GEOLOGY OF
PART OF THE BEAVERHEAD MOUNTAINS AND NICHOLIA CREEK BASIN

BEAVERHEAD COUNTY, MONTANA

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Submitted in partial fulfillment of the requirements for the degree of Master of Arts in Geology, University of Michigan, 1948.

It is scarcely necessary to state that many of the problems which arose in the course of the study remain unsolved, or but partly solved, for such is the nature of most complex questions

(Blackwelder)

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ILLUSTRATIONS

ABSTRACT

The part of the Beaverhead Mountains investigated is in the extreme southwest corner of Montana,and includes Nicholia Creek Basin, an intermontane basin east of the mountains and parallel with them. The oldest rocks in the area are a crystalline complex of pre-Cambrian age. Paleozoic formations include the Cambrian Flathead (?) quartzite,the Ordovician Kinnikinic quartzite, the Devonian Threeforks, and the Mississippian Madison limestone. Tertiary sedimentary beds occur in the basin and volcanic rocks form the foothills. No Mesozoic rocks are present. An intrusive mass of granitic composition forms the backbone of the mountains in the center of the area. Laramide structures are folds, faults, and one major thrust-fault, here called the Beaverhead thrust. During mid-Tertiary time the area was affected by high-angle faulting. During Pleistocene time glaciers developed in the mountains and spread moraines and outwash in the basin. Dissection resulted in terraces which are now a prominent part of the valley.

INTRODUCTION

Location of area

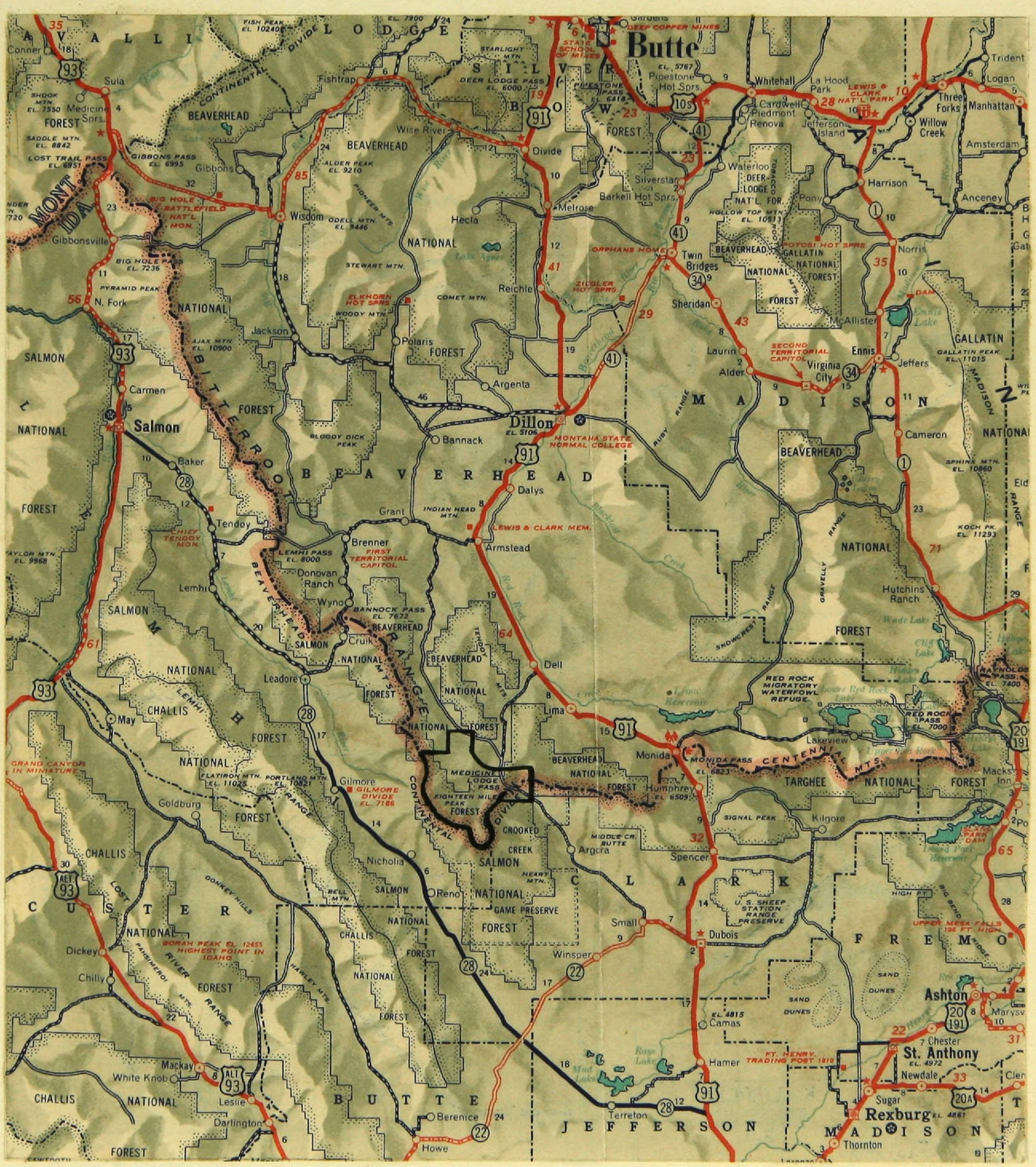
The area shown on the map (pl. 1) is in Beaverhead County in the extreme southwest corner of Montana. It lies in a quadrangle bounded by parallels ~~41° 30'~~ 44° 25' and ~~48° 30'~~ 44° 50' N. latitude and meridians 112° 42' and 113° 3' W. longitude. Large parts of it lie within the boundaries of the Beaverhead National Forest. It comprises approximately 160 square miles and is bounded on the west and south by the Montana - Idaho borderline, which is here coincident with the Continental Divide. To the east the boundary is less well defined geographically, but in general follows the ridge which lies along the east-side of Nicholia Creek basin. The north boundary is an arbitrary east - west line approximately along 41° 30' N. latitude. The area comprises completely or partly the following townships in Montana: Townships 14, 15, 16, 17 S., Ranges 9, 10, 11, 12 W. A small part of it is in Idaho: part of Townships 13, 14 N., Ranges 31, 32 E. Of this area the southeastern part has been mapped by Mr. Robert Scholten, the northwestern part by the writer, as indicated on the diagram (pl. 1). Nicholia Creek has been taken as the dividing line between the two areas. Unless otherwise indicated this report deals only with the part mapped by the author.

Accessibility

Nicholia School, which is approximately the geographical center of the area, can be reached by car along a gravelled and graded motor-road which branches from U.S. highway 91 about 1½ miles south of Dell and follows Big Sheep Creek. Plate 3 shows only the first part of this road. Beyond Nicholia School the road is not graded but is passable by car to a point 1 mile south of Tendoy Creek (also called Trail Creek). From here on a trail follows Nicholia Creek to the end of the valley. In the central and northern part of the area, several good roads connect the different ranches in the basin. The main road follows Cabin Creek to the north. The western part in general can be reached by car along east - west roads which end where the mountains begin. From there on only trails follow the main creeks. No road crosses the Continental Divide within the area of this report.

Available geographic maps,without contourlines, are:

1. Forest Service of the U.S. Department of Agriculture. Map of Beaverhead National Forest, 1940, scale ½ inch to the mile or ¼ inch to the mile. Best map available.
2. General Highway and Transportation Map,Beaverhead County, Montana. Prepared by the Montana State Highway Commission, 1936, revised 1943 and 1945. Scale ½ inch to the mile.



<u>Plate 3.</u> Index map. (Part of "Map of the Montana State Highway System" issued by Montana State Highway Commission, Helena, Montana, 1947)

Topography

Types. Three topographically different sections can be recognized: the Nicholia Creek basin, the East Ridge and the Beaverhead Mountains.

Nicholia Creek basin. The central and northern part of the area is in a broad gravel-covered valley, called Nicholia Creek basin, which has a maximum local relief of about 100 feet. The average elevation of the basin is approximately 7500 feet, the average width 7 miles. It has a northwesterly trend.

The East Ridge. To the east the basin is paralleled by a ridge of older, harder rocks which rises sharply from the valley floor to an elevation of about 8500 feet.

The Beaverhead Mountains. The Beaverhead Mountains are west of the basin. The name has been given by Umpleby (1913 I, p.23) to about 100 miles of the Continental Divide from Lost Trail Pass to Monida Pass, through which the Oregon Short Line runs (pl. 3).
North of the Lost Trail Pass the range splits, and according to Umpleby the eastern part continues as the Continental Divide and the western as the Bitterroot Mountains. According to the Montana State Highway Map the name Bitterroot Range applies also to the mountains south of the Lost Trail Pass and extends to the southwest corner

of Montana. In this nomenclature the Beaverhead Mountains would be the southern part of the Bitterroot Range. In the area investigated the Beaverhead Mountains rise to elevations well over 10,000 feet (Eighteenmile Peak). The summit consists in most places of low, rolling hills, except at the heads of the various creeks where glaciers have carved precipitous walls and a sharp divide. In the front of the range foothills of low relief are found (pl. 4).

Drainage. The drainage belongs to the headwaters of the Missouri. All creeks drain into Big Sheep Creek which is the eastward extension of Nicholia Creek. In the mountainous part many springs and closely spaced permanent and intermittent streams are found. These unite at the foot of the mountains and only Nicholia Creek, Meadow Creek,Alkali Creek, Tex Creek, Simpson Creek,all running in a west - east direction, and Cabin Creek which runs north - south, cross the basin. The mountainous part of the major creeks is in U-shaped valleys, with steep walls rising about 1,000 feet above the valley floor (pl.2) and terminated by cirques. At several places lakes are found in the cirques or in the morainic material at the end of the valleys.

Regional features. West of the area investigated two other parallel ranges of the same general topographic

Plate 4. Nicholia Creek basin and Beaverhead Mountains. Continental Divide forms the skyline. Highest peak is Eighteenmile Peak. Mountains consist of granite. Foothills are Tertiary volcanic rocks and hummocks of glacial material. Two different terraces in the basin. Photo taken from ridge of Basin beds south of Nicholia creek.

character are found: the Lemhi Range and the Lost River Range, both in Idaho. These also trend in a northwesterly direction, and broad flat-floored basins are found in between the three ranges. The Beaverhead Mountains, as well as the other two ranges, plunge toward the south under the lavas of the Snake River Plain (Kirkham, 1927, p. 6 - 9).

Climate and vegetation

<u>Climate.</u> The nearest substation of the U.S. Weather Bureau is located at Lima (elevation 6,265 feet). The following data refer to this station and have been taken from "Climate of the States, Montana", Agricultural Yearbook, Separate no. 1844, Washington 1941.

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

Annual average precipitation 9.27 inches.

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

The data represent a continental climate of the arid type. Although no data are available for the Nicholia Creek basin, the precipitation will be about the same as in the wide valley in which Lima is. The vegetation in the mountainous part is, however, an indication that the precipitation is higher here than in the adjacent basin. The prevailing winds are westerly and much of the moisture will precipitate in the Beaverhead Mountains before reaching the basin. In winter snow accumulates to considerable depth in the mountains and provides water for the creeks in the summertime. Freezing temperatures and snowfall may occur late in May, or even early in June, and as early as September in the fall. In the summer nights are cool in the mountains. Strong winds occur in the afternoon, but usually disappear at sunset. Thunderstorms and light showers are frequent.

Flora. Vegetation in the basin and the foothills is quite different from that in the mountains.
In the basin sagebrush (Artemisia tridentata) is abundant together with grasses. Occasionally a cactus can be found. Along the channels in the basin swampy meadows occur and willows and other shrubs grow close to the water. The lower parts of the basin are used for the production of wild hay and the grazing of cattle.
The mountains support a usually sparse, occasionally dense, evergreen forest with Douglas fir, mountain mahogany, and lodgepole pines. Grasses are sufficient to the highest altitudes to provide grazing for sheep. The rugged parts of the divide, at the head of the cirques, are without any vegetation, as are the numerous talus-slopes.

Fauna. The basin itself is almost devoid of any wildlife. In the foothills herds of antelope are present. Also the coyotes live here. In the mountains deer, moose, bear and smaller animals like badger and porcupine can be seen. The creeks provide good fishing, because of numerous trout. Beavers have dammed the streams in some places.

Previous work

Little work has been done in the area or in adjacent regions. During the summer of 1946 E.S. Perry and U.M. Sahinen made a reconnaissance map of southwestern Montana, in which the Nicholia Creek area is included. Photostatic copies were made of this map, but it was not published (Perry and Sahinen, 1946). Reports dealing with adjacent regions are listed in the bibliography.

Field work

Field work was done from July 15 until August 23, 1947, and represents a start on the decipherment of the geologic history of the area. Mapping was done on aerial photos at a scale approximately of 1 : 20,000. The report is written as a Master's thesis at the University of Michigan.

Acknowledgments

The fieldwork, the preparation of the accompanying

geologic map, and the writing of the report have been done under supervision of Dr. A.J. Eardley, Professor of Geology at the University of Michigan. Much help was received from Dr. Clyde P. Ross, of the U.S. Geological Survey, who accompanied the writer and his associate on several fieldtrips. Dr. E.W. Heinrich was kind enough to check the petrographic descriptions of the thin-sections, and Dr. E.C. Stumm identified some fossils. Both are connected with the University of Michigan. Mr. M.V. Denny, also from the University of Michigan, aided in preparing the photographs. Mr. Robert Scholten, graduate student at the University of Michigan, mapped an adjacent part of Montana and Idaho. His mapping and the writer's were combined on one geologic map, which accompanies this report.

STRATIGRAPHY

Regional features and the stratigraphic column

In the Beaverhead Mountains, as well as in the Lemhi Range (Ross, 1947, p. 1095) no Mesozoic rocks are exposed. According to Ross (1947, p. 1126) the western border of present exposures of Mesozoic rocks extends from near the southeast corner of Idaho northwestward to the southeastern part of the Beaverhead Mountains and from there into Montana, approximately along 113° W. longitude. This borderline lies just outside the area investigated. But already a few miles more to the east in the areas mapped by Wallace, Krusekopf, Lipp, and Becker (1948) outcrops of Mesozoic rocks are found. The thickness of Paleozoic rocks increases to the west, that of Mesozoic rocks to the east, according to Ross (1947, p.1126). In the area mapped by the writer, Paleozoic, Tertiary, and Quaternary sedimentary beds are exposed. The assignment of these strata to different formations involves considerable speculation. The general sequence of the Paleozoic rocks in this part of the country has never been worked out and much confusion exists for example about the position of the different limestones and the fossils they contain.

Tabel 1 shows the stratigraphic column of the area. The thicknesses given are more or less approximations.

Several factors made accurate determinations impossible. In the first place the writer, as well as his associate, were unfamiliar with the region and had to search for sections that were suitable to measure. Intense folding, faulting, thrusting, erosion, and a cover of vegetation and younger deposits make most of the sections unfit for measurement.

Cambrian system

Flathead (?) quartzite. The name of this quartzite was given by A.C. Peale (1893, p. 20 - 21) for exposures in Flathead Pass in the northeast corner of the Three Forks Quadrangle, Montana. They were originally described by him as Lower Cambrian, but are now considered to belong to the Middle Cambrian.

The best exposure of Cambrian quartzite in the area investigated can be found in Trail Creek Canyon and along the west side of Nicholia Creek Canyon. Here an anticlinal fold brings these oldest sedimentary rocks to the surface. They appear again in the northwest part of the area along Tex Creek. A third exposure is found in the extreme northern part, where the Cambrian rocks come through the Quaternary terrace gravels at Island Butte.

The quartzite has a reddish chocolate - brown to maroon color. It is commonly well -bedded and in places cross - bedded. The bedding is due to thin dark - red, nearly black bands between layers of brown.

A few conglomeratic beds were noted which have the same red - brown color as the quartzite and which show stretched pebbles. The quartzite is massive, but generally highly fractured. It forms high precipitous cliffs, as for instance along the mountainous part of Trail Creek with extensive talus - slopes at the foot of the cliff. Study of a thin-section of this quartzite revealed much feldspar in addition to the quartz-grains. The feldspar is mostly microcline, much weathered to sericite and kaolinite. Plagioclase is also present. The color of the quartzite is possibly due to little flakes of hematite embedded in the cementing material. Minerals subordinate in amount are: zircon, magnetite, limonite, hematite. The cementing material is mainly sericite and represents former argillaceous material. The degree of metamorphism is only very slight. Few of the quartz-grains show wavy extinction. From a mineralogical standpoint this rock can better be called a feldspathic sandstone than a quartzite.

The thickness of the Cambrian quartzite exposed along Trail Creek was estimated to be about 900 feet. As the base of the formation is not exposed within the area this is the minimum thickness.

No fossils were found and the correlation with the Cambrian Flathead quartzite is only tentative. Previous workers (Perry and Sahinen, 1946) have mapped this and the overlying quartzite as pre-Cambrian, belonging to the Belt Series. But the degree of metamorphism is too slight to justify this correlation. The maroon quartzite is overlain by a white quartzite of which the Ordovician age is fairly well established. Since no break has been recognized between the two it seems again that the lower is not pre-Cambrian. The same sequence of maroon and white quartzite has been described by Umpleby (1917, p. 23) in the Lemhi Range. He speaks of the upper and middle quartzite. The two lower members of his series, to which he assigns a Cambrian age, do not seem present in the Beaverhead Mountains. Shenon (1928, p. 7), who worked in Idaho a few miles west of the author's area, also found only the maroon and the white quartzite, not the two lower members. He followed Umpleby's classification and put both quartzites in the Cambrian period. Anderson and Wagner (1944, p. 6), who reworked the area formerly mapped by Shenon, disagreed, however, and wrote: " The oldest rocks are composed of quartzite formerly regarded as Cambrian, but now known to be identical with Ordovician quartzite in the neighboring Lemhi Range." Dr. C.P. Ross, who recently reworked part of the Lemhi Range (1947), accompanied the writer on a fieldtrip in order to see both quartzites. He thought that the maroon quartzite belonged to the Cambrian (Flathead ?) and the white quartzite to the Ordovician. According to Dr. Ross the visibility of the composing grains and other evidences of a fairly low metamorphism would exclude the assignment of the maroon quartzite to the Belt Series. He expressed his view about the quartzite in a letter to the writer (Sept. 7, 1947): " The reddish well-bedded quartzite below the Kinnikinic is probably Flathead, as I suggested to you, but if this is correct the apparent absence of Cambrian limestones is somewhat surprising. North of the area the Belt Series is extensively exposed but I doubt if there is any Belt in your areas."

Ordovician system

Kinnikinic quartzite. The Kinnikinic quartzite was named by C.P. Ross (1934 II, p. 947) for exposures along Kinnikinic Creek, at Clayton, Custer County, Idaho. It is of Upper Ordovician age. In the area mapped by the writer the quartzite is exposed at several places west of Nicholia Creek above the basin. It can be found overlying the Cambrian maroon quartzite on top of the ridge immediately west of the creek. A very good exposure is found in section 15, T. 16 S., R. 11 W. Along the Continental Divide the quartzite is found on both sides of the intrusive mass in the center of the area. At the southern end of this pluton the quartzite has come to a higher position along faults and is in immediate contact with the Mississippian limestone. A small outcrop is found amidst Tertiary volcanic material along Meadow Creek.

The quartzite is white to light grey. Iron stains give it a light-yellow to pink color in irregular spots.

The color and the absence of the fine bedding make it easy to distinguish from the underlying Cambrian quartzite. It has a fresh appearance and is massive, but much fractured. At the base a conglomeratic layer has been found in some places. The study of a thin-section revealed a very pure quartzite. Quartz-grains, well-rounded, and free from inclusions, build up the rock. They are not interlocking and poorly sorted. No feldspar is present, and only a few small flakes of biotite could be seen. Also zircon, chlorite, and iron-oxide are present in very small amount. Metamorphism has been low, no strong shearing has occurred, and from a mineralogical standpoint the rock is on the borderline between a sandstone and a quartzite.

The thickness in this area is considerably less than that given by Ross (1947, p. 1095) for exposures in the Lemhi Range, where it is approximately 3000 feet. Here the thickness was estimated by the writer to be about 800 feet. Anderson and Wagner (1944, p. 7) mentioned only 200 feet, whereas Umpleby (1917, p. 23) states that the upper quartzite is at least 800 feet thick.

In the area mapped by Ross (1947, p. 1104) fossils were found in an intercalated limestone. They were determined as belonging to the early Upper Ordovician. No fossils were found by the writer. Also the fucoidcasts mentioned by Ross (1947, p. 1103) were absent. The white quartzite was correlated by Dr. Ross, who visited the area, on lithological grounds with the Kinnikinic quartzite. In a letter to the writer (Sept. 7, 1947) Dr. Ross writes: "...I am personally convinced that the white, crystalline quartzite I told you looked like Kinnikinic does belong to that formation and is hence of Ordovician age." The white quartzite is conformable with the maroon quartzite to which a Cambrian age was assigned.

Devonian system

Threeforks formation. The Threeforks name was given by A.C. Peale (1893, p. 29) to a formation of Upper Devonian age exposed at the junction of the three forks of the Missouri River, near Three Forks, Montana. Beds which presumably belong to the formation have been found in a belt extending through sections 16, 21, 22, 27, and 28 of T. 16 S., R. 11 W., where they form part of the major anticline west of Nicholia Creek. They also appear along the Continental Divide in sections 27, 30, T. 16 S., R. 11 W., where they flank the Mississippian rocks on both sides in the upthrown block, which here constitutes the divide.

The formation is soft and embedded between hard quartzites on one side and hard cherty limestones on the other. It is slope forming and generally concealed by débris. It consists of yellow and gray calcareous shales with lumpy brown masses in it. In the lower portion is conspicuous a purplish cherty shale. The slope is covered with shale fragments and pieces of chert and the more shaly parts weather bright yellow. Cubes of limonite pseudomorph after pyrite are common in section 22, T. 16 S., R. 11 W. Also calcite veins occur and in one place a calcite vein containing 7 parallel rows of equally spaced limonite cubes was found, giving the piece of shale a checkerboard appearance. The upper beds progressively get more limey and contain thin-bedded, grayish-blue limestones with chert layers.

The thickness of the formation has been estimated at 600 feet, but because it is nearly everywhere concealed the dip determinations made may not be representative and hence the calculation of the thickness may not be right. Another factor is the unknown boundary between the Threeforks formation and the overlying Mississippian. As a soft formation the Threeforks is apt to have a broad outcrop which may overemphasize thickness. The thickness of the Threeforks formation varies considerably within short distances, a fact also recognized by Ross (1947, p. 1112). He thinks that this is due to differences in amount of material originally deposited.

No fossils were found in the various shales and limestones. Dr. Eardley, who accompanied the writer on a fieldtrip, tentatively assigned the beds described above to the Threeforks formation on lithological grounds. The formation rests unconformably on the Kinnikinic quartzite.

Mississippian system

<u>Madison (?) limestone</u>. The Madison limestone is of Lower Mississippian age and has been named by A.C. Peale (1893, p. 33 - 39) for exposures in the Madison Range, Montana.

Mississippian beds crop out over extensive parts of the area. The best exposure of these rocks is at the head of Tex Creek in sections 2, 3, 10, 11, T. 15 S., R. 12 W. From here on a belt of the same rocks extends along the Continental Divide to the intrusive which occupies the central part of the area. South of the intrusive mass, along the western side of Nicholia Creek valley, we find Mississippian limestones in the outer belt of the southward pitching anticline that here brings older rocks to the surface. The limestones are also exposed along the Continental Divide, and are flanked on both sides by Devonian Threeforks shales. This occurs in section 35, T. 16 S., R. 11 W. The western part of Nicholia Creek in its upper course has also been mapped as Mississippian Madison (?) limestone, but determinations of fossils collected make the assignment of the shales to the Mississippian doubtful. The Madison age of the beds on the eastern side of the creek is more firmly established according to Scholten (1948). Mississippian beds occur not only on the west side of the Nicholia Creek basin, but also along the east side.

The Mississippian comprises a monotonous series of gray to bluish-gray limestones and lesser amounts of shales. Most of the limestone is massive, but also thinner bedded limestones occur, especially at the base. The limestone effervesces very rapidly with cold dilute hydrochloric acid and the magnesium content is thought to be small. Silica is present in great amount and is concentrated in nodules and streaks of chert. In the gray-weathered limestones the chert nodules stand out in relief. The chert is black on fresh surface, but where weathered it is covered with a thin coating of brown iron oxide. The chert usually occurs in irregular lenses and nodules which are all parallel with their longest dimension to the bedding and to each other. A few extensive bands parallel to the bedding occur. Fossils in the limestone are silicified and hard to cut with the diamond-saw. Some beds contain many large cupcorals, others crinoidal remains, completely recrystallized. Other beds, however, are not fossiliferous at all. On a freshly broken surface the rocks give a distinctly fetid odor. Besides limestones dark gray shales and some arenaceous limestones are found in the series.

Of the following section the upper 640 feet were measured by Mr. Scholten alone, the underlying beds by him and the writer.

Madison (?) formation measured in sections
7, 8, 9, 17, T. 17 S., R. 10 W.

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

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

10. Limestone, light to medium gray, massive, strongly jointed, almost entirely built up of fossils, mainly crinoids, calcite veins, chert layers -------------------------------- 60'

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

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

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

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

The measured section represents only part of the total thickness of Mississippian beds. About 3000 feet in total are thought to be present, which is in correspondence with Shenon (1928, p. 7), who found 3500 feet of Mississippian rock. This estimate is based on the assumption that the various gray limestones and shales are of the same Mississippian age.

Future investigation of the fossil content of the beds is essential, as it appears hardly possible to distinguish between the various rocks only on lithologic ground. In this respect the following sentence, written by Dr. C.P. Ross in a letter (Oct. 30, 1947) to the writer, is interesting: " The pamphlet (Anderson and Wagner, 1944) refers to rock of supposed Devonian age, but as no fossils are reported, it might be that the supposed Devonian is similar to rock in your area that, as I told you, looks like Devonian, but that Williams found fossils in which, on field inspection, appears to him to be Carboniferous." Not only the lower boundary of the Madison (?) limestone is hard to distinguish, but also the upper one. The writer collected some fossils in shales cropping out in section 31, T. 16 S., R. 10 W., which in the field were thought to represent Mississippian strata. One of the corals, however, was identified by Dr. Stumm as Lophophyllidium species (?). The genus is index fossil for the Pennsylvanian and Permian and has not been reported from the Mississippian, according to Shimer and Shrock (1944, p. 87). It is therefore possible that some Pennsylvanian beds have been included in what was mapped as Mississippian Madison (?) limestone. Also the age of the typical cherty limestones is not at all certain. They were mapped as belonging to the Lower Mississippian Madison (?) limestone, but the possibility can not be excluded that they also represent beds of Upper Mississippian (Brazer) age. The description of the Madison and Brazer limestones as given by various writers are very similar and only a thorough investigation of an extensive fossil collection can bring any light in this matter. Brazer age has been attributed by Shenon (1928, p. 7 - 8) and Ross (1934, II p. 977) to rocks of similar lithology as the Mississippian beds described in this report and outcropping in the Lemhi Range and Beaverhead Mountains. They do not report any Madison limestone. Ross (1947, p. 1112) describes the Milligen formation, which is more or less equivalent in age to the Madison limestone, in the southwest part of the Lemhi Range. He does not exclude the possibility that the Madison limestone crops out in the less known parts of the Beaverhead Mountains (1934 II, p. 966). Summarizing this we see the possibility that the various gray limestones and shales mapped as Madison (?) limestone might include some beds of Devonian, Upper Mississippian, (Brazer), and Pennsylvanian age.

Tertiary system

Nicholia Creek basin beds. This name has been given to the series of Tertiary beds in the Nicholia Creek basin, which were formerly called " Lake Beds " and " Fanglomerates " by Perry and Sahinen (1946). The name Bozeman Lake Beds was first used by Peale (1893), who mapped, but did not describe these beds in the vicinity of Three Forks, Montana. Without the prefix Bozeman the name Lake Beds had been used previous to this by the Hayden Survey, for deposits of Neocene age. Because the name Lake Beds suggests a lacustrine origin of these beds, which might not be true in all cases, provisionally the name Basin Beds was preferred. It has also been used for similar beds in the Muddy Creek basin more to the east by Wallace, Krusekopf, Lipp and Becker (1948).

In the area investigated, the beds are confined to the Nicholia Creek basin. Here they are exposed at several places, standing out as ridges. One of these ridges follows Nicholia Creek, another one Meadow Creek. A third extensive exposure is along the east side of the basin. The Basin Beds do not occur at an elevation higher than about 7500 feet.

The series consists of a great variety of strata, usually well-indurated. It is made up mainly of material derived from the adjacent mountains, forming conglomerates, sandstones and shales. In a conglomerate near the base of the formation pebbles of Cambrian and Ordovician quartzites, Madison (?) limestone and Tertiary lavas can be clearly recognized. Intense volcanic activity took place during the deposition of the basin beds. Volcanic ash, now bentonite, is found at several places in the section. The continental origin of the basin beds is indicated by the numerous plant fragments found in brown shale, the petrified wood occurring in some of the sandstones, and the freshwater gastropods in a limestone member at the top of the series. The conglomerates are more or less lens-shaped and imbedded in and transitional to the sandstone. Pebbles are well-rounded and of nearly equal size from 1 to 2 inches. Flat-pebbles lie parallel to the usually ill-defined bedding. The color is cream to light brown. The sandstones are yellowish-brown and weather pink to brown. Lamination and cross-bedding are evident in many places especially in the finer grained sandstones. The cement is quartz, no lime cement is present throughout the section. Small pebbles of lava are common in the sandstones and they might partly represent lapilli ejected by adjacent volcanoes. The sandstones as well as the conglomerates are cliff-forming, in contradistinction to the softer bentonites and shales. The only fossils in the sandstones are pieces of fossilized wood. The sandstone shows vertical jointing (pl. 5). Blue-gray to milky white translucent chalcedony found on the cliff near the three-forked road in S.E. $\frac{1}{4}$ section 11, T. 15 S., R. 11 W., might have been deposited by hot springs. The bentonites represent volcanic ashes, are of gray color, and weather white. Gypsum crystals of the variety selenite occur at several places in the bentonite. Also volcanic ejectamenta are scattered throughout the bentonite, which, because of its impure character, could better be called a bentonitic clay. It is poorly indurated and has a typically cracked surface, often with a white crust. It is slope-forming. The shales

Plate 5. Two sets of joints in sandstone member of basin beds. In N. E. $\frac{1}{4}$ section 13, T. 15 S., R. 11 W. Both systems dipping 90°, one striking N 30 W, the other N 45 E.

occur in thin layers of about 10 inches thick in the sandstones. Two of such shale layers were recognized in the field. One of these was a brown shale, composed of thin flakes, with numerous, but poorly preserved plant fragments. The second one was a dense white shale, 7 inches thick, not breaking up in flakes and containing no fossils. Lignitic seams of limited extent and not thicker than 1 inch are exposed in the sandstones at various places. Limestone, white to cream colored, weathering gray or tan, lies on top of the series. It is exposed along Cabin Creek Road in section 25, T. 14 S., R. 11 W. It is fine grained and dense, in places cavernous and some of the vugs are filled with calcite spheroids. On the weathered surface a pink crust is locally formed. It is thick-bedded. No fossils were found by the writer, but fresh-water gastropods are reported by Scholten (1948), who describes the same limestone farther south.

The following section, covering somewhat more than the lower half of the total section, was measured by the writer in cooperation with Mr. Scholten.

Nicholia Creek basin beds measured in sections 31, 32, T. 15 S., R. 11 W. and 19, T. 15 S., R. 10 W.

16.	Same as 12 ----------------------------------	10.0'
15.	Shale, white, non-fissile, non-fossiliferous	0.5'
14.	Same as 12 ----------------------------------	70.0'
13.	Shale, brown, fissile, plant fragments ------	0.5'
12.	Sandstone and conglomerate in alternating layers, brown to yellow, thick-bedded, cross-bedding in places, vertical jointing, petrified wood, lignitic layers, cliff-forming, pebbles consist of: quartzite, limestone, granite, basalt, occasionally shale ---------	10.0'
11.	Same as 7 -----------------------------------	100.0'
10.	Same as 8 -----------------------------------	2.0'
9.	Same as 7 -----------------------------------	100.0'
8.	Sandstone, dark brown, weathering grayish brown, fine to medium-grained, well-sorted, faint striations due to color differences, slope-forming ------------------------------	110.0'
7.	Bentonitic clay, gray to light brown, weathering white, not indurated, cracked surface,gypsum crystals, pyroclastic material, slope-forming ------------------------------	60.0'
6.	Sandstone and conglomerate, brown, lighter colored sandstone interbedded, cross-bedding, grain size finer in upper part, less volcanic material than in 2, cliff-forming -----------	750.0'

5. Same as 3 ------------------------------------ 75.0'

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

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

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

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

Total thickness -------------2613.0'

The thickness of the complete series in Nicholia Creek basin is at least 5000 feet, if no repetition of beds by faulting or folding took place. There are no indications of any extensive distortion. Because of the fact that deposition took place in local basins it is not possible to compare this figure with thicknesses reported by other writers in adjacent areas.

The fossils found by the writer do not throw any light on the exact age of the formation. Similar beds have yielded diagnostic fossils at several places in southwestern Montana. Russel (1902, p. 56) lists fossils collected and assumes that the lower part of the deposit belongs to the Miocene and the upper part to the Pliocene. Umpleby (1913 I, p. 39) assignes a Miocene age to the beds on floral evidence. According to Kirkham (1927, p. 12) and Umpleby (1913 I, p. 39) the beds can be correlated with the Payette formation, which Buwalda (in a personal communication to Mansfield, 1927, p.358) regards as being in large parts of Upper Miocene and in some parts of Lower Pliocene. It includes also beds as old as Eocene. Hence it is evident that the deposition of the basin beds took place during a long time in the Tertiary period. It is very well possible that the various basin beds in southwestern Montana were not all deposited during the same span of time. It is, however, safe to assume that the main deposition took place during Miocene time and reached into Lower Pliocene, as indicated by fossil finds.

As to the environment of deposition of the basin beds not much is known. Blackwelder (1915, p. 107) supposes that they could have formed in the following ways :

1. by lakes and marshes,
2. by graded streams upon their floodplains,
3. by wet-weather streams making alluvial fans,
4. by the wind upon dry land surfaces.

It is possible that all these agencies have taken part. The only thing that is definitely known is that they represent continental deposits. Also Russell (1902, p. 57) assumes that the deposits were partly formed by streams, but mentions that it was impracticable to determine what part is the result of still-water and what part of flowing water. Investigation in the field has convinced the writer that the name Lake Beds is not appropriate and that some of the cross-bedded, lenticular, sandstones, with well-worn pebbles, were deposited by streams. The brown shale, with the numerous plant fragments, on the other hand, probably represents marshy conditions in a shallow lake. Some of the coarser conglomerates at the base of the formation might well be fanglomerates.

Gravel deposits. Gravel consisting of well-rounded, ill-sorted, pebbles up to 2 inches in size, mainly limestone was mapped in three places. Only small patches are left and their extent as indicated on the accompanying geologic map is only approximate and exaggerated. The exposures occur in section 1, T. 15 S., R. 12 W., sections 16, 28, T. 16 S., R. 11 W. All three lie high above the valley floor at an elevation of about 8500 feet. They are thought to represent gravels older than the Quaternary period and are supposedly of Pliocene age as they cover part of the Mio-Pliocene lava flows.

Quaternary system

<u>Glacial</u> <u>deposits.</u> Along the western boundary of Nicholia Creek basin and in the valleys of the larger streams, which come from the Beaverhead Mountains, Pleistocene glacial drift is present. The deposits can be divided into two different age groups, an older which will be called the Bull Lake and a younger, the Pinedale. The distinction has been made chiefly on physiographic grounds, which will be discussed later. The material itself shows some differences too, in that the larger and less weathered boulders are found in the younger deposits. In both groups we deal with material derived from the adjacent mountains to the west which consists of quartzites, limestones, shales, volcanic rocks and granite, ill-sorted and little rounded and smoothed. Some of the limestone boulders in the younger moraine are polished and scratched. The terms Bull Lake and Pinedale are used in northwestern Wyoming (Blackwelder, 1915, p. 325) and the deposits of Nicholia Creek basin compare so closely that the same names seem appropriate. Both belong to the Wisconsin stage of glaciation. The Pinedale drift is found in the present stream valleys and extends only a short distance into the basin. The Bull Lake drift extends much farther into the basin and is found all along the mountainfront. No glacial deposits are present along

the east side of the Nicholia Creek basin.

<u>Terrace gravels</u>. Quaternary gravels cover extensive parts of the Nicholia Creek basin, especially in T. 14 S., R. 11 W., and T. 15 S., R. 11 W. They are very well exposed in a gravel pit along the road about 200 feet past Martinell Ranch in section 4, T. 15 S., R. 11 W. Here the material ranges in size from sand to boulder with a maximum diameter of 8 inches. It is well- sorted, the pebbles are well-rounded and embedded in a sand matrix containing some lime. Induration has hardly taken place and the grains are loosely packed. The sand matrix is brown. A few pockets of greenish sand also occur. Many of the pebbles have a thin cover of lime and are weathered white to gray. The bedding is inconspicuous, but a faint cross-bedding can be seen. The gravel consists of the products of erosion of the Beaverhead Mountains. The accurate thickness of the deposit is unknown but it is at least 100 feet thick, because the creeks have cut in to about that amount. The material is thought to have been deposited by glacial streams which were particularly active after the Bull Lake stage and later again, to a lesser extent, after the Pinedale stage.

<u>Alluvium</u>. Alluvial deposits laid down after the Terrace gravels are found along the modern creeks. Their extent is often limited to only a few feet on both sides of the stream and hence could not be mapped. In the basin

the alluvium coated flood plains are considerably wider. They are mostly covered by grassland, which is used to produce hay and to graze cattle and horses. All the ranches are on or very close to the alluvial deposits. The alluvium consists of sand, silt and clay brought down from the mountains. The transporting power of the streams in the basin is not sufficient to carry boulders but pebbles form the stream bed. In the various lakes filling by sediments derived from the adjacent hills takes place. Some are completely filled. These lake-sediments have not been mapped separately.

Landslides. Several landslides are present in the area, but only two, which were well-developed and of large extent, were mapped. Both occur in Nicholia Creek Canyon on the west side. The first one lies mainly in section 23, T. 16 S., R. 11 W., and consists of quartzite blocks in its northern half and of basalt blocks in its southern half. Because of the difference in color between the lighter colored quartzite and the dark brown to black basalt, the two composing parts of the landslide are easily distinguished (pl. 6) . The second landslide is in section 25, T. 16 S., R. 11 W. It consists of limestone blocks only. Both landslides have supposedly taken place in the Recent epoch, but long enough ago to be covered with vegetation.

Plate 6. Lower part of landslide in Nicholia Creek valley. Section 23, T. 16 S., R. 11 W. Light colored part is quartzite, dark part basalt. Material at the end overlies glacial deposits in valley. Cliff at opposite side is Madison limestone.

Summary of depositional events

At the end of pre-Cambrian time the sea invaded the crystalline complex, and sedimentation took place almost continuously during the entire Paleozoic era. First, sands were deposited, later argillaceous and calcareous sediments. In total more than 4500 feet accumulated in a gradually subsiding basin. During Mesozoic time there was either no deposition or the beds deposited have been removed by later erosion. The former supposition is the more likely one, because not even small remnants of Mesozoic rocks have been found. In the Tertiary period deposition took place in an intermontane basin. Continental deposits were laid down by streams and in a fresh-water lake. Breaks in the sedimentation occurred and plants could grow in the basin, probably under marshy conditions. Volcanoes in nearby regions sent clouds of ashes and coarser material over the area. These ejectamenta settled in the lake. In Pliocene time a fresh-water limestone was deposited. After the basin was filled the beds became subject to erosion and locally gravels were formed, supposedly of Pliocene age. In Quaternary time mountain-glaciation occurred twice and glacial till was deposited in Nicholia Creek basin. Streams laid down extensive gravel deposits as the ice melted. Recent streams have dissected these gravels and deposited alluvial material on their flood plains. This deposition goes on today. Landslides caused some local changes in the distribution of rocks.

Tabel 1. Stratigraphic column.

System	Series	Group and formation	Character	Thickness (feet)
Quaternary	Recent	Landslides	Masses of blocks of quartzite, basalt, and limestone, soil and other debris.	
		Alluvium	Meadowland with fine soil, locally gravelly. Pebbles in streambed.	
	Pleistocene	Terrace gravels	Flat lying deposits without relief. Well-rounded pebbles and boulders. Matrix of sand, limey. Not indurated. Cross-bedded.	100 +
		Pinedale glacial deposits	Hummocky masses of fresh surface boulders and other glacial material. Confined to modern valleys and extending but little into basin. Glacial lakes still existing.	
		Bull Lake glacial deposits	Glacial topography not very well preserved. Surface boulders disappeared. In basin along mountain front. No lakes exist.	
		Unconformity		
Tertiary	Pliocene	Gravel	Well-rounded, ill-sorted, pebbles up to 2 inches, mainly Paleozoic limestone, Above elevation of 8000 feet.	
	Miocene	Nicholia Creek Basin Beds	Conglomerates, sandstones, shales and limestone. Buff to cream colored. Much volcanic material: bentonite with gypsum, lapilli, pebbles of basalt. Plant fragments in brown shale. Fossilized wood in sandstone. Snails in limestone. Forms cliffs in Nicholia Creek Basin.	5000 +
	Oligocene	Challis (?) volcanic rocks	Lava flows, volcanic tuffs, and breccias of basaltic composition. Flows dark colored, tuffs and breccias lighter gray. Cliff-forming.	1000 +
		Unconformity		
Carboniferous	Mississippian	Madison (?) limestone	Gray to bluish-gray limestone and shale. Chert nodules, black and weathered brown. Calcite veins. Cup corals, crinoid remains. Fetid odor.	3000 (?)
Devonian	Upper Devonian	Threeforks formation	Gray calcareous, fissile shale with lumpy brown parts in it. Purplish cherty shale in lower part. Calcite veins. No fossils. Slope forming.	600 ±
Ordovician	Upper Ordovician	Kinnikinic quartzite	White to light gray quartzite weathering light-yellow to pink in irregular spots. Massive. Conglomeratic part at the base. Well-rounded quartz grains are almost only mineral. Jointing.	800 ±
Cambrian	Middle Cambrian	Flathead quartzite	Reddish to maroon quartzite. Fine bedding, often cross-bedded. Conglomeratic beds with stretched pebbles. Cliff-forming. Jointed. Much feldspar in addition to quartz.	900 +
		Unconformity		
pre-Cambrian	Pre-Belt series	Pony (?) formation	Gneisses and schists, not described in this report. Mapped by Perry and Sahinen in northeast corner of area.	

IGNEOUS ROCKS

Regional features

The Geologic Map of the United States and geologic maps of Idaho and Montana show intrusive igneous rocks at several places in nearby central Idaho, and in central and northern Montana. Ross (1928) distinguishes three different groups in this region :

1. Idaho Batholith with outliers. Composition is mainly quartz-monzonite. Age is probably late Jurassic to early Cretaceous.

2. Boulder Batholith with outliers. Composition is mainly hornblendic quartz-monzonite and diorite. Is somewhat younger than the Idaho Batholith, but distinctly older than no. 3. (On the Tectonic Map of North America the Boulder Batholith with its outliers has been mapped as a Tertiary intrusive.)

3. Tertiary granitic rock. Composition ranges from granite, in part granophyric, to quartz- monzonite. Is characterized by abundant perthite and micropegmatite. Is at least of late Miocene and possibly of Pliocene age, according to Ross.

More abundant than intrusive igneous rocks are extrusive igneous rocks in the neighboring regions. They have been described by various writers (Ross, 1934 II, Umpleby, 1913 I, Kirkham, 1927, Shenon, 1928, Anderson and Wagner, 1944) from the Lost River, Lemhi and Beaverhead Ranges, as well as from the Snake River Plains, where flows of Quaternary age cover almost the entire surface. The Tertiary volcanic rocks can be divided into two groups: (Kirkham, 1927, p. 31 - 38.)

1. Tertiary "Early Lavas" of Oligocene and Miocene age,
2. Tertiary "Late Lavas" of Pliocene age.

Intrusive igneous rocks

Varieties. In the area of this report a pluton of granite and several small dikes of basic composition occur.

Granite. Along the Continental Divide a granitic intrusive mass extends from section 21, T. 16 S., R. 11 W., in a northwesterly direction to section 35, T. 15 S.,R. 12 W. It has a length of about 6 miles and an average width of about 1½ mile, assuming that its center coincides with the Continental Divide, across which the mass was not mapped. The granite forms the highest peaks of the area (pl. 4, Eighteenmile Peak).

The rock is moderately coarse-grained and ranges in color from light gray to pink and light green. Also some darker brick red parts are present. Some of the red granite shows stains in iridescent colors, probably due to a thin film of iron oxide. This was found only in S.W.

$\frac{1}{4}$ section 21, T. 16 S., R. 11 W. Coarse quartz veins occur and also small aplite dikes of the same composition as the granite but of much finer texture. The granite weathers in large blocks, which on Eighteenmile Peak reach higher than 6 feet. On the south side of the pluton where the rock is much more weathered, they attain only boulder-size. There is coparatively little variation in the composition of the granite. Macroscopically quartz and pinkish feldspar can be recognized, but no dark minerals can be seen. Specimens were collected at various places and microscopical investigation showed a composition of quartz and potash-feldspar mainly (orthoclase and less microcline). The K-feldspar is nearly everywhere weathered, Plagioclase is locally present and badly weathered, which made a determination of the composition impossible. The feldspars have been changed mainly to kaolinite and sericite, and in one thin-section the plagioclase made up an integral part of the rock which therefore has a quartz-monzonitic composition. Usually the plagioclase is only subordinate in amount and we deal with a true granite. Dark minerals are very scarce: biotite, and pyroxene in one thin-section were the only ones noted. The biotite is not fresh, but is in the initial stage of alteration to chlorite, as indicated by the green color. Additional minerals are chlorite, zircon, epidote, hematite, and limonite, magnetite, sericite and kaolinite.

The last two minerals are alteration products of the feldspars. Micropegmatitic intergrowths of quartz in the orthoclase are abundant. Perthites have not been noticed, but this does not exclude their existence, as they might be obscured by the alteration of the feldspars.

From the descriptions given by Ross (1928, p. 676 and 685) it is evident that the intrusion is of quite different composition than either the Idaho or Boulder batholith. It corresponds more to the granitic plutons which according to Ross (1928, p. 693) have been intruded in late Miocene, or early Pliocene time. In the area investigated the field relations show that the intrusion took place after the Mississippian, as an intrusive contact with the gray limestones has been found. A hand-specimen collected shows inclusions of limestone in the granite. The upper age-limit is given by the relation with the Tertiary volcanic rocks. As far as the writer has been able to find out these have been extruded on the surface of the previously eroded pluton, as shown at the head of Meadow Creek. No indication was found that the intrusive was younger than these extrusives. Also the sedimentary inclusions derived from the granite and incorporated in the volcanic tuffs point to the conclusion that the volcanic rocks are younger. If the assignment of the Tertiary flows, breccias and tuffs to Oligocene and Miocene time is true, then this would exclude assignment of the granitic intrusive to late Tertiary time, as suggested by Ross (1928, p. 693). Apparently the same intrusive mass has been mentioned by Umpleby (1913,I, p. 42), who describes an exposure on the Idaho side of the Continental Divide. He assignes it to the late Cretaceous or early Tertiary. Also Anderson and Wagner (1944, p. 9) mapped a granite of like composition just across the state-line in the Birch Creek District, Idaho. They write: "The granite is much more alcalic than the rock that composes the Idaho Batholith (Cretaceous) and probably belongs to the group that was intruded in early Tertiary time". On the accompanying geologic map of this report the intrusion has been put in Cretaceous-Tertiary time, pending further investigations. It is, however, more probable that it took place early in the Tertiary period.

Dikes. Three dikes of limited extent have been mapped. One in Mississippian limestone in the N.W. corner of section 27, T. 15 S., R. 12 W. The second one in Threeforks shale in the southeast corner of section 27, T. 16 S., R. 11 W. And the third one in a shaly member of the Mississippian in N.W. ¼ section 7, T. 17 S., R. 10 W. All three are exaggerated in dimensions on the map, as they are only of small width and length, being not more than 30 feet wide and having an exposed maximum length of 100 feet.

All three bodies have the same general composition and will therefore be treated together. They are ultramafic, peridotite dikes. A single plagioclase phenocryst was found. In some thin-sections there is a suggestion of former presence of feldspar, but through alteration they have completely disappeared. In general much alteration has taken place. Augite crystals are common as phenocrysts and many are altered to chlorite, carbonate, iron oxide, and quartz. Locally sphene is present in large crystals and great quantity. Biotite might be abundant too. Additional minerals are: magnetite, chlorite, calcite, limonite, zoisite, apatite.

Extrusive igneous rocks

Varieties. Flows, volcanic breccias and volcanic tuffs are found in the area. They have been mapped together as one unit, because they belong to the same period of volcanic activity. Also the volcanic breccias and tuffs are limited in extent and in order to separate them it would require a map of a larger scale. The volcanic rocks are found mainly in an extensive belt along the western margin of Nicholia Creek basin, forming the foothills of the Beaverhead Mountains. Remnants of a former capping have been found on the ridges on both sides of Trail Creek.

Lava flows. Lavas are especially well exposed in the two remnants mentioned above and north of Meadow Creek in E. ½ of section 19, T. 15 S., R, 11 W. They generally form cliffs, but this seems to depend on local conditions, because in certain places rolling hills are formed and the volcanic rocks are broken down to soil.

The rocks are usually dark in shades of gray and brown to black. They are mostly massive, but vesicular lava is present. The vesicles usually are not filled, but in some places, quartz has been deposited in them and also calcite to a lesser extent. The massive rock when broken down, occasionally shows spherical weathering. When struck with a hammer in these cases, a concentric outer shell will split from the ball-like interior body (pl. 7). Usually the flows have a blocky appearance, but also slabby fragments are present. Locally brown opal-like chert is present, but this was found only as loose material on a slope and not in place. White, bluish and reddish quartz in veins and as incrustations was found in place. This is thought to be due to later hydrothermal solutions adding the silica, which otherwise is foreign to basaltic rocks. Quartz is well-developed north of Meadow Creek. Here also calcite veins are found. The basalts are fine grained and phenocrysts are inconspicuous except for certain types in which hornblende crystals are clearly visible. In the cliffs jointing is prominent. Microscopic investigation shows most of the lavas to be of

Plate 7. Spherical weathering in basalt. In S. W. ¼ section 23, T. 16 S., R. 11 W.

basaltic composition. The plagioclase has the composition of labradorite to bytownite and occurs as phenocrysts as well as in the groundmass in the form of numerous laths. Hornblende and augite both occur, but the augite is much more common. The pyroxene is developed as phenocrysts often showing a glomeroporphyritic texture. It is also forming an important part of the groundmass. Hornblende phenocrysts in large amount were found only once. Biotite and olivine seem to be practically absent, although both minerals have been noticed. Additional minerals are : magnetite, calcite, limonite, chlorite, apatite, volcanic glass. The rocks show a porphyritic texture with a felted groundmass.

Besides basalt a minor amount of andesite has been found. A flow of this composition is exposed in E. ½ section 19, T. 15 S., R. 11 W. Here is an andesite-porphyry of slaty habit and greenish-blue color. Greenish-black phenocrysts of hornblende are about ½ inch long. They are long prismatic and have their greatest dimension in planes parallel to the horizontal planes along which the rock breaks. In these planes the longest dimensions of the hornblende crystals lie in a haphazard orientation. Under the microscope phenocrysts of plagioclase can be seen having the composition of andesite. The feldspar also makes the larger part of the groundmass. Hornblende and less augite are found in the matrix. The large hornblende crystals are strongly resorbed. Additional minerals are: chlorite, carbonate, magnetite, The andesite is both overlain and underlain by basalt, but is believed to occur near the top of the total series of volcanic rocks.

Pieces of the basalt are common as water-worn pebbles in the basin beds. The lava flows therefore have to be older than the basin beds, which are supposedly of Miocene to early Pliocene age. The main outpouring of lavas probably took place during the Oligocene. Lavas intermingling or lying on top of the basin beds, as described by Umpleby (1913 I, p. 48) have not been noticed by the writer. Only volcanic ash (bentonite) and lapilli occurring in the basin beds are indicative of volcanism.

Volcanic breccias. Volcanic breccias are very well exposed at three places in the area. The first is an isolated outcrop on all sides surrounded by glacial material. It lies about 500 yards west of the Nicholia Creek Road crossing of Trail Creek in S.E. ¼ section 9, T. 16 S., R. 11 W. The outcrop is shown on plate 8. The second exposure is in N.W. ¼ section 26, T. 16 S., R. 11 W. Here the breccia is found together with flows. The third mass of breccias is on the south side of the first landslide in Nicholia Creek Canyon, S. ½ section 23, T. 16 S., R.11 W., and is also associated with flows. There three knobs of

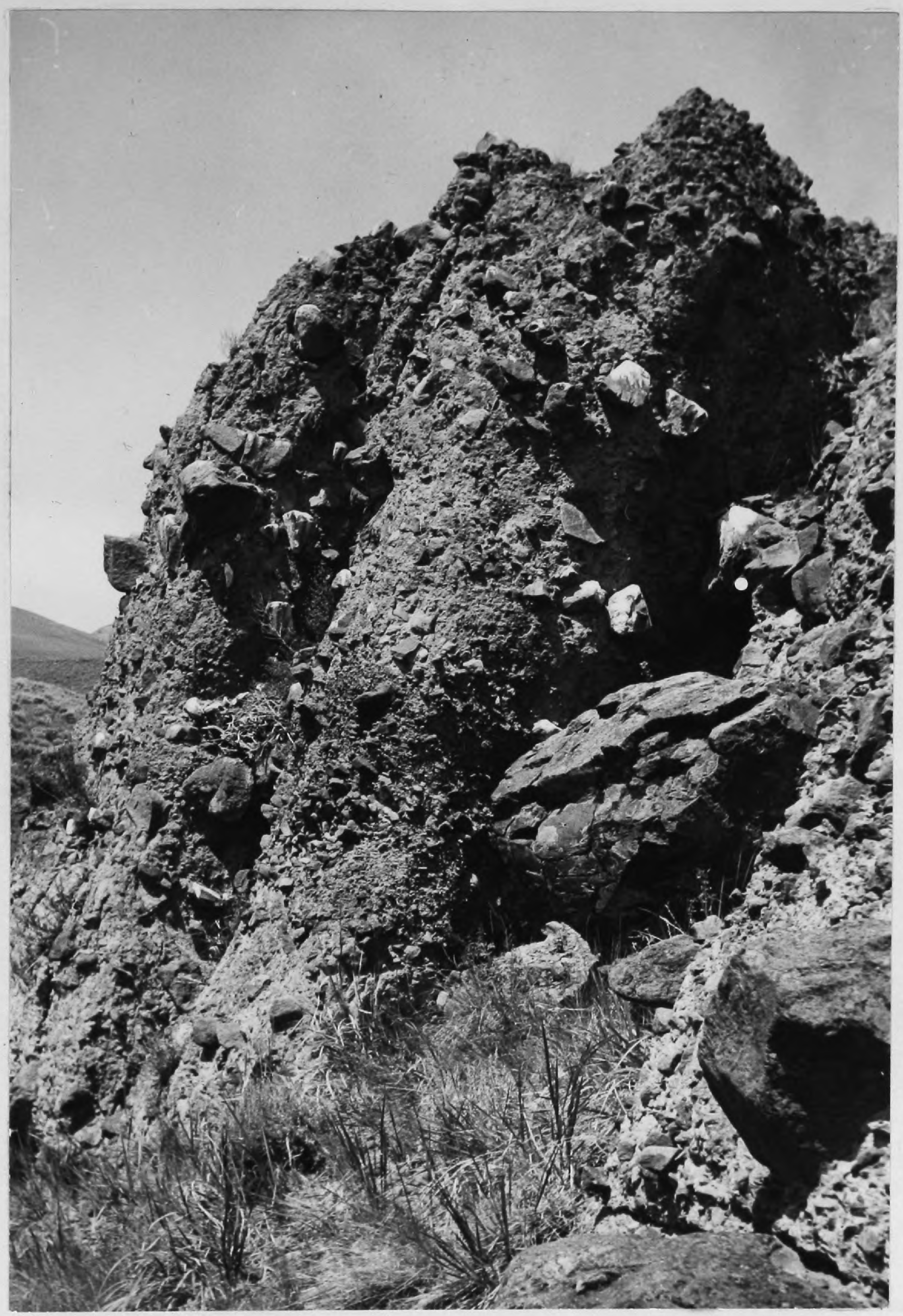


Plate 8. Volcanic agglomerate. S. E. ¼ section 9, T. 16 S., R. 11 W.

breccia are surrounded by basalt.
The rocks consist of dark brown and gray pebbles and boulders of basalt embedded in gray, fine-grained matrix. They are well- cemented. The material varies between a volcanic breccia and an agglomerate, as some boulders are imperfectly rounded. The fragments range in size from sand to 8 foot boulders. The very large boulders are found in the first outcrop mentioned above. The material is practically not sorted, but some stratification can be seen in one or two places. Finer,shaly material is found along the bedding-plane. Most of the enclosed pebbles and boulders consist of older basalt, but also pieces of Mississippian limestone, quartzite and granite have been found embedded in the gray matrix. The boulders of granite found were of the pink and of the greenish variety and they were well-rounded. Microscopical investigation shows pieces of the familiar basalts cemented together by material probably representing tuff. The cement consists of quartz, plagioclase-feldspar, biotite, zircon, rutile and volcanic glass.

The rounded boulders and the bedding, although both are only imperfectly developed, suggest a deposit of clastic origin in which running water has played a rôle. The very large boulders found in the exposure near Trail Creek and Nicholia Creek indicate that the site of volcanism was not far, probably only a few miles. The characteristics of the deposit are those of the large mudstreams that are common of several volcanoes in the Dutch East Indies and which are able to carry large boulders over several miles distance. Recent mudflows of this kind have been described by Edelman (1946, p. 6 - 15).

The breccias are interbedded in the lava and their exact position in the series of volcanic rocks could not be determined. It is believed that they occur near the base.

Volcanic tuffs. Several kinds of tuffs occur in section 19, T. 15 S., R. 11 W. All are slope-forming and not well exposed. They are light colored rocks in shades of greenish- and purplish-gray. Pieces of darker reddish-brown to violet material are enclosed, which are about 2 inches long at the maximum and having an angular form with rounded edges. In the lighter as well as in the darker part we find needles of hornblende plainly visible to the naked eye, but smaller than those previously described in the andesite. Under the microscope two different parts of the tuff can be recognized. One is truly igneous material of basaltic character, the other is sedimentary material. In the sedimentary material myrmekitic intergrowths of quartz are abundant, an indication that the sediment was derived from the older granite. The quartz in this part is clearly of detrital origin. The plagioclase has the composition of oligoclase. Also orthoclase

is found. Other minerals in this part are:
sericite, chlorite, magnetite, limonite, hornblende.
In the igneous part we find feldspar having a composition of labradorite. Much hornblende is present and also augite. It resembles some of the basaltic lavas.
The tuff has probably been sorted by water, as there are some indications of bedding. It is water-laid material resulting from explosive eruptions of volcanoes together with detrital grains derived from the adjacent granite. It occurs at the top of the series of volcanic rocks together with the andesite flows.

Age-relationships of extrusive rocks. Pieces of granite have been found in the breccia and detrital grains, presumably derived from the granite are in the tuffs. The series is younger than the granitic intrusion and older than the basin beds, as basalt pebbles are common in the sandstones and conglomerates of the Nicholia Creek basin beds. In these basin beds bentonites and lapilli are present, which are believed to represent the last part of the same period of volcanic activity that is responsible for the volcanic rocks discussed in this chapter. The whole series from top to bottom would then consist of:

Volcanic ash (bentonite)	Miocene
Volcanic tuffs	) Oligocene
Andesite flows	)
Basaltic flows	)
Volcanic breccias and agglomerates	) "
Basaltic flows	)

The dating has been done on the assumption that the assignment of the basin beds to the Miocene is correct. Because the volcanic rocks are mainly Oligocene and extent into the Miocene, they are tentatively correlated with the Challis volcanics farther west. About these Ross (1947, p. 1121) writes: " The Challis Volcanics are possibly, if not probably, of Oligocene age and they can hardly be younger than Miocene." He describes a series of volcanic rocks which is very similar to that in this report. Also Anderson and Wagner (1944, p. 11) correlate the extrusive rocks found in their area with the Challis volcanics. Kirkham (1927, p. 31 - 38) distinguishes between " Tertiary Early Lavas " and " Tertiary Late Lavas ". The former correspond with the Challis volcanics. The latter of Pliocene age, are not represented in the area investigated by the writer. Scholten (1948), however, has found rhyolitic lavas clearly younger than the basin beds near Bannack Pass. These he has correlated with the "Tertiary Late Lavas" of Kirkham.

Summary of igneous events

Intrusion of a granitic mass took place possibly in the Cretaceous or more probably in the early Tertiary. Its composition seems to be different from that of the Idaho Batholith, in which the magma cooled relatively slow and steady in a large body (Ross,1934, I, p. 59)

The features of the pink granite on the other hand suggest, according to Ross (1934 I, p. 59), a lower pressure and consequently shallower depth at the time of formation.

Extrusion of igneous rocks took place during the Oligocene and continued into Miocene time. There is a change from basalts at the bottom of the formation to andesites on top. Also the amount of pyroclastics increases toward the top.

STRUCTURE

Regional features

Three major periods of deformation have been reported from this general region. They are:

1. Crumpling and crushing of pre-Cambrian rocks near the close of the Algonkian period, accompanied by regional metamorphism of varying intensity.

2. Folding, faulting and thrusting of Paleozoic rocks during the Laramide orogeny. This is believed to have taken place in two separate disturbances. In central Idaho, close to the Idaho Batholith, these two steps probably took place as early as Jurassic and Cretaceous time. More to the east the deformation came at the close of the Cretaceous period, at the beginning of Tertiary time. This is the concept of the eastward migration of deformation and intrusion during the latter part of Mesozoic time from the Pacific Coast into Montana and Wyoming. (Lindgren, 1915, p. 261 - 263; Ross, 1947, p. 1126). In the area included in this report the Laramide deformation is assumed to have taken place in two phases in late Mesozoic, probably Cretaceous time (Ross, 1947, p. 1127). The folds which originated during the Laramide deformation are generally described as having a northwest trend in this region. Overturning to the northeast takes place. The folds produced an anticlinorium in the Lemhi Range (Ross, 1947, p. 1130) and a

synclinorium in the Beaverhead Mountains (Anderson and Wagner, 1944, p. 12). Faulting of the rocks accompanied the folding in several places. Four great thrustfaults were mapped by Kirkham (1927, p. 26 - 29): Medicine Lodge Creek -, Lost River -, Hawley Mountain -, and Lemhi overthrust. All trend approximately northwest and are hence parallel to the major fold axes. Kirkham (1927, p. 27) thinks that the Medicine Lodge overthrust is the extension of the Bannock overthrust, which has been mapped south of the Snake River Plains by Richards and Mansfield (1912). This major fault plunges under the basalts that cover the Snake River Plains and rises again on the north side of the plains near Medicine Lodge Creek (Kirkham, 1927, p. 26 - 27), just outside the area mapped by Scholten (1948) in the extreme southeast corner of the map (pl. 1). According to Kirkham (1927, p. 26 - 27) this thrust finds its possible extension in the thrust fault west of Dillon. The Medicine Lodge sheet is overthrust to the east and Mississippian rocks are superimposed on Triassic strata. The other three thrust faults described by Kirkham (1927, p. 26 - 29) appear to him to be overthrust to the west. Ross (1947, p. 1137) opposes this view and assumes an overthrust to the east. Wallace, Krusekopf, Lipp, Becker (all 1948) and Eardley (personal communication) have mapped thrust contacts in the Tendoy Mountains and southwest of Lima with an overthrust to the east.

3. Gentle folding and high-angle faulting in Tertiary time. The Tertiary volcanic material in this region, supposedly of Oligo- Miocene age, is flexed more gently than the underlying Paleozoic rocks. Later than this folding high-angle faulting took place. Some faults may be revivals of faults formed during Mesozoic time. They strike approximately parallel to the Laramide structures. The faulting was accompanied by tilting of strata up to 30°. Movement along some of these faults has taken place in Recent time (Wallace, 1948, p. 41).

Algonkian deformation

The deformation of the pre-Cambrian rocks in the northeast corner of the area is supposed to have taken place near the close of Algonkian time. Investigations in neighboring regions point to this conclusion (Umpleby 1917, p. 9).

Laramide deformation

Folding. The thick series of Paleozoic sediments has been folded into anticlines and synclines striking northwest. This folding is especially evident in the mountainous part of Nicholia Creek. Two different kinds of folding are present, which accounts for the striking difference in topography between the western and eastern side of the valley near the head of the creek. On the west side broad, fairly gentle anticlines and synclines with an average dip of about 25 - 30° produce a low, grassy divide. Because of much vegetation cover it was not possible to follow the anticlinal and synclinal axes for a long distance and no attempt was made to put these on the accompanying map. On the east side of the creek steeply dipping Mississippian strata are present. Scholten (1948) measured here dips usually greater than 35° and up to nearly vertical. Also overturning of the beds to the northeast has been reported. These steeply dipping strata give the west side of Nicholia Creek a very rugged appearance, especially because no vegetation covers the steep cliffs. The only place on the west side of Nicholia Creek where the Mississippian beds seem to be more intensely deformed is in section 35, T. 16 S., R. 11 W., along the Continental Divide. Here several close folds can be recognized. At the mouth of Nicholia Creek canyon a broad anticlinal structure brings older Paleozoic rocks to the surface. Several minor anticlines and synclines have been mapped here, which all strike in a direction slightly west of north. They show moderate dips. More to the north at the heads of Meadow, Coyote and Tex Creek we find again broad structures, which in places show numerous minor folds on their flanks. These can be clearly seen on the ridge north of Tex Creek, near the head of the canyon in section 2, T. 15 S., R. 12 W. Here the minor folds give a very complicated appearance to the beds, which lie nearly horizontal where the minor folds are absent. The intensely folded masses seem to have a sporadic distribution, a fact also noticed by Ross (1947, p. 1131). He describes a similar folding in the Brazer limestone of the Lemhi Range and believes that it is due to erratically applied localized forces and formed under relatively thin cover. Some plastic deformation has also taken place, which is possible in a limestone already under very light load. In the northeastern part of the area the larger anticlines bring rocks older than the Mississippian to the surface in two places. The structural picture of the Beaverhead Mountains suggests a synclinorium, with the Mississippian strata as the youngest in the center (Anderson and Wagner, 1944, p. 12).

Thrusting. The following observations have led Mr. Scholten and the writer to postulate thrust in the region investigated by them:

1. In the northeastern part of the author's area pre-Cambrian rocks are immediately overlain by Mississippian beds. According to the map of Perry and Sahinen (1946) this situation extends for several miles north of the area covered in this report. A similar condition was thought to exist by Scholten (1948) in the central eastern part of T. 15 S., R. 10 W. But the assignment to the pre-

Cambrian of the rocks found here may prove erroneous. Microscopic investigation showed that the rocks mapped in the field as pre- Cambrian may represent metamorphosed Tertiary granite and contactmetamorphosed limestone (Scholten, 1948).

2. The striking difference in structure between the west and east side of the head of Nicholia Creek, already referred to above. The eastern part is believed to represent the overthrust block and to be more deformed during the overthrusting than it was already before. Overturning to the northeast took place, indicating a force acting in that direction.

3. Not only the structure is different on both sides of Nicholia Creek, but also the character of the Mississippian. This is especially evident at the head of Nicholia Creek, where the western half of the Continental Divide consists of a much darker, more cherty, limestone than the eastern half, which is more shaly. It is suggested that the darker, eastern facies has been thrust eastward over the lighter. If the shales along the west side of Nicholia Creek belong to the Pennsylvanian, as is indicated by one fossil find, then this would mean that we deal with two different formations instead of facies. The Madison would then be thrust over the Pennsylvanian.

4. Along the Continental Divide on the west side of the upper part of Nicholia Creek, a slaty cleavage in the

Mississippian shales was found (pl. 9). This cleavage developed in the underlying block possibly because of the thrusting. Also slickensides found here are evidence of strong movements. The cleavage strikes N. - S., and dips 50° W., whereas the bedding strikes N. 15 E., and dips 35° W. These data also suggest a movement in an eastern direction.

In the southern part of the area the thrust-fault which has been named Beaverhead Thrust by Mr. Scholten and the author, follows the course of Nicholia Creek. At first the trend is north - south. It then changes to north - west to disappear under the Quaternary deposits and the Tertiary volcanic rocks that form the foothills of the Beaverhead Mountains. All along Nicholia Creek the overlying block consists of highly deformed Mississippian rocks. At the lower end of Nicholia Creek valley, where anticlinal folding and high-angle faulting bring up older Paleozoic rocks, Cambrian quartzite is overlain by the Mississippian rocks. Here, however, Quaternary deposits conceal the underlying structures. The panorama along Nicholia Creek (pl. 2) shows the relationships as they are believed to exist along the valley. In the writer's area the Beaverhead thrust appears again in the extreme northeast corner, where the Mississippian is thrust over the pre-Cambrian. A more doubtful outcrop is in the northwest corner, section 1, T. 15 S., R. 12 W. Here, a hasty reconnaissance gave the

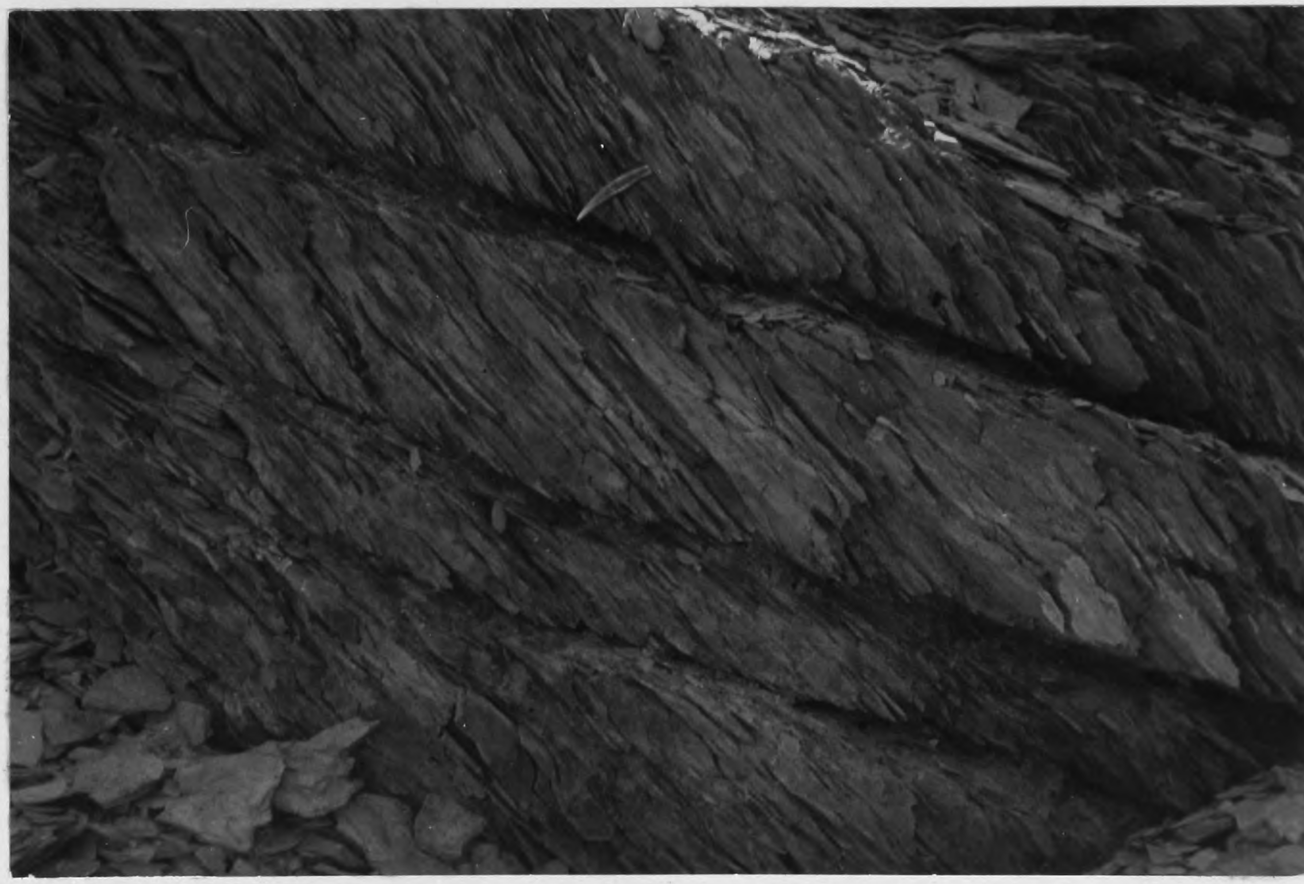


Plate 9. Slaty cleavage in Mississippian strata. In S. W. ¼ section 6, T. 17 S., R. 10 W. Cleavage: strike N - S, dip 50° W. Bedding: strike N 15 E, dip 35° W.

impression that the Cambrian and Mississippian were in fault-contact and that the Cambrian would represent a " klippe ". It is very well possible that a more careful mapping will reveal different relationships.

The Beaverhead thrust has been warped after its formation. The deformation of the thrust plane is evident from the cross-section, A - A' - A" on plate 1, which is at about right angles to the strike of the thrust. A similar deformation has been noticed by Richards and Mansfield (1912, p. 705) in the Bannock overthrust, and they write: " Deformation of fault planes is usually attributed to a renewal of the compressive forces and the folding tends to continue along the lines formerly developed." Also in the Beaverhead thrust the strike of the folds in the thrustplane is parallel to the strike of the older structures. After the deformation the thrust has been broken by high-angle faults. This is also evident in the cross-section. These faults are believed to belong partly to the Laramide deformation, partly to the younger Tertiary deformation.

An accurate determination of the horizontal displacement of the thrust was not possible because of its hypothetical character. In profile A - A' - A" is an indication that the part of the thrust at the right side of the profile might come from the west side of Nicholia Creek. This would give a horizontal displacement of about 10 miles, a figure which is in accordance with other great thrust faults described from the region (Richards and Mansfield, 1912, p. 703).

Faulting. Besides folding and thrusting, normal faulting took place during the Laramide deformation. Large normal faults, which bring different formations in contact with each other, are especially evident in the mountain mass west of the canyon of Nicholia Creek, (pl. 2). The faulting is older than the Tertiary volcanic rocks which overlie the fault and are not broken by it. The relation of the faulting to the Laramide thrusting is difficult to determine. In section 23, T. 16 S., R. 11 W., a normal fault has been cut off by the thrust. Hence here the thrust is younger. More to the west, along the Continental Divide, a large normal fault occurs but its relation to the thrusting is not clear.

In section 21, T. 16 S., R. 11 W., it is evident that the faulting is older than the intrusion of early Tertiary time (cross-section B - B') . Usually the faulting brings Ordovician quartzite in direct contact with the Mississippian limestone. The same kind of faulting occurs a few miles southwestward in Idaho around the Viola Mine, described by Anderson and Wagner (1944, p.12). This would indicate a vertical displacement of about 1500 feet.

Jointing. Of the minor structural features jointing is the most prominent. It is especially well-developed in the Cambrian and Ordovician quartzites. In the latter jointing was observed in section 16, T. 16 S., R. 11 W., where two distinct systems were seen, one strikes N. 25 E. and dips 85 W., and the other strikes N. 21 W., dipping 84 E. At many other places jointing often obscures the original bedding and makes strike and dip determinations difficult.

Tertiary deformation

Folding. In the Tertiary volcanic rocks a broad shallow warping can be observed, which is discordant with the more sharp and well-defined folds in the Paleozoic rocks. The region around the mountainous part of Meadow Creek is especially suitable to study this kind of folding. Some of the local variations in dip in the Tertiary volcanic rocks may be due to doming in the original lavas, as suggested by Ross (1947, p. 1139). Or to the irregularities of the surface over which the lavas were poured out.

Although folding in the Tertiary volcanic rocks is not as evident as in the Paleozoic rocks it has apparently taken place. The deformation probably happened in the Miocene.

It is difficult to prove that the Tertiary folding also affected the basin beds. Gentle monoclinal folds might be present, because variations in dip ranging from 10 to 30 degrees have been observed. The direction of the dip was the same in the basin beds north of Nicholia Creek, where all dips point in an eastern direction. Scholten (1948) has mapped opposite dips 2½ miles due east of Bannack Pass, and here an ill-defined anticline might be present.

Faulting. In the Tertiary rocks faulting of the high-angle type is much more pronounced than folding. It is especially evident along the eastern ridge of Nicholia Creek basin. Here a fairly recent fault is suggested by the escarpment and the triangular facets. The vertical displacement was assumed to be approximately 1500 feet. No accurate determination was possible, because no corresponding beds on both sides of the fault were found. This high-angle fault is the eastern boundary of Nicholia Creek basin. On the west side of the basin no indication of a fault was found. Similar one-sided faulting of Tertiary basins has been described by Mansfield (1927, p. 355). Tilting accompanied the faulting and dips up to 35° were produced in the basin beds. This is much too high to represent an initial dip. According to Blackwelder (1915, p. 113) it is improbable that the fine clays were deposited at angles of even 5° - 10°.

As to the question when these Tertiary high-angle faults came into existence and if they are responsible for the formation of the Nicholia Creek basin, no satisfactory answer can be given. Field evidence only indicates that movement along the faults took place after deposition of the basin beds. But that this was along a pre-existing fault can neither be denied nor confirmed.

Jointing. At one place in N. E. ¼ section 13, T. 15 S, R. 11 W., a well-developed jointing was observed in the basin beds. The two systems show both a dip of 90°, the one striking N 30 W, the other N 45 E, to form a diamond-shaped pattern in the rock (pl. 5) .

Summary of structural events

Important earth movements affected the area at the end of Algonkian time, when the pre-Cambrian sedimentary and igneous rocks were folded, faulted, and metamorphosed. It is possible that similar disturbances of pre-Cambrian rocks had already taken place earlier in the earth history. Discordant on the pre-Cambrian the Paleozoic rocks were deposited. No major disturbances took place during the Paleozoic era. During Mesozoic time the area was probably above sea level and at the end of the Cretaceous period the Laramide revolution took place. Folding and faulting initiated the disturbance, followed by thrusting. A renewal of the compressive forces during the second phase folded and faulted the previous developed thrust. During the whole disturbance the main force pointed in an eastern direction, causing structures generally trending northwest. Rocks were thrust from the west to the east and folds were overturned to the northeast. In Tertiary time, probably Miocene, the area was again subjected to compressive forces, but the deformation was far less pronounced than the previous one. Tertiary rocks were slightly affected and changes in the older rocks are not noticeable. Still later, during the Pliocene (?), important vertical movements took place along high-angle faults. These involved the Tertiary as well as the older rocks. Since then movement has gone on with interruptions up to the present time. Earthquakes are still frequent in this general region.

PHYSIOGRAPHY

Regional features

According to the physiographic map by Fenneman (1930) the area investigated is in the Northern Rocky Mountain Province. The writer agrees, however, with Anderson and Wagner (1944, p. 4) where they write: "...the region seems more like a part of the Great Basin country than of the Northern Rocky Mountains." Ross (1947, p.1140) also makes the same remark and notices that Fenneman places the region of the Lost River, Lemhi and Beaverhead Mountains in the Northern Rocky Mountain Province"... largely because the wide expanse of the Snake River Plain effectively separates it from the mountainous part of southeastern Idaho". The region is characterized by long, parallel ranges, separated by broad, arid valleys. Therefore it is quite different from the dissected upland area that makes the northern Rockies in central Idaho.

Old erosion surfaces

Much has been written about erosion surfaces in nearby areas and especially in Idaho. The existence of some and their assignment to certain periods in the geologic history is still a matter of controversy. A summary of the various hypotheses has been given by Mansfield

(1924 and 1927, p. 354). Kirkham (1927, p. 12) postulates an early Tertiary and a Pliocene erosion surface. Also Ross (1947, p. 1141) assumes two major surfaces; one of pre-Challis age and one of post-Challis age. In the area investigated the older surface was the one which was partly covered by the lavas and is probably of Eocene age. Remnants of it are believed to be represented by the summit of the Beaverhead Mountains, where this has a topography of low rolling hills. The more rugged parts of the mountains, where the divide is sharp, are due to later ice action. Also faulting has probably obscured the original surface. This Eocene surface continues under the basalts and some of the Tertiary gravel mapped as Pliocene might indeed be older than the lavas and belong to the old erosion surface. The lower contact of the lavas shows that they were deposited on a landscape having too much relief to be called a peneplain. The higher parts of the Beaverhead Mountains were probably standing out as monadnocks.

The younger erosion surface is much better defined, and it developed after the deposition of the basin beds. It is assumed to be of Pliocene age. It was nearly featureless and because it only developed along the mountain front leaving the higher parts of the Beaverhead Mountains standing out as a ridge, it can best be called a pediment surface. Remnants of it are found in the Nicholia Creek basin, where it truncates the basin beds. It became dissected later and the basin beds with this erosion surface disappeared from the northern part of the basin. Below this Pliocene surface another plain is found in the basin. This is not a surface of erosion, but one of deposition. Below are the modern flood plains.

Origin of the basins

The origin of the broad intermontane basins in this region is a much discussed subject. Several theories have been proposed. Umpleby (1913 I, p. 17 and 1917, p. 22) assumes that the valleys were formed in the Eocene by stream erosion. Atwood (1916, p. 708) stresses faulting and warping before the basin beds were laid down. Still another solution was proposed by Blackwelder (1917, p. 543), who favors the theory that the basin beds covered a much larger area when they were deposited, that they were downfaulted and subsequently eroded to the broad valleys because they were weak beds between masses of harder rock. Faulting certainly took part in the development of the modern valleys: a fault affecting the basin beds and forming the eastern scarp of Nicholia Creek basin has been mapped. If this faulting occurred only after, or also before and during the deposition of the basin beds, or went on more or less continuously, could not be determined. Shenon (1928, p. 5) thinks that the faulting has been recurrent: the first adjustment defined the valleys, later movements brought the basin beds into fault-contact with the older rocks. The writer assumes that the basins had more or less developed to their present form when they received the Tertiary sediments, as no remnants of basin beds, indicating a former larger distribution, have been found. Erosion, faulting and warping may all three have contributed to the formation of the basins.

Glaciation

Glacial cirques are found at the heads of most major streams. Especially well-developed are those of Nicholia and Meadow Creek. Also a tributary to Nicholia Creek has a small, but perfect cirque (pl. 2). Extensive talus-slopes now cover the oversteepened walls of the cirques. U-shaped valleys, like Nicholia Creek valley, were formed below the cirques. The narrow ridges, cliffs and pinnacles along the Continental Divide are also due to ice action. Eighteenmile Peak was surrounded on three sides by valley-glaciers. Two of these went westward and one eastward down Cottonwood Creek valley. The three glaciers gave the peak the shape of a " horn ". Besides these erosional features also deposition by glaciers is evident. Two different periods of glaciation could be recognized. They have been mapped as belonging to the Bull Lake and Pinedale stage of the Wisconsin period of glaciation. Both left morainic material and the distinction between them has been made largely on their topographic expression. The writer has followed Blackwelder (1915) who gives a description of the glacial deposits in central western Wyoming and points out the differences.

Pinedale stage. The Pinedale stage is the youngest, and its deposits are fresh and almost untouched by erosion. A good example are the two terminal moraines at the junction of Trail and Nicholia creeks (pl. 10). Also the characteristic hummocky topography is present there. It is also very well preserved where Cottonwood Creek enters the basin. Glacial lakes still exist and have not yet been filled. Nearly all lakes of the area occur in Pinedale morainic material and at the foot of the cirque of Cottonwood Creek. The Pinedale moraines are closely related to the present valleys. Their material is little affected by weathering and large boulders are still at the surface.

Bull Lake stage. The Bull Lake stage is slightly older than the Pinedale. Its glacial features are less sharp and the topography consists of a series of low, rolling hills. No typical hummocky surface is present. No glacial lakes exist in its deposits, and some that once existed have been completely filled. The till is not in

Plate 10. Terminal moraines and hummocks of Pinedale age. Rounded hills to the left are Bull Lake moraine deposits. In foreground Trail Creek, uniting with Nicholia Creek, which crosses the basin. Smooth terrace along Nicholia Creek. East Ridge across basin (distance 10 miles) is Madison limestone. At the right side of the picture is Madison limestone, light colored, and Tertiary volcanic rock, dark. Ridges of basin beds in the basin difficult to distinguish. Photo taken from Cambrian quartzite, looking east.

close relationship with the modern valleys, but is found all along the mountain front and blends into the modern terraces. No large boulders are found at the surface. The glaciation of the Bull Lake stage was of greater extent than that of the Pinedale. Perhaps a piedmont-glacier existed, whereas the Pinedale glaciers were valley types.

Terraces

The greater part of Nicholia Creek basin and especially the northern half of it is occupied by river terraces. Along Nicholia Creek two distinct terraces can be recognized, besides the present flood plain. The younger one is of less extent. All terraces have been mapped as one unit. They are thought to have been deposited by glacial streams carrying much outwash. The higher very extensive terrace was formed during Bull Lake time. Another was deposited during Pinedale time.

Summary of post-Cretaceous physiographic events

At the end of the Cretaceous period or during early Eocene time intrusion took place and the already previously folded strata were uplifted. Mountains were formed, which were continuously attacked by erosion. In fact, erosion had produced a subdued topography by the end of Eocene time. During the Oligocene lava flows were poured out on the surface together with mudflows from nearby volcanoes. Renewed uplift took place and the development of parallel, northwesterly trending basins started. Faulting and warping together with erosion may have been the cause. During the Mio-Pliocene these basins were filled with sediments derived from the adjacent lands and volcanic ash blown in. It was a time of erosion in the mountains and deposition in the basins. Volcanic activity also went on during the Miocene. In Pliocene time the highlands were worn down and the basins filled. A landscape of low relief resulted. In middle Pliocene faulting took place, causing a rejuvenation of the streams, which started to erode and formed a pediment surface, truncating the basin beds. This time the material was carried away and not deposited in local basins. Regional uplift and rejuvenation of faults went on into Pleistocene time and part of the basin beds was eroded away. Then valley glaciers came into existence, spreading out at the foot of the mountains and forming a piedmont glacier during the Bull Lake stage of glaciation. In flood stage the streams were full of water from the melting ice. They carried away material from the till, and deposited it as river terraces between what was left of the basin beds. Glaciation during the Pinedale stage was not as severe as during the previous Bull Lake stage. When the glaciers receded they left moraines, which are still very well preserved. At some places lakes developed in them. Also in the higher parts of the mountains the ice had wrought some changes: glacial cirques and a rugged divide. No glaciers are left, but some snow banks are persistent throughout the year. The meltwater of the Pinedale glaciers cut the older terraces and deposited sand and gravel in terraces which are of less extent than those of the Bull Lake stage. At the present time erosion is active in the mountains and cut-and-fill in the basin.

ECONOMIC GEOLOGY

Mineral deposits

General remarks. No operating or abandoned mines are present in the area, but at two places prospect holes were noticed. The geology of each is of different character and will be treated separately.

Prospect hole no. 1. Near quarter section marker 30 ; 31, T. 15 S., R. 11 W., several prospect pits are present. Here we find unaltered, brown, and shattered basalt and andesite tuff. In the immediate vicinity of the prospect pits the color is green in different shades. A zone, about 50 feet wide of the green volcanic rocks runs through the brown. The green color decreases in intensity toward the contact with the brown rock. Translucent white and bluish quartz was found in the altered zone, as well as brown banded chalcedony. Microscopic investigation revealed that hydrothermal alteration had taken place. Chlorite, sericite, limonite, carbonate, and quartz were the most important secondary minerals. No ore was found. Umpleby (1913 I, p. 54 - 57) describes similar mineralizations in nearby Idaho, as belonging to the epithermal group. Here the zones carry microscopic gold and silver.

<u>Prospect hole no. 2</u>. Prospect pits are also found about 1000 feet north of Montana - Idaho boundary, marker no. 574 in section 36, T. 16 S., R. 11 W. The pits are about 3 feet deep and are made in gray limestone, with a gossan of quartz and limonite. The oxidized outcrop is close to the Kinnikinic quartzite, which is here faulted against the Paleozoic limestones.

The report of Anderson and Wagner (1944) mentions similar conditions in the Birch Creek district, Idaho. There all the deposits, except one, are in limestone and lie within a few hundred feet of the quartzite. The ore of the district is mainly oxidized and the chief ore minerals are secondary, mostly carbonates of lead, zinc, copper. The mineralization belongs to the mesothermal type (Anderson and Wagner, 1944, p. 15 - 16) .

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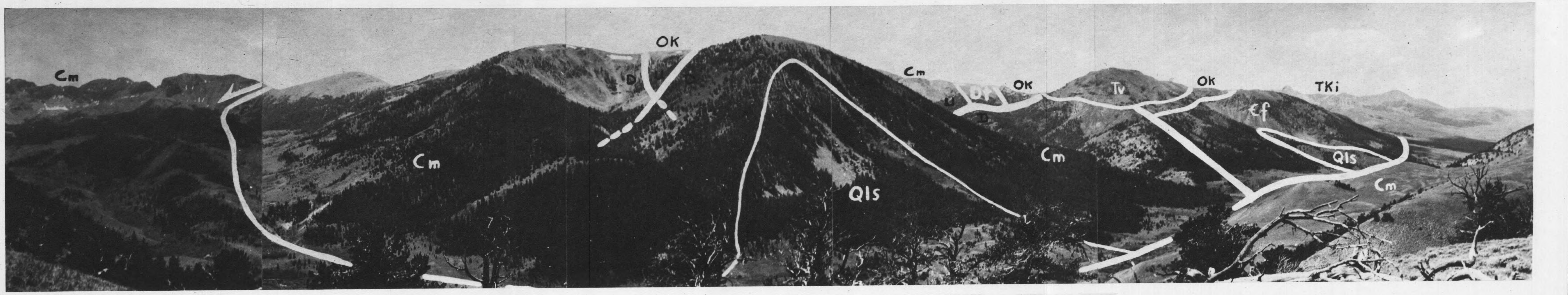

Plate 2: Panorama along the western side of the mountainous part of Nicholia Creek.

The Continental Divide forms the skyline in the background and is shown at the right and at the left of the panorama and in the middle of the second strip from the right. At the left is the head of Nicholia Creek, and the extreme right shows part of Nicholia Basin. A glacial cirque is shown in the middle of the picture and two landslides are indicated by Qls.

Beaverhead Thrust is in the foreground. At the left Cm is thrust over Cm and at the right Cm over older rocks, mainly Ꞓf. Three high angle faults are shown in the mountains west of Nicholia Creek. These mountains are partly capped by Tertiary volcanic rocks.

Qls = Landslides; Cm = Madison (?) limestone; Dt = Threeforks formation; Ok = Kinnikinic quartzite; Ꞓf = Flathead (?) quartzite; Tki = granitic intrusive; Tv = Mio-Pliocene lava flows and breccia.
U = up; D = down.

NO MAP IN

FOLDER.

JM

7-5-82