition. Local intervals of erosion recorded.

7. Continuing moderate fluctuating uplifts in borderlands to east and west in Lower Triassic. Alternating sandstone, limestone and shale deposition. Some constriction of seas into interior basins, perhaps some aridity.

8. Extensive erosion from Middle Triassic through Middle Jurassic, leaving an uneven surface. Submergence by seas in Upper Jurassic, with islands remaining emergent in earliest seas, accounting for uneven distribution of earlier Upper Jurassic sediments. Emergence and continental deposition of clays, silts and sands.

9. Orogenic (?) uplift of borderlands with nearer and perhaps more rugged western highlands furnishing more of the sediment for this region. Marine Lower Cretaceous sediments grade upward into nonmarine beds. Locally coarse sediments and interbedded volcanics indicate pre-Laramide orogenic movements had commenced. Continuing orogenic (?) movements through Cretaceous period.

10. Sharp initial Laramide uplift, folding, and faulting at close of Cretaceous or in Paleocene; deposition of unnamed conglomerate derived from these new mountains, and continued uplift.

11. Orogenic movements in lower Eocene with folding of unnamed conglomerate.

12. Renewed orogenic movements in middle Eocene with thrusting of unnamed conglomerate. Middle and upper Eocene erosion. Downwarping

causing broad intermontane valleys. Slight orogenic movements, deposition of some continental beds.

13. Erosion in lower Oligocene, gentle uplift, deposition of middle Oligocene clastics. Middle or upper Oligocene block faulting (?), delineating intermontane basins, erosion, deposition of pebble beds.

14. Continued block faulting (?) in lower Miocene, erosion, volcanism, extensive alluviation in Miocene, development of widespread erosion surface.

15. Extensive volcanism, alluviation in Pliocene creating a surface of little relief. Uplift at close of epoch, adjustment of drainage and canyon cutting.

16. Recurrent block faulting, tilting or warping, volcanism, glaciation, alluviation, pediment dissection and continued adjustment of drainage in Pleistocene.

17. Uplift (?) and alluviation in Recent times.

# ECONOMIC GEOLOGY

## General features

The natural resources of the region include the mineral resources, water, timber, wild hay and other natural forage, and scenery. The Centennial Valley is well watered by the Red Rock River and its tributaries, Odell Creek, Long Creek and many others. Wild hay is abundant in the valley and it is used for summer grazing or harvested for winter cattle feed, (see figure 2). The tributaries that rise in the mountains water the higher surrounding areas, and support abundant forage for bands of sheep that are herded into the mountains every summer. Many springs issue from the dipping sandstones or porous lavas and replenish the tributaries. Timber, mainly lodge-pole pine, grows on most of the mountain spurs, valleys and basins. Certain formations favor growth of timber. The Woodside formation in the Centennial Range supports a very thick timber stand in otherwise grassy terrain. The basin of Blacktail Creek in the Snowcrest Range, underlain by Upper Cretaceous beds and the Cretaceous or Tertiary unnamed conglomerate is heavily timbered. The lava capped hills of the Gravelly Range invariably support stands of timber, which is cut by the local ranchers and used for corral poles and fence posts.

## Mineral resources

General statement. - Placer gold and coal have been mined from the Centennial Region; copper has been reported from it; phosphate rock is present but not mined; and oil may be a potential resource.

__Gold__. - Placer gold has been recovered in small amounts from the gravels in the valley of the West Fork of the Madison River in sections 14, 23, and 24, T. 12 S., R. 3 W., and section 30, T. 12 S., R. 2 W. Mining has been by dry-land dredge or by hand sluicing, (see figure 11). The __Minerals Yearbook for 1937__ (p. 420) lists production for 1936 as 4.63 fine ounces, valued at $162, and for 1941 (p. 370), 28 fine ounces of gold, valued at $980. Records are not available for every year but production apparently has been small. Other streams in the Centennial Valley region in which placer gold has been discovered include the north-flowing streams from the crest of the Centennial Range and Ruby River and its tributaries (Dingman, 1932, pp. 20, 25).

__Coal__. - Lignitic coal occurs in the Aspen formation of Upper Cretaceous age. Coal has been locally mined on Coal Creek in the Ruby River basin though not mined within the Centennial Region. Coal Creek enters and leaves the Centennial Region in sections 1, 2, 3, T. 12 S., R. 3 W. Coal has also been mined in Clark County, Idaho, a few hundred feet south of the Continental Divide in section 12, T. 14 N., R. 38 E., where the old Scott and Bucy mine is located. A road leads up Cottonwood Creek from the south side of the range to the mine where are located the mine camp, dump piles and a slightly northward dipping adit. When examined by the author the adit contained water and it was deemed unwise to try to investigate the coal bed in the mine. The small dump indicated not very much coal had been mined. The coal on the cump was very soft, of low grade, and in layers from a quarter of an inch to an inch thick. Pelecypods were found in the interbedded shales and these were tentatively identified as Corbula subtrigonalis of Upper Cretaceous (Aspen) age, (see figure 10, locality 8). Mansfield (1920, pp. 147-152) investigated the mine and found the coal to be of sub-bituminous rank or low-rank bituminous. Of the coal bed he said (1920, p. 124).

> "On the Continental Divide in T. 14 N., R. 38 E., a 32 inch bed of good coal was found, but the area in which it crops out is not large and its remoteness from lines of transportation and a suitable market make its early exploitation doubtful."

Phosphate. - In southwestern Montana the thickness of the phosphate-rock beds in the Phosphoria formation generally varies from 5 to 20 feet, and of this thickness up to 5 feet may be high grade phosphate rock.[9] In Idaho where extensive strip mining is done upwards to 180 feet of phosphatic shale may be present, but much of it is low grade. Montana produced 176,944 long tons of phosphate rock valued at the mine at $1,207,054. (Minerals Yearbook, 1946, p. 997).

Phosphate rock is present in the Phosphoria formation in all three ranges of the Centennial Region. Two beds of soft oölitic phosphate rock, each about 3 feet thick, and separated by about 100 feet of chert

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[9] Newton and Finkelnburg (1947, p. 5) define high-grade phosphate rock as

> ". . . By high-grade we shall mean the commercial high-grade rock that is suitable for direct acidulation. . . . Most of the phosphate rock mined is converted into superphosphate fertilizer by acidulation with sulfuric acid, and for this purpose a minimum of 31.4 percent $P_2O_5$ is desired. In many discussions, phosphate concentrations are given as percent of bone phosphate of lime (BPL) which is tricalcium phosphate, $Ca_3(PO_4)_2$. Values of $P_2O_5$ content can be converted to percent BPL by multiplying by the factor 2.18, thus 31 percent $P_2O_5$ is equivalent to 69 percent BPL."

and limestone are present in the Snowcrest Range. One bed of phosphate rock about 1 foot thick crops out in the Gravelly Range, but more may be present. Two beds of phosphate rock are present in the Centennial Range, a lower hard pisolitic phosphate rock bed about 5 feet thick, and an upper soft oölitic bed about 3 feet thick, separated by about 100 feet of chert and limestone. Some of these occurrences may be of commercial importance. The deciding factors are grade of the phosphate rock, accessibility of terrain, thickness of phosphate rock zone, areal extent of zone and amount and character of the overburden.

<u>Oil</u>. - Oil is a potential economic resource of the region. Extensive leasing and exploration campaigns have been conducted in 1947 and 1948 by several companies in the west half of the Centennial Valley area and adjacent areas. Counterbalancing the prejudice of oil men against a thick section of continental sediments are many favorable indications.

There are several definite anticlines in the vicinity. The Lima and Clover Creek anticlines which are west of the Centennial Region have closure in the Upper Cretaceous. The Metzel Creek anticline has closure in the Mississippian. The Peet Creek anticlinorium is a major fold in the Aspen formation and may be present in the older rocks below. This fold also may be a southward extension of the Clover Creek trend. Data presented by Kirkham (1928, p. 4) indicate that the folding represented by the Peet Creek Anticlinorium affects the Aspen formation to the south into Idaho. Other surface indicators include mud volcanoes formed by gas seeps in section 35, T. 12 S., R. 3 W., and in section 7, T. 12 S., R. 2 W. Unfortunately the chemical nature of the gas is not known. The Paleozoic limestones in the Centennial Region all have a highly petroliferous odor. Figure 28 is a structure contour map with contours drawn on the base of the Aspen formation and Lodgepole limestone. The area of the structure contour map is extended westward in order to present a clearer picture.

The extensive Jurassic erosion surface has made stratigraphic traps possible throughout the region. A post-Aspen, pre-unnamed conglomerate unconformity offers other stratigraphic trap possibilities. The regional stratigraphy is generally available for study at the surface. Thicknesses are fairly constant except in the Triassic, Jurassic and the Upper Cretaceous or Tertiary unnamed conglomerate.

## CONCLUSIONS

Some of the more significant conclusions set forth in this report are as follows:

1. The stratigraphy of the Centennial Region includes rocks ranging from Precambrian to Recent in age. Twenty formations of Paleozoic, and Mesozoic and Cenozoic rocks are present totaling approximately 12,560 feet in thickness, in addition to Precambrian metamorphics, Tertiary volcanics and basin beds (?) and Quaternary alluvium.

2. Pennsylvanian, Permian and Triassic strata thin eastward in the direction of the shelf zone of the Cordilleran geosyncline.

3. An unnamed conglomerate of latest Cretaceous or Paleocene age may correlate with other conglomerates as the Sphinx and Pinyon conglomerates in Montana and Wyoming. The unnamed conglomerate was

probably derived from mountains to the west.

4. Five types of volcanic rocks are present in the Centennial Region. The rocks are probably of Pliocene age.

5. High level gravels are a residuum of conglomerate that once covered the Centennial Region. A so-called "Eocene skyline moraine" on the Gravelly Range crest is composed of high-level gravels.

6. Laramide and post-laramide structures are present in the Centennial Region. Laramide structures include folds and faults, and post-Laramide structures are mainly block faults.

7. Movement along a normal fault bounding the south side of the Centennial Valley caused uptilting of the Centennial Range and down-tilting of the Centennial Valley. The tilting occurred in late Pliocene or Pleistocene time.

8. Volcanism, uplift, downwarp, tilting and superimposition have caused many stream adjustments in Tertiary and Quaternary time.

9. Four surfaces of erosion or deposition are present in the Centennial Region.

10. Phosphate rock and oil offer the best possibilities for future mineral exploitation.

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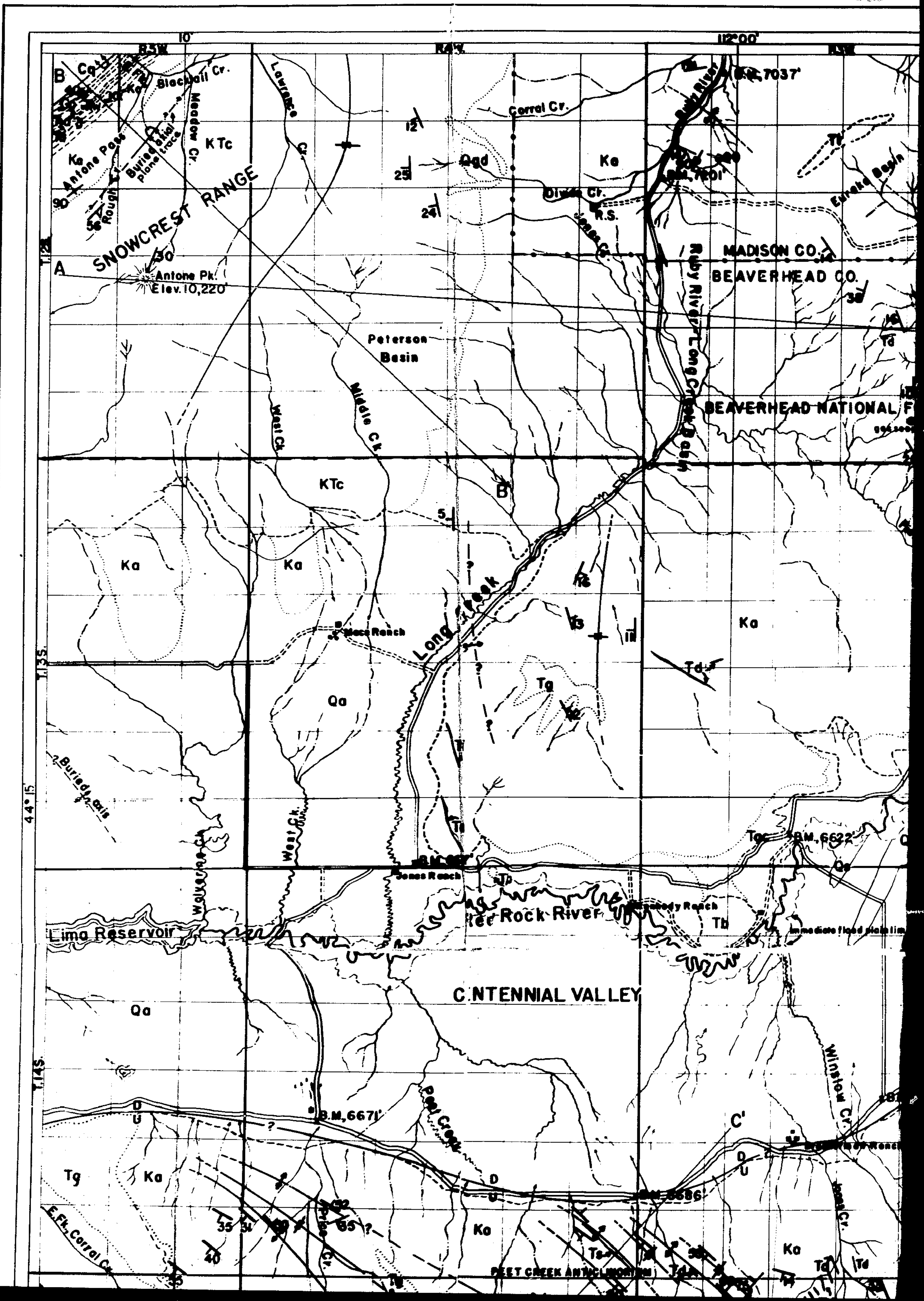
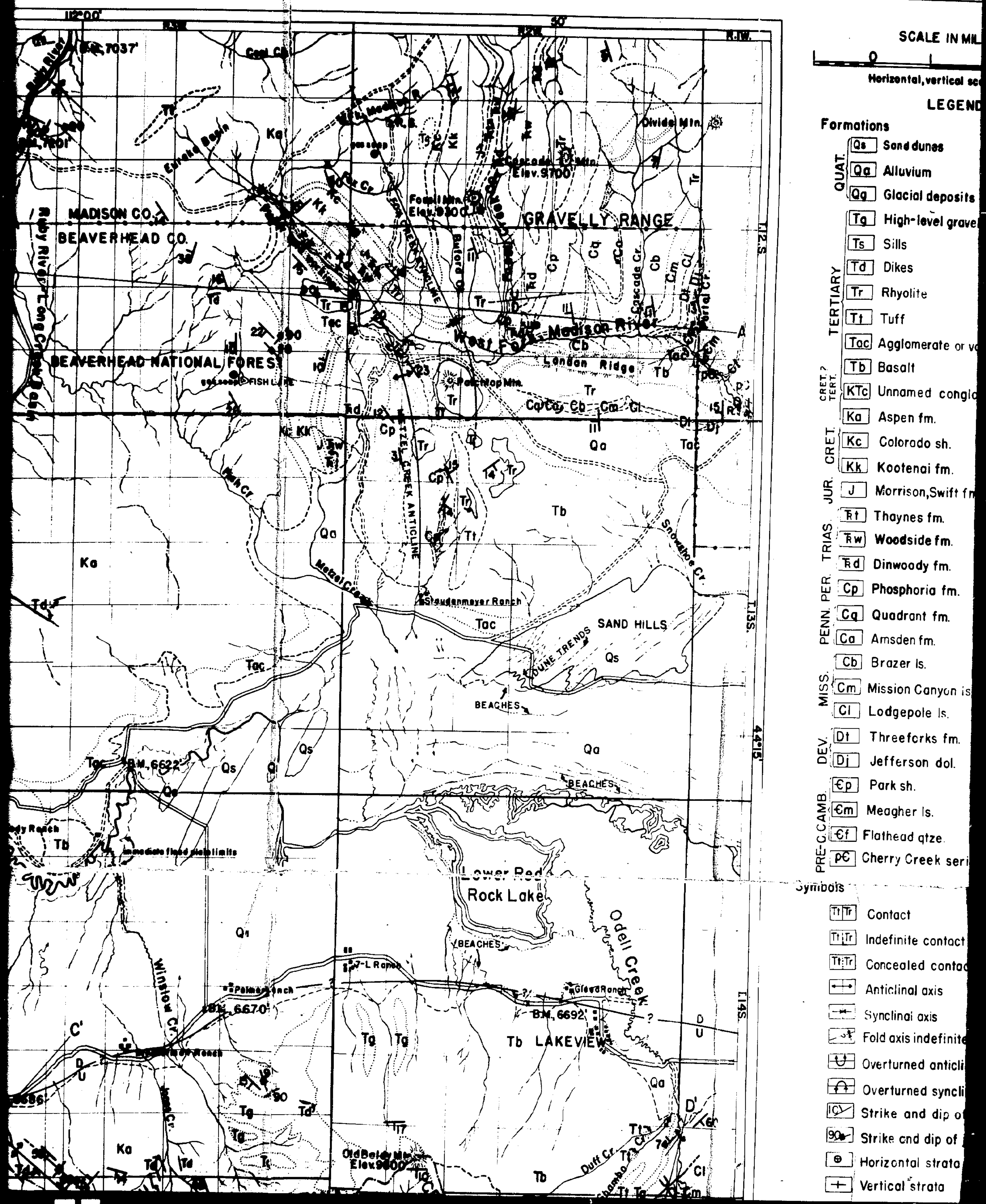
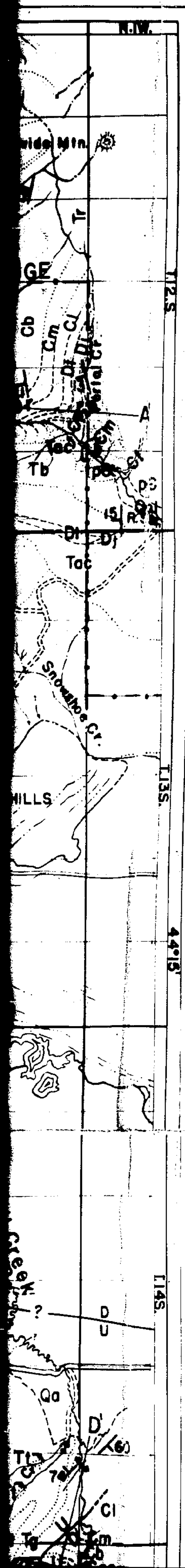

R.3W.
R.4W.
R.3W.
10'
112°00'
SNOWCREST RANGE
Antone Pass
Antone Pk.
Elev. 10,220'
Blackball Cr.
Meadow Cr.
Buried axial plane trace
Rough Cr.
Lawrence Cr.
Corral Cr.
Divide Cr.
R.S.
Ruby River
B.M. 7037'
B.M. 7201'
Eureka Basin
MADISON CO.
BEAVERHEAD CO.
Peterson Basin
Ruby River - Long Creek Basin
BEAVERHEAD NATIONAL F
West Ck.
Middle Ck.
Long Creek
Mace Ranch
Jones Ranch
Kennedy Ranch
Lima Reservoir
Wolverine Ck.
Buried axis
Rock River
Immediate flood plain lim
CENTENNIAL VALLEY
Winslow Cr.
Peet Creek
Price Cr.
E. Fk. Corral Ck.
B.M. 6622'
B.M. 6671'
B.M. 6686
PEET CREEK ANTICLINORIUM
T.13S.
T.14S.
44°15'
A
B
B'
C'
D
U
KTc
Ka
Ke
Qa
Qad
Tg
Td
Tb
Tac
Ts



SCALE IN MIL
Horizontal, vertical sc
LEGEND
Formations
QUAT.
Qs Sand dunes
Qa Alluvium
Qg Glacial deposits
TERTIARY
Tg High-level gravel
Ts Sills
Td Dikes
Tr Rhyolite
Tt Tuff
Tac Agglomerate or vo
Tb Basalt
CRET.? TERT.
KTc Unnamed conglo
CRET.
Ka Aspen fm.
Kc Colorado sh.
Kk Kootenai fm.
JUR.
J Morrison, Swift fm
TRIAS.
Ŧt Thaynes fm.
Ŧw Woodside fm.
Ŧd Dinwoody fm.
PENN. PER.
Cp Phosphoria fm.
Cq Quadrant fm.
Ca Amsden fm.
MISS.
Cb Brazer ls.
Cm Mission Canyon ls
Cl Lodgepole ls.
DEV.
Dt Threeforks fm.
Dj Jefferson dol.
CAMB.
Єp Park sh.
Єm Meagher ls.
Єf Flathead qtze.
PRE-C.
pЄ Cherry Creek seri
Symbols
Contact
Indefinite contact
Concealed contac
Anticlinal axis
Synclinal axis
Fold axis indefinite
Overturned anticli
Overturned syncli
Strike and dip o
Strike and dip of
Horizontal strata
Vertical strata
112°00'
50'
R.3W.
R.2W.
R.1W.
T.12S.
T.13S.
T.14S.
44°15'
MADISON CO.
BEAVERHEAD CO.
BEAVERHEAD NATIONAL FOREST
GRAVELLY RANGE
Divide Mtn.
Cascade Mtn. Elev. 9700'
Fossil Mtn. Elev. 9300'
Eureka Basin
Coal Cr.
West Fork Madison River
London Ridge
Baldy Mtn.
FISH LAKE
Fish Cr.
METZEL CREEK ANTICLINE
Metzel Creek
Staudenmeyer Ranch
SAND HILLS
DUNE TRENDS
BEACHES
Snowshoe Cr.
B.M. 6622'
immediate flood plain limits
Lower Red Rock Lake
Odell Creek
J-L Ranch
Palmer Ranch
Gleed Ranch
B.M. 6670'
B.M. 6692'
LAKEVIEW
Winslow Cr.
Old Baldy Mtn. Elev. 9600'
Duff Cr.




SCALE IN MILES

0 1 2 3 4

Horizontal, vertical scales are same.

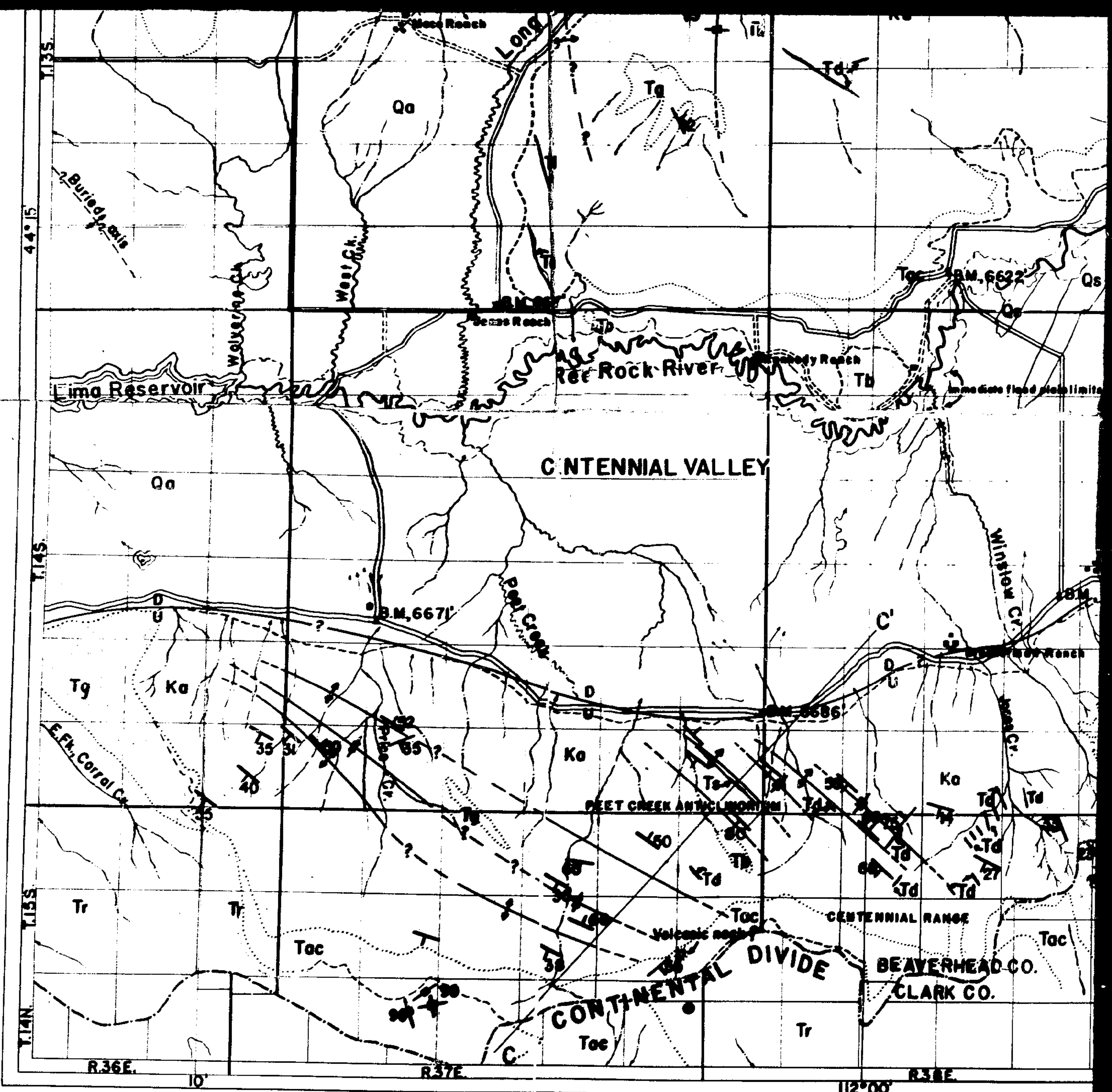
## LEGEND

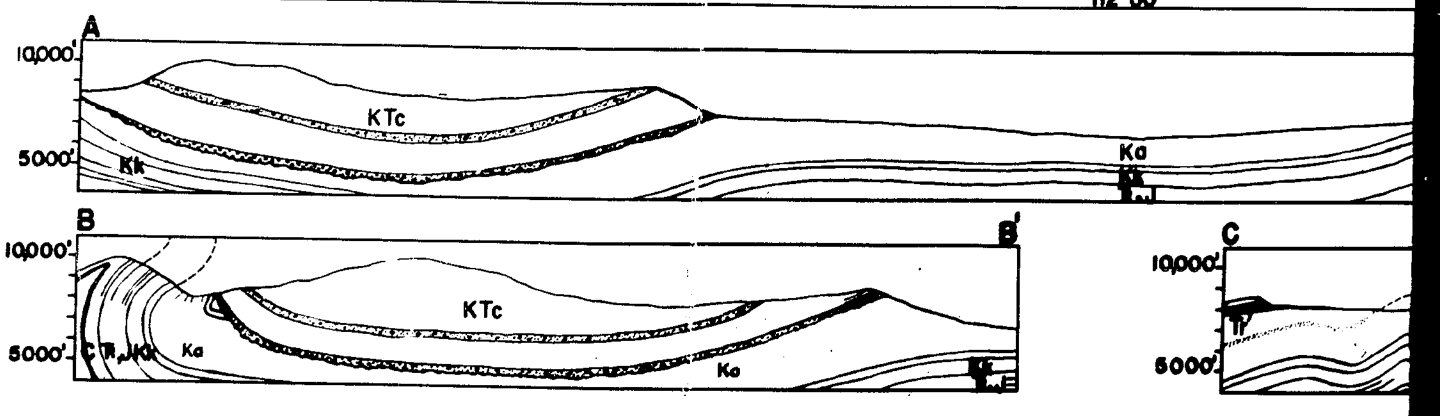
**Formations**

| | | |
|---|---|---|
| QUAT. | Qs | Sand dunes |
| | Qa | Alluvium |
| | Qg | Glacial deposits |
| TERTIARY | Tg | High-level gravels |
| | Ts | Sills |
| | Td | Dikes |
| | Tr | Rhyolite |
| | Tt | Tuff |
| | Tac | Agglomerate or vol. conglomerate |
| | Tb | Basalt |
| CRET.? TERT. | KTc | Unnamed conglomerate |
| CRET. | Ka | Aspen fm. |
| | Kc | Colorado sh. |
| | Kk | Kootenai fm. |
| JUR. | J | Morrison, Swift fms. |
| TRIAS. | Ꞓt | Thaynes fm. |
| | Ꞓw | Woodside fm. |
| | Ꞓd | Dinwoody fm. |
| PER. | Cp | Phosphoria fm. |
| PENN. | Cq | Quadrant fm. |
| | Ca | Amsden fm. |
| MISS. | Cb | Brazer ls. |
| | Cm | Mission Canyon ls. |
| | Cl | Lodgepole ls. |
| DEV. | Dt | Threeforks fm. |
| | Dj | Jefferson dol. |
| CAMB. | €p | Park sh. |
| | €m | Meagher ls. |
| | €f | Flathead qtze. |
| PRE-C. | p€ | Cherry Creek series |

**Symbols**

| | |
|---|---|
| Tt Tr | Contact |
| Tt Tr | Indefinite contact |
| Tt Tr | Concealed contact |
| | Anticlinal axis |
| | Synclinal axis |
| | Fold axis indefinite or buried |
| | Overturned anticline |
| | Overturned syncline |
| 10 | Strike and dip of strata |
| 90 | Strike and dip of joints |
| | Horizontal strata |
| | Vertical strata |
| U D | Fault; U=upthrown side, D=downthrown side |




**Geologic Structure Sections**

Fi

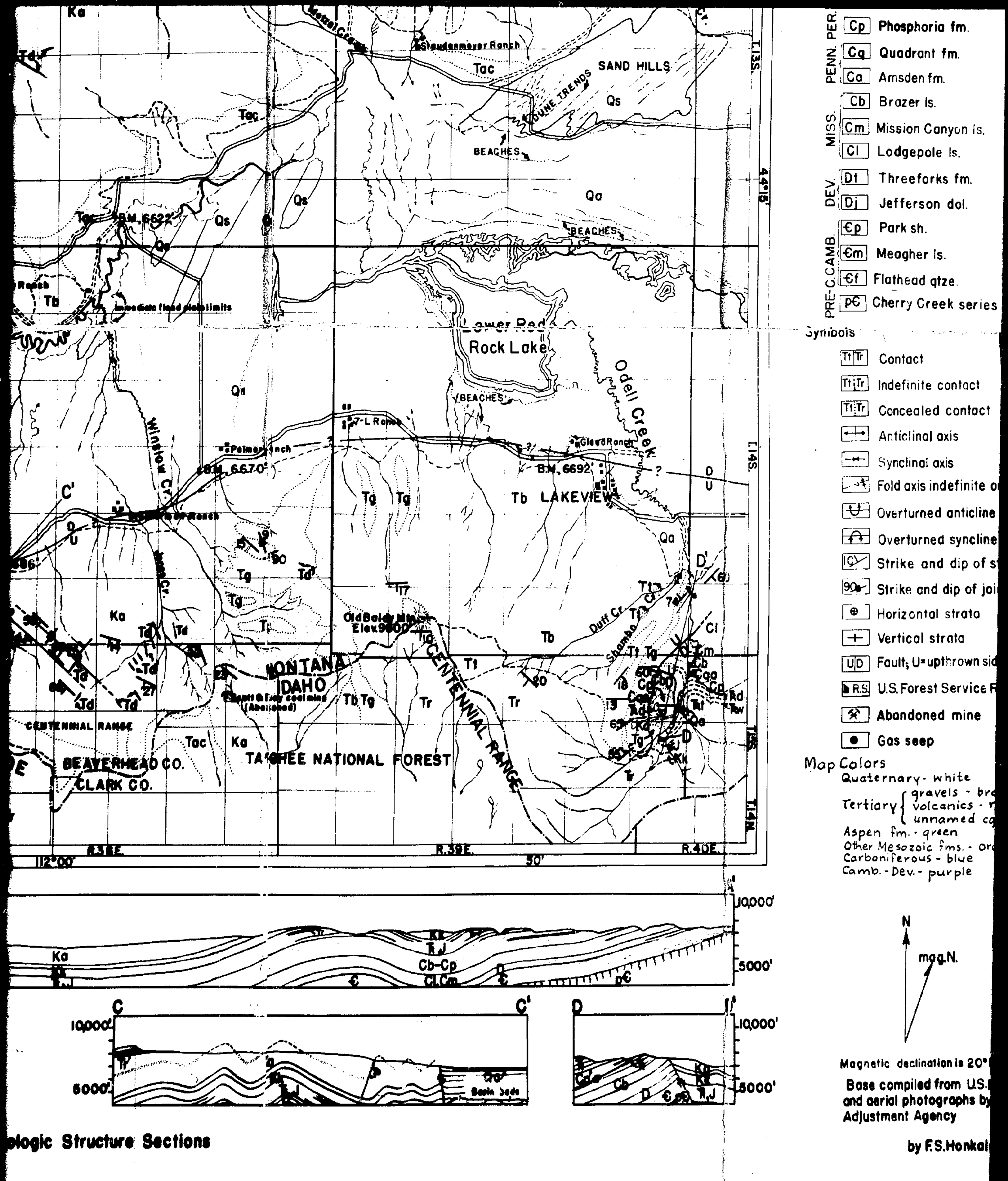
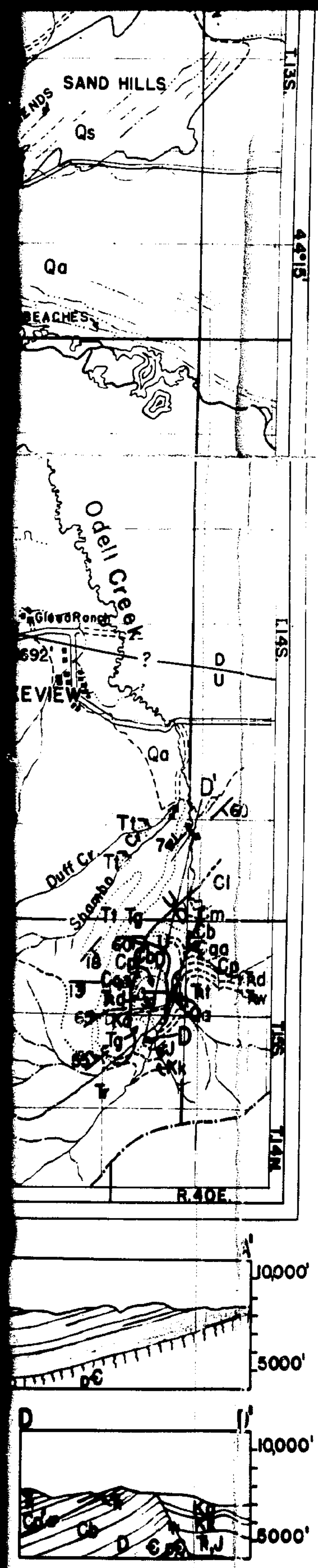



**Figure 27 Geologic map of Centennial Region.**




PENN. PER.
- Cp Phosphoria fm.
- Cq Quadrant fm.
- Ca Amsden fm.

MISS.
- Cb Brazer ls.
- Cm Mission Canyon ls.
- Cl Lodgepole ls.

DEV.
- Dt Threeforks fm.
- Dj Jefferson dol.

CAMB.
- €p Park sh.
- €m Meagher ls.
- €f Flathead qtze.

PRE-C.
- p€ Cherry Creek series

Symbols

- Contact
- Indefinite contact
- Concealed contact
- Anticlinal axis
- Synclinal axis
- Fold axis indefinite or buried
- Overturned anticline
- Overturned syncline
- Strike and dip of strata
- Strike and dip of joints
- Horizontal strata
- Vertical strata
- Fault; U=upthrown side, D=downthrown side
- U.S. Forest Service Ranger Station
- Abandoned mine
- Gas seep

Map Colors

Quaternary - white
Tertiary { gravels - brown; volcanics - red; unnamed cgl. - yellow }
Aspen fm. - green
Other Mesozoic fms. - orange
Carboniferous - blue
Camb.-Dev. - purple

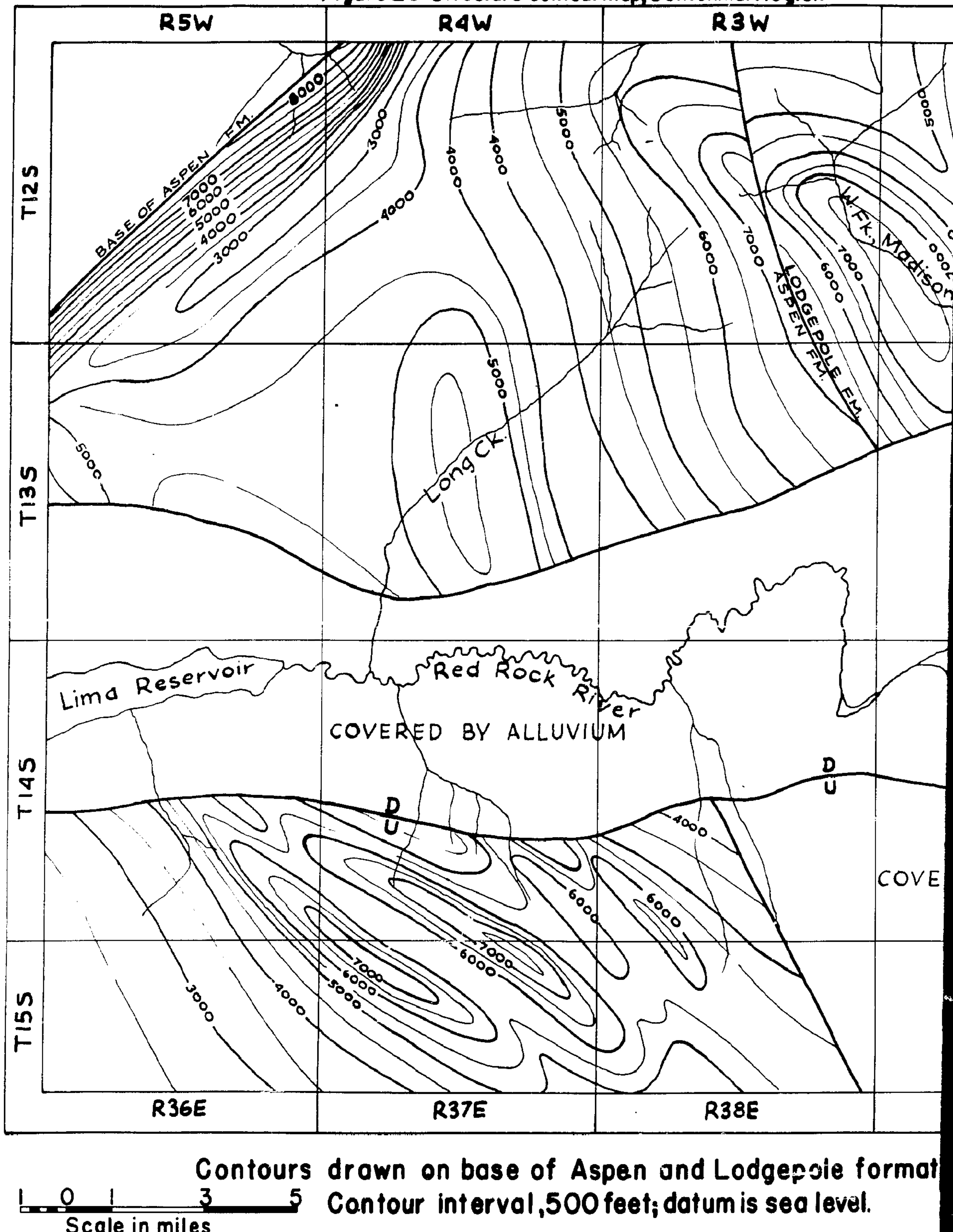
N
mag.N.

Magnetic declination is 20°E

Base compiled from U.S. Forest Service maps and aerial photographs by Agricultural Adjustment Agency

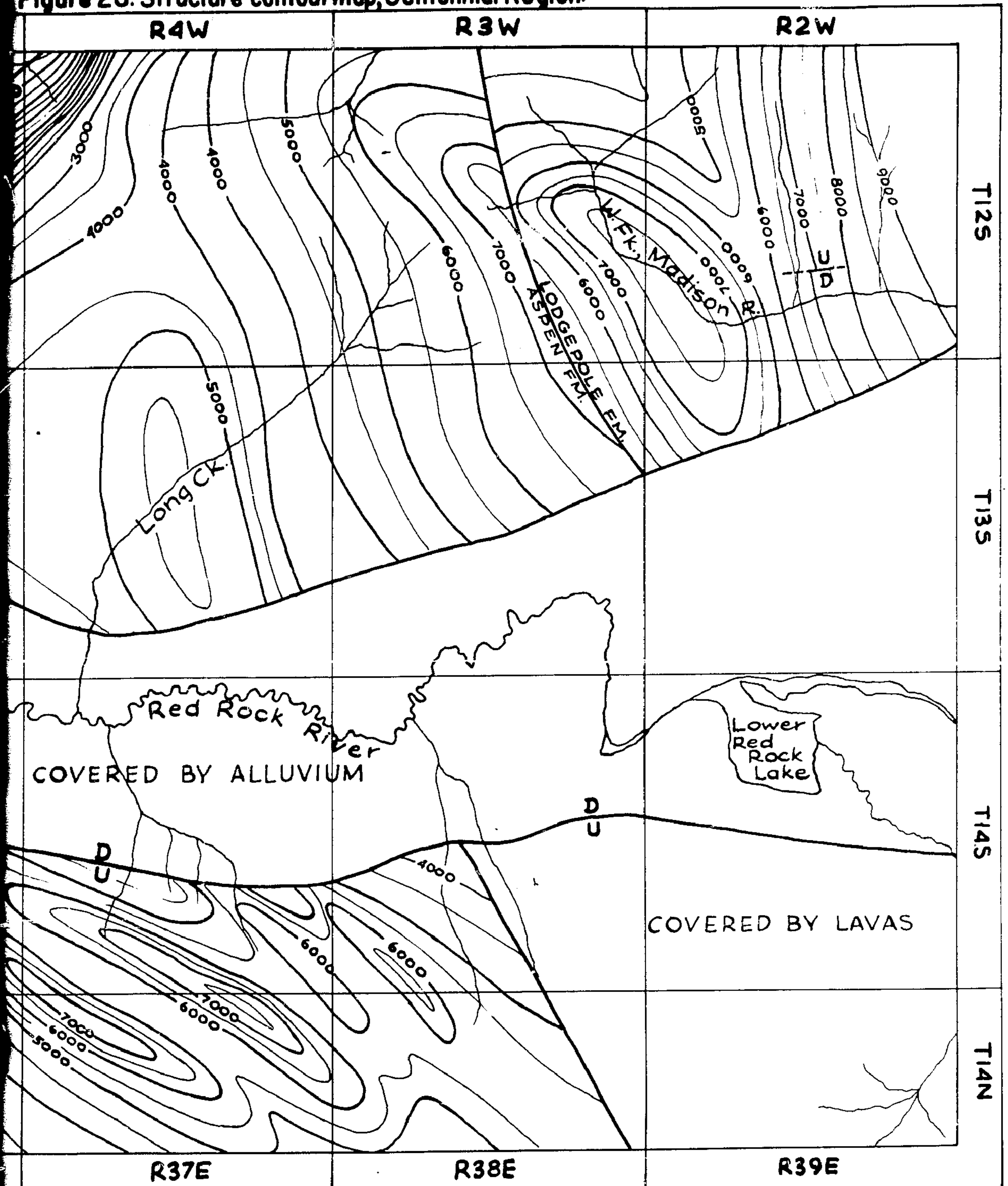
by F.S. Honkala

Figure 28. Structure contourmap, Centennial Region.




Contours drawn on base of Aspen and Lodgepole format
Contour interval, 500 feet; datum is sea level.

Figure 28. Structure contour map, Centennial Region.




s drawn on base of Aspen and Lodgepole formations.
Contour interval, 500 feet; datum is sea level.

N mag. N
Declination is 20° E.