G429 Field Geology

in the Rocky Mountains

Guidebook

BLOOMINGTON, INDIANA, TO INDIANA UNIVERSITY
GEOL O GIC FIELD STATION, CARDWELL, MONTANA

DEPARTMENT OF GEOLOGY
INDIANA UNIVERSITY
GUIDEBOOK

Bloomington, Indiana, to Indiana University Geologic Field Station
Cardwell, Montana

Prepared for the course

GEOL OGY G429 FIELD GEOLOGY IN THE ROCKY MOUNTAINS

By

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DEPARTMENT OF GEOLOGY
INDIANA UNIVERSITY
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The uniformly excellent quality of the illustrations is due to the fine work of William H. Moran and the drafting section of the Indiana Geologic Survey. Their help is gratefully acknowledged.

Thanks are given also to Gerald Woodard and William Hanna who have kindly criticized drafts of the guidebook.
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INTRODUCTION

The Department of Geology at Indiana University offers course 0429, Field Geology in the Rocky Mountains, as a part of its geologic training program and a requirement for the Bachelor of Science degree. This guidebook is intended to provide basic information about the geology along the route from Bloomington to the Field Station during the first part of the course. The book is in two parts. The first contains detailed road logs for most of the trip, and includes short descriptive sections on points of geologic interest along the way. The second part, beginning on page 94, contains general information on the regional geology and geologic history of broad segments of the middle and western United States, and somewhat more detailed information on the geologic setting of specific areas such as the Black Hills, and the Bighorn Region.

The trip from Bloomington to the Indiana University Geologic Field Station in Montana takes approximately nine days and serves as an introduction to the study of field geology. The trip is designed primarily to give the student a view of the regional geology of the Central Stable Region and the eastern Cordillera.

West from Bloomington the trip enters an area of extensive continental glaciation. Moraines, till sheets, and a host of other glacial features are presented in abundance in Indiana, Illinois, Iowa, and South Dakota. In the White River Badlands and the Black Hills of western South Dakota the geologic story of the Rocky Mountains begins to develop. Chapter after chapter of this story unfolds with exciting rapidity on the westward journey across Wyoming and into Montana.

We urge participants to take full advantage of this opportunity to see the Rocky Mountains and to learn all they can about their geology. You will never again see so much new and interesting geology in such a short period of time.
Figure 1. -- Geologic strip map, Indiana and eastern Illinois. From state geologic maps of Indiana, 1936, and Illinois, 1945.
FIRST DAY: ROAD LOG FROM BLOOMINGTON, INDIANA, TO OTTUMWA, IOWA

0.0 Leave parking lot behind Geology Building. Turn left on 10th Street and proceed eastward. The Geology Building rests on Salem Limestone, (Mississippian).

0.9 Rail underpass.

1.2 Intersection of 10th Street and Indiana 46 Bypass. Turn left (North) on Bypass.

1.7 St. Louis Limestone well exposed in road cuts on both sides of road. Blue-gray, laminated, dolomitic limestone; excellent marker horizon for Mississippian limestones of the Mitchell Plain. To the west at Spencer evaporites begin to appear in the St. Louis at this horizon.

2.1 Salem Limestone. Note massive bedded character.

2.6 Thick red residual soil (Terra Rosa) over Salem Limestone. Typical of soils developed over limestone in this area.

3.1 Harrodsburg-Salem Limestone transition beds. New IU stadium visible to left.

3.5 Intersection of Indiana 37 and Indiana 46. Good crossbedded limestone on left. Turn left (south) on Indiana 37.

4.0 Stoplight. Intersection of Indiana 37 and Indiana 46. Turn right (west) onto Indiana 46. The rolling topography both to the left and the right is typical of the topography developed on the Mississippian limestones in the Mitchell Plain.

4.8 Base of the St. Louis Limestone on the right.

5.3 Hoisting frames of the Texas Co. and B. J. Hoadley limestone quarries to right and left of road. Salem Limestone is removed in large blocks from these quarries and used for building purposes.

6.2 B. J. Hoadley limestone mill on left. Salem Limestone exposed along road to the right.

6.4 Cross Stout's Creek. Thin-bedded Harrodsburg Limestone exposed in creek bottom.

8.0 Poor, but typical exposure of St. Louis Limestone.

10.4 Cross Jack's Defeat Creek and enter the village of Ellettsville.

10.8 Stoplight.
13.0 View of old bed of Glacial Lake Flatwoods to left of road.

This broad, flat area west of Ellettsville and southeast of Indiana Highway 46 was once the site of an ice margin lake known as Glacial Lake Flatwoods. Lake Flatwoods formed when Illinoian ice reached a terminal position along the south bank of White River near Spencer and effectively blocked the drainage from this segment of the Mitchell Plain. The level of the water in the lake rose slowly until it submerged all but the highest hills in the area. Gradually an outlet was worn southward into White River via Racoon Creek. Later, as the Illinoian ice retreated, the ice dam to the northwest was removed and a new outlet was started into White River over the present course of McCormicks Creek. At the time of its maximum development Glacial Lake Flatwoods is believed to have occupied an area of about 10 square miles.

13.6 Small sinkhole on the right; developed in the St. Genevieve Limestone.

15.4 Small quarry in hillside ahead and to the right is in the St. Genevieve Limestone. Lithographic, tan-colored limestone. Old county highway crushed stone quarry.

15.8 Leave Monroe County; enter Owen County.

15.9 St. Genevieve Limestone in road cut to right. Notice how ground water solution has widened joints and allowed red soil to wash down into rock.

16.4 Upper Mississippian (Chesterian) rocks well exposed in deep road cut. Bethel Formation - upper 6-7 feet thin-beded shaly sandstone. Underlain by about 15 feet of dark-gray carbonaceous shale.

16.5 Paoli Limestone on right at west end of road cut. Gray, oolitic limestone.

18.0 Intersection of Indiana 43 and Indiana 46. Continue straight ahead on Indiana 46. Illinoian till caps hill to the left. This is the approximate boundary of Illinoian glaciation in this part of Indiana.

18.1 Entrance to McCormicks Creek State Park.

18.8 Slumping in sandy till over St. Louis Limestone to right. This has occurred within last two years since construction of new roads.

18.9 Excellent solution collapse features in St. Louis Limestone to right.

19.4 Bridge across the White River. During Wisconsin glaciation the White River was an active sluiceway carrying glacial debris southward from the ice margin. As a result it developed a wide flood plain over much of its course. Here at Spencer, however, the river was confined by a narrow bedrock gorge and the flood plain is not very wide.

19.5 St. Louis Limestone on the right. This exposure marks the approximate eastern edge of an important evaporite basin in the St. Louis Limestone. To the south and west in Owen, Greene, and Martin counties individual gyspum beds reach thicknesses of over 10 feet.
19.7 Enter the town of Spencer. Continue straight ahead on Indiana 46.
20.8 Bear right on Indiana 46 leaving Spencer.
21.7 Crushed stone quarry in hillside on right. St. Genevieve Limestone.
22.0 Ascending small hill which is an outlier of the Crawford Upland. Bedrock is the Chester Series. Note well-developed sinkholes.
22.6 Back into Mitchell Plain. Old quarry on right in St. Genevieve Limestone.
23.2 Cross Rattlesnake Creek.
23.6 Ascend hill onto Crawford Upland. Bedrock is alternating sequence of shale-sandstone and limestone.
24.8 Typical Crawford Upland topography on both sides of the road.
26.0 Mansfield sandstone (basal Pennsylvanian) exposed in road cut on left.
29.2 Mansfield sandstone. Crossbedded. Note slumping. Occasional low exposures of yellow, orange or brown sandstone, probably Mansfield sandstone, occur along Indiana 46 to Bowling Green.
36.3 Village of Bowling Green.
36.8 Cross Kel River. Extensive floodplain due to fact that Kel River was a glacial sluiceway.
39.0 Tailings piles (left) from old coal-stripping operation. For the next three miles there are numerous strip pits on either side of the road. The coal removed in these pits was the Lower Block Coal of Pennsylvanian (Atokan) age.
41.8 Stop Sign. Intersection of Indiana 46 and Indiana 59. Continue straight ahead.
42.8 Cross drainage ditch. Low flat area just beyond last major road intersection is part of the Wabash Lowland physiographic province. Perhaps the dominate feature of this area is the broad, flat-floored valley of the Wabash River, which in places reaches a width of 15 miles.
45.6 Flat area is Illinoian till plain.
48.9 Leave Clay County, enter Vigo County.
52.0 Riley City Limit.
58.3 Intersection of Indiana 46 and Indiana 42. Turn left after stop.
59.8 Stoplight. Entering the city of Terre Haute. Follow the lead car through Terre Haute.
Figure 2.—Glacial geology of Indiana and Illinois. After G.S.A. glacial map of the United States east of the Rocky Mountains, 1959.
Figure 3.--Sub-Pennsylvanian geologic map of Illinois. From geologic map of Illinois, 1945
Figure 4.—Bedrock geology at Champaign - Urbana, Illinois. After geologic map of Illinois, 1945.
Figure 5.--Geologic strip map, east-central Illinois. From geologic map of Illinois, 1943.
Figure 6.—Geologic strip map, west-central Illinois and southeastern Iowa. After state geologic maps of Illinois, 1945, and Iowa, 1937.
Figure 7.—Geologic strip map, southeastern Iowa. After geologic map of Iowa, 1937.
Just after crossing the Wabash River at Terre Haute, we cross the Wisconsin (Chancellor) boundary, which is well marked by the Shelbyville Moraine. Follow our route shown on the glacial maps, figures 1 and 2, and you will be able to recognize the elaborate moraine systems from here to Champaign-Urbana.

STOP: Nira Station, about 1/4 miles north of Villa Grove, to discuss the major events of Pleistocene history in the upper Mississippi Valley. The caravan will park in the schoolyard to the right of the highway.

Notice on figures 3 and 4 that Champaign-Urbana is on the LaSalle Anticline. The age of the bedrock beneath the drift in this region ranges from Pennsylvanian to Devonian.

Lunch in Urbana.

We are traveling on the Champaign-Urbana moraine systems from Champaign-Urbana to beyond Mahomet. Notice the typical hummocky topography. We leave Wisconsin drift and enter Illinoian drift area about 1/4 miles west of McLean, Illinois. What differences do you see in the amount of dissection?

At Havana we cross the Illinois Valley. This valley has been an important glacial sluiceway, and the valley-train material has served as a major source for the loess (windblown silt) that is found throughout Illinois. Evidence of wind activity is seen in the sand dunes on the flood plain of the Illinois River.

At Hamilton, Illinois, we cross the Mississippi River and enter the area of Kansan drift. The bedrock exposed in the valley walls is dominantly limestone of middle Mississippian age. The Mississippian rocks are overlain by Pennsylvanian sandstone and shale. Do these rocks look like the ones we saw in the vicinity of Bloomington? The mantle rock is till of Kansan and Illinoian age and loess of Wisconsin age on the uplands. Glacial fluvial material of Pleistocene age is found in the river valley.

In preglacial time there was no single, large stream along the course of the present Mississippi River in this area. The major stream of the area was in a channel extending eastward from Rock Island, Illinois, to about LaSalle-Peoria, Illinois. The stream valley followed the present Illinois Valley southward and then down the present Mississippi Valley south of Alton, Illinois. An ice lobe of Illinoian age forced the Mississippi River to form a new channel to the west around the edge of the lobe. The channel has been traced into Iowa several scores of miles west of the present Mississippi Valley. As the ice of the lobe melted, a “shortcut” was found by the stream between Clinton, Iowa (to the north) and Keokuk.

OTTOBRA, IOWA. Stay at the CHEERY HOTEL.
Figure 8.--Geologic strip map, south-central Iowa. Taken from geologic map of Iowa, 1937.
Figure 9.—The Des Moines and Dakota Glacial Lobes in Iowa, Minnesota, and South Dakota. Taken from G.S.A. glacial map of the United States east of the Rocky Mountains, 1959.
Figure 10.—Geologic strip map, central Iowa. After geologic map of Iowa, 1937.
SECOND DAY: ROAD LOG FROM OTTUMWA, IOWA, TO SIOUX FALLS, SOUTH DAKOTA

Our route across Iowa to Sioux Falls, South Dakota is over the northern part of the Forest City Basin. Near Des Moines we leave the area of Kansan drift and enter the region covered by the Des Moines Glacial Lake (Wisconsin). See figure 10 on page 15.

STOP: Fort Dodge, Iowa. Visit a gypsum pit. See sketch below.

Figure 12.—Section through gypsum pit, Fort Dodge, Iowa. After Thomas, 1960.

The Fort Dodge gypsum field outlier occurs in a small basinal area of some 60 square miles. The gypsum attains a maximum thickness of about 30 feet. The age of the Fort Dodge Fm. is questionably placed as Permian, although the deposit can be as old as late Pennsylvanian and may be Cretaceous or younger. Prominent distorted gray and white bands suggests that the evaparite may have been deposited originally as anhydrite and later hydrated to gypsum.

Lunch in Fort Dodge, Iowa.
STOP at Midwest Limestone Co. quarry, Gilmore City, Iowa.

The Gilmore City Formation is best known for the beautiful whole crinoids which it has yielded. The age of the formation is essentially early Mississippian Kinderhookian, but Osage fossils occur at the top; however, the upper beds are eroded from this area and the bottom of the quarry is not far from the base of the formation. (Covered thickness 55 ft. at this stop)

Just west of Laurens, Iowa, our route crosses the present eastern edge of the Cretaceous overlap. At about the same time we cross from upper Wisconsin (Mankato and Carv), to lower Wisconsin (Iowan) and Kansas drift. Just east of Sioux Falls the Iowan drift border is crossed again. Sioux Falls is built on a thin cover of Cary drift of the Dakota Glacial Lake. The bedrock at Sioux Falls is the Sioux quartzite of late (?) Precambrian age (1,2 b.y.). Look for exposures of the Sioux quartzite as we approach Sioux Falls.

In late Cretaceous time a shallow sea transgressed eastward across this area, and may have extended as far east as the present position of the Mississippi River. At first the Sioux quartzite stood as an island in the Cretaceous sea, but at times of maximum sea invasion it was covered.

SIoux FALLS, SOUTH DAKOTA. Stay at the PLAZA MOTEL.
Figure 15.--Geologic strip map, northwestern Iowa II. From geologic map of Iowa, 1937.
STOP: Sioux Falls, South Dakota. Sioux quartzite quarry.

Figure 16.—Photograph of a large quarry in the Sioux Quartzite, Sioux Falls, South Dakota.

The fresh, unaltered quartzite in this quarry is pink to red in color, well indurated, and in general looks very much like the Baraboo quartzite of Wisconsin and other middle Precambrian quartzites of the Lake Superior region. Recently, however, Goldich (1950) reports a date of 1.2 b.y. for the Sioux Quartzite of Minnesota (just to the northeast of Sioux Falls), suggesting a late Precambrian age for this rock.

From Sioux Falls to Chamberlain, South Dakota, we traverse the Dakota Lobe and cross from Cary drift into Mankato drift, and back into Cary drift. The Altamont and Cary Moraines are crossed twice. Between Plankinton and Kimball we cross into drift of the Iowan substage. The Missouri River at Chamberlain approximates the continental drift border. Compare the landforms developed on material of various ages that we have crossed. Explain any variation in these landforms.

The complexion of the trip west changes rather suddenly at Chamberlain, South Dakota. Extensive sheets of glacial drift are now behind us to the east; the Badlands and the Black Hills of South Dakota lie ahead to the west.

Missouri River. Niobrara limestone exposed in the lower part of the valley.

STOP: Caravan will make a short stop on the west side of the river to examine the deep road cut where black shales of the Pierre Formation (Cretaceous) are exposed.
Figure 17.--Geologic strip map, eastern South Dakota. Taken from geologic map of South Dakota, 1953.
Figure 19.—Geologic strip map, central South Dakota. Taken from the geologic map of South Dakota, 1953.
UPPER CRETACEOUS

Pierre Formation - 500 - 1,300 feet.

Elk Butte Member (60-110 feet) - medium-gray fine-textured shale; weathers to gumbo; sandy toward top; Type - Corson County, South Dakota.

Mobridge Member (136 feet) - highly calcareous shale and marl; weathers buff; Type - Mobridge, South Dakota.

Virgin Creek Member (97-125 feet) - silver-gray shale below, gumbo-forming gray shale above. Sage Creek fauna.

Verendrye Member (160 feet) - gumbo-forming shale with large iron-carbonate concretions.

DeGrey Member (40-160 feet) - clay and shale; light-gray silicious shale to dark-gray bentonitic clay with many iron-magnesium concretions. Vertebrate remains common in silicious phases.

Crow Creek Member (15 feet) - sandstone and calcareous shale.

Gregory Member (34 feet) - gray shale with bands of concretions, calcareous layers, and locally marl at base; Type - Gregory County.

Sharon Springs Member (7-175 feet) - fish-bearing bituminous shales.

Niobrara Formation - 200 feet - dark-gray shale on fresh surface; weathers yellow to white.

1. What are the clear to translucent crystals lying about on the outcrop? What is their origin?
2. What are the cream-colored layers? What is their origin?
3. What sort of depositional environment does the rock suggest?

The route from Chamberlain to the White River badlands is across Pierre shale of Cretaceous age.

Lunch Murdo, South Dakota

About 25 miles west of Murdo you should be able to see the Badlands in the distance, to the left and ahead.

After leaving the White River Badlands we take U. S. 16A to Wall, South Dakota and thence west to Rapid City via U. S. 16. About 3 miles east of Rapid City, we see a low pine-covered hogback ridge on the right. This is the outermost hogback of the Black Hills and is underlain by the Moery Shale of Cretaceous age.

RAPID CITY - Stay at the MARCO MOTEL.
UPPER CRETAUCEOUS

Pierre Formation - 500 - 1,300 feet.

Elk Butte Member (60-110 feet) - medium-gray fine-textured shale; weathers to gumbo; sandy toward top; Type - Corson County, South Dakota.

Mobridge Member (136 feet) - highly calcareous shale and marl; weathers buff; Type - Mobridge, South Dakota.

Virgin Creek Member (97-125 feet) - silver-gray shale below, gumbo-forming gray shale above. Sage Creek fauna.

Verendrye Member (160 feet) - gumbo-forming shale with large iron carbonate concretions.

DeGrey Member (40-160 feet) - clay and shale; light-gray silicious shale to dark-gray bentonitic clay with many iron-rich magnetite concretions. Vertebrate remains common in silicious phases.

Crow Creek Member (15 feet) - sandstone and calcareous shale.

Gregory Member (34 feet) - gray shale with beds of concretions, calcareous layers, and locally marl at base; Type - Gregory County.

Sharon Springs Member (7-175 feet) - fish-bearing bituminous shales.

Nobrarara Formation - 200 feet - dark-gray shale on fresh surface; weathers yellow to white.

1. What are the clear to translucent crystals lying about on the outcrop? What is their origin?
2. What are the cream-colored layers? What is their origin?
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RAPID CITY--Stay at the MARCO MOTEL.
Figure 20.--Geologic strip map, the White River Badlands and west-central South Dakota. From geologic map of South Dakota, 1953.
And so began the stampede to the Black Hills of South Dakota. This was to be one of the last great gold rushes in the western territories, and the more or less professional prospectors from the gold camps of Montana, Wyoming, and elsewhere were determined to make it a good one. A rather complete assortment of characters, including actors, assayers, bankers, blacksmiths, bullwhackers, bums, bumbo artists, clowns, doctors, engineers, gamblers, geologists, lawyers, merchants, newspapermen, professors, prostitutes, saloonkeepers, and undertakers soon arrived on stage to complete the scene.

The gold was in the gravels along French Creek in the southern Black Hills and along Deadwood Gulch in the northern hills. Gold was discovered along French Creek in the fall of 1875 and in 3 short months the population of Custer exploded from 6 to 10,000. Gold was found in Deadwood Gulch at about the same time, but the news seems to have been lost on the excited citizenry of Custer—at least until the spring of 1876. Then a mass exodus began to Deadwood. By midsummer only 250 people were left in Custer, but Deadwood had a population of 25,000.

Progress came swiftly to this once-bypassed area, however. By 1880 the northern part of the Black Hills was linked to the outside by several rail lines. Wild Bill Hickok was rotting in his grave on Mt. Moriah, and Calamity Jane had rolled her last drunk. The frontier days of Deadwood were over.
Figure 21.--Geologic strip map, the Black Hills of South Dakota. After the geologic map of South Dakota, 1953.
We shall spend approximately 1-1/2 field days in the Black Hills. In this time you will examine the entire stratigraphic section, see two important pegmatites near Keystone, visit the world-famous memorial on Mt. Rushmore, study some structures in the Precambrian and see the structure of the post-Precambrian strata. Remember that you are looking at what many geologists consider to be the easternmost exposure of the Rocky Mountains. Remember, also, as you look at the rocks, structures, etc., that fieldwork is more than mere gathering of data. You should begin to form impressions, to generate ideas about the things you are seeing. Some of the things you should speculate about in the Black Hills are:

1. The nature of the eastern part of the Cordilleran geosyncline during its existence. For instance, why is the Cretaceous section in the Black Hills predominantly clastic, and why is it so much thicker than the Paleozoic section?

2. The absence of Silurian and Devonian strata from the Black Hills. Are they missing because of nondeposition, or were they eroded?

3. Variations in the thickness and lithology of the strata exposed in the Black Hills. For instance, why is the Deadwood Formation 500 feet thick at Deadwood, 200 feet thick at Rapid City, and only 6 feet thick in the southern Black Hills?

4. The origin of the pegmatites at Keystone. Are they directly related to the Harney Peak Granite? Do they represent late stage fluids from the Harney Peak magma, or are they of later vintage? Are the pegmatites fracture fillings, or are they replacement bodies? How can spodumene single crystals grow to lengths of 42 feet?

5. The Harney Peak Granite. How was it emplaced? Is it a "granitized" granite, or is it a "magmatic" granite? Was it formed in place from pre-existing rocks, or did it come in as a fluid body? If the latter is true, did it eat its way in? If so, its way in? force its way in?

6. Origin of the Black Hills structure. Was the force that folded the Paleozoic and Mesozoic envelope directed vertically or horizontally? When did this deformation take place? Do the folds in the Precambrian date from this same period?
Figure 22.—Geologic strip map and Paleozoic section at Rapid City, South Dakota. After Darton and Paige, 1925.
DAKOTA SANDSTONE ........................................ 45 feet
Upper part: brown slabby sandstone 15 feet thick.
Lower part: massive dark-weathering sandstone 30 feet thick. Contains 5 feet conglomerate

FUSION SHALE ............................................. 100 feet
Upper Member: dark shale
Middle Member: light-colored mudstone
Lower Member: clay shale; thin limestone at base

LAKOTA SANDSTONE ....................................... 150 feet
Sandstone: buff, massive, hard, 40 feet
Shale: 20 feet
Sandstone: buff; weathers brown; 5 feet
Shale: 20 feet
Sandstone: coarse, slabby to brown; weathers brown; 30 feet

MORRISON FORMATION .................................... 170 feet
Greenish-gray shale; thickness varies greatly north and south of Rapid City.

UNKPAPA SANDSTONE ................................... 125 feet
Soft white massive sandstone.

SUNDANCE FORMATION .................................... 275 feet
Sandstone: buff, hard, slabby; grading into sandy shale; 0 to 20 feet
Shale: dark-gray to greenish gray, with concretions; hard beds of fossiliferous limestone and thin beds of sandstone; 100 to 125 feet.
Sandy shale or impure sandstone: reddish color; 50 feet
Buff sandy shale, merging down into fine sandstone; 20 feet
Sandstone: fine, moderately hard, buff to faintly reddish; massive to slabby beds; strongly ripple marked; cliff maker; 10 to 40 feet.
Shale: dark-gray or greenish; 50 feet
Sandstone: buff, massive; 0 to 8 feet

SPRAWLISH FORMATION ................................ 600 to 700 feet
Red shales and sandstones with two persistent gyspum beds: one 6 to 30 feet thick about 100 to 150 feet above the base of the formation, and a second gyspum bed 8 to 25 feet thick near the top of the formation.
Includes Nugget and Gypsum Springs formations.
Poorly exposed in Red Valley west of Rapid City.

Figure 23.—Stratigraphic section of the Mesozoic rocks at Rapid City, South Dakota.
FOURTH DAY: ROAD LOG FOR THE SOUTHERN PART OF THE BLACK HILLS

About five miles west of Rapid City the Paleozoic section is exposed in the walls of a deep gorge cut by Rapid Creek. See figure 22 on page 30.

Lunch: Rapid City

After lunch the caravan will regroup facing east on the south side of the city park. Proceed eastward to intersection with U.S. Highway 16. Turn right (south).

0.8 Road is on GRANERO SHALE; terrace gravels to left. DAKOTA-LABOTA hogback is right.

1.1 Brown laminated DAKOTA SANDSTONE.

2.2 Road on terrace gravels. Harney Peak, the highest point in South Dakota at 7,242 feet, on horizon to southwest. Note badlands in distance to east.

2.75 Reptile Gardens.

6.2 Start down hill. Observe greenish-gray laminated sandy and calcareous shale of the UPPER SUNDANCE as we pass down through the section. Towenites denseus.

6.5 Passing through the SUNDANCE FORMATION. At this locality the Sundance consists of three prominent divisions. The upper Sundance consists of about 115 feet of massive glaumonic buff-colored sandstone and highly fossiliferous greenish-gray calcareous shale. The middle part, about 70 feet thick, consists of pink soft massive sandstone and red sandy shale. The lower part is about 40 feet thick and consists of buff marine sandstone and fossiliferous greenish-gray shales.

7.0 Crossing SPEARFISH Valley.

7.35 Gypsum in LOWER SPEARFISH. Note veined and disseminated character.

7.55 MINNIEKAHA purple to gray laminated limestone.

7.75 MINNIEKAHA in road cut, left and right. We are driving up a dip slope.

9.3 Red laminated crossbedded sandstone in top of MINNIEKAHA or in base of OPRICH.

10.1 Crest of hill. MINNIEKAHA in road cut. Harney Peak ahead in the distance, slightly to left.

11.0 Now driving on PAPASAPA.

11.3 PAPASAPA in road cut. Near contact with underlying BROOKWOOD. Contact covered.
11.5 DEADWOOD SANDSTONE in road cut to right. Deadwood here is about 150 feet thick. WHITewood FORMATION absent.

12.0 Precambrian schists in road cut, right. We now drive on Precambrian rocks for many miles, passing over schists, quartzites, granulites, and other metamorphic rocks, intruded by dikes and sills which become more numerous as we approach the Harney Peak granite.


19.6 Tunnel. Foliation in gneiss parallel to strike of tunnel.

20.2 Village of Keystone.

Keystone is in the center of a swarm of pegmatites that occurs on the northeast side of the Harney Peak Granite. There is considerable speculation about the relationship between the pegmatites and the granite. Several observations are pertinent:

(1) The pegmatites have not been seen to connect with the Harney Peak Granite to the depths yet reached in mining and exploration of the pegmatites.

(2) Both the pegmatites and the granite are tourmaline rich.

(3) The Harney Peak Granite is coarse-grained, in places approaching a pegmatite.

(4) Pegmatites in the southern Black Hills are found only around the margins of the Harney Peak Granite.

(5) Pegmatites at Keystone have been dated (Kulp) at 1.6 b.y. This would place them in the middle Precambrian, or the same era postulated for the Harney Peak Granite (Paige).

About half a mile south of Keystone we will turn left off U.S. 16 and take the secondary road to theitta Mine.

THE ITTAA PEGMATITE. The Itta Pegmatite is the leading lithium producer in the Black Hills. It began as a mine prospect shortly before 1883, became a tin mine when cassiterite was found in 1883, and finally became a lithium mine under the ownership of the Maywood Chemical Company of Maywood, New Jersey. The pegmatite is on a small knob, known as Itta Knob, about 1 mile south of Keystone,
NW 1/4 section 16, T. 2 S., R. 6 E. (See sketch map below.) The pegmatite is found in a fine-grained gray schist consisting principally of quartz and biotite with scattered grains of garnet, muscovite, and tourmaline. The pegmatite is roughly oval in plan with dimensions of 250 by 200 feet. Mining operations have shown it to be a pipe-like body that plunges steeply to the north.

Figure 55.—Etta Pegmatite, Black Hills, South Dakota. From Schwartz, 1925.

The Etta Pegmatite is a zoned pegmatite as follows:
1. Border zone - 5 feet thick zone of altered schist.
2. Wall zone - 5 to 15 feet thick; plagioclase-quartz-muscovite. Grades into perthite-quartz over the top of the pegmatite.
3. Intermediate zone - spodumene, with some albite.
4. Core - quartz.

Single crystals of spodumene 10 to 20 feet long are commonly found in the Etta Pegmatite. One "log" of spodumene measuring 48 by 6 by 3 feet was uncovered in 1904. Other minerals that may be found at the Etta mine include quartz, albite, microcline, oligoclase, muscovite, columbite, tantalite, lepidolite, epidote, beryl, cassiterite, biotite, tourmaline, and opal.

After examining the Etta Mine we will skip over to the Hugo pegmatite.

The Hugo Pegmatite. The Hugo Pegmatite is the leading feldspar producer in the Black Hills. It is about 1,000 feet west of the Etta Pegmatite in the NE 1/4 sec. 17, T. 2 S., R. 6 E.

The Hugo Pegmatite is considerably larger than the Etta Pegmatite, measuring 700 by 400 feet. The long axis of the pegmatite trends in a N120°W direction; the body appears to be dipping eastward.
The pegmatite is enclosed in a fine-grained quartz-biotite schist. Four mineral zones are recognized within the pegmatite:

1) Wall zone - muscovite-beryl
2) Intermediate zone A - K feldspar and mica
3) Intermediate zone B - subhyaline-perthite-quartz
4) Core - spodumene-quartz.

Microcline is the chief mineral mined from the Hugo Pegmatite.

Return to U.S. 16A. Turn left and proceed for 0.6 mile to intersection. Turn right for Mt. Rushmore Memorial.

MT. RUSHMORE. Information concerning the Mt. Rushmore Memorial can be procured from the signs and from the pamphlets available at the observation point. The brief description below is concerned mainly with the geologic setting of Mt. Rushmore.

Mt. Rushmore (see sketch map on page 33) is near the northeast margin of the Harney Peak Granite. The rock is predominantly granite with numerous blocks, stringers, and pods of schist, presumably as xenoliths. Look also for the numerous dikes, veins, and veinlets that line the faces of the figures on Mt. Rushmore.

MT. RUSHMORE TO RAPID CITY. From Mt. Rushmore the caravan will work its way west and north through the Harney Peak Granite. Several stops will be made in the Needles to view the peculiar weathering forms in the granite and to gain a view of the southern Black Hills.

THE NEEDLES. The needles are slender, lofty spires and pinnacles of granite which owe their form and beauty to the weathering and erosion of once-solid granite along two or more vertical joint sets.

RAPID CITY. Stay at the MARCO MOTEL.
FIFTH DAY: ROAD LOG FROM RAPID CITY, SOUTH DAKOTA, TO SHERIDAN, WYOMING

The route from Rapid City to Sturgis follows the Red Valley or "race track" underlain by the Spearfish Formation. At Sturgis we turn west and go down through the Paleozoic section on the way to Deadwood and Lead. At Lead we see some of the Precambrian metamorphics, and at Deadwood we examine the Precambrian-Cambrian contact. Mileage in road log begins at northernly bend in U.S. 14 on the west side of Rapid City.

0.0 Intersection. Bear right on U.S. 14.
2.1 Cement plant. Lower gypsum member of SPEARFISH well shown.
2.4 Terrain ahead underlain by MINNEKABA dipping toward us.
3.3 Quarry and rock crusher in MINNEKABA. We have come around the nose of an anticlinal fold and are now driving north up a synclinal valley.
5.1 We drive onto the SPEARFISH FORMATION. Note basal gypsum to east.
6.9 Leave Pennington County and enter Meade County. SPEARFISH Valley.
12.7 Wind gap in MINNEKABA LIMESTONE to west. Pink and white sandstone outcrops along base of cliff to east are UNEKAPA.
14.0 Piedmont Butte to east. Capped by LAKOTA SANDSTONE.
15.8 Note local disturbance in MINNEKABA at mouth of canyon to west. What has caused this?
20.0 Village of Tilford.
20.7 Contact with SPEARFISH gypsum and LOWER SUNDANCE (gray-green shale) at right.
21.2 Vanocker laccolith (quartz monzonite porphyry and rhyolite) causes topographic high to west.
21.6 LOWER SPEARFISH gypsum on left.
22.6 SUNDANCE sandstone in cut.
27.9 UPPER SPEARFISH gypsum.
28.6 Bear Butte through gap on right. Prominent plug of rhyolite; Tertiary in age.
28.7 Sturgis. We turn left at the intersection and follow U.S. 14A to Deadwood and Lead.
32.0 MINNEKABA limestone at left in road cut. Entering Boulder Canyon.
32.6 Bear Butte Creek.
32.7  UPPER MINNEKANOA on right. Overlying OPESHE partly covered.

33.3  Leave Meade County; enter Lawrence County.

33.6  PAHASAPA LIMESTONE. Pahasapa is an Indian word meaning "Mountains that are black."

34.2  Approximate axis of Boulder Canyon anticline. Exposed thickness of Pahasapa limestone is 300 feet.

34.4  Approximate MINNEKANOA-PAHASAPA CONTACT on steeply dipping west flank of anticline. Complete section of MINNEKANOA well exposed on cliff at right. Boreal shales and limestones in road cut. Thickness is 403 feet.

35.0  UPPER MINNEKANOA sandstone at curve.

35.1  OPESHE and MINNEKANOA on right.

35.2  Axis of Boulder Park syncline. We are driving on a SPEARFISH outlier.

36.2  MINNEKANOA.

37.0  OPESHE (Indian word for "Battle Creek").

37.6  LOWER MINNEKANOA in cut on right.

37.7  Top of PAHASAPA in road cut on right. Brecciated and cherty.

41.7  WHITETOWN DOLomite in road cut on left and right. Overlying ENGLWOOD is about 60 feet.

42.5  UPPER DEADWOOD FORMATION.

DEADWOOD. Type section of upper Cambrian Deadwood Formation on west side of Deadwood Gulch.

Caravan will proceed to Lead and the Homestake open cut.
In 1877 Samuel McElroy, a practical mining expert, was sent to the Black Hills by a San Francisco syndicate to investigate glowing reports of new silver and gold discoveries in the northern hills. He was impressed by the gold he saw at Lead and soon optioned the Homestake and Gold Star claims—about 10 acres in all—for $70,000 from Moses and Fred Manuel. Additional acreage was soon added to the syndicate's holdings.

The Homestake Mining Co. was incorporated in California on November 5, 1877, and the mine was brought into production early the following year. The mine has been worked continuously since then, producing gold worth over $750,000,000. The mine today ranks as one of the leading gold producers of the world and has larger ore reserves than any other American gold mine.

The ore deposits are in the Homestake Formation of Precambrian age. Originally this was a bed of ambroite (iron-magnesium carbonate) about 50 feet thick. The Homestake Formation was metamorphosed to cummingtonite (iron-magnesium amphibole) and chlorite and was deformed during the earliest period of Precambrian orogeny recorded in the Black Hills. The beds in the vicinity of the Homestake deposit were deformed into a series of complex folds whose axial planes trend approximately N 10 to 15°W and dip steeply to the east. (See geologic map of the Homestake area on next page.)

Drag folds with amplitudes ranging from a fraction of a millimeter to several hundred feet were formed on the flanks of the major folds. The axial planes of these drag folds trend northeastward-southeastward and dip steeply northeastward; fold crests and troughs plunge southeastward at shallow to moderate angles. Both the major and the minor folds are cross-folded and sheared; this causes the fold axes to vary in strike and plunge.

The Homestake Formation varies greatly in thickness across the folds, ranging in thickness from a knife edge on the flanks of the drag folds to 300 feet in the axial regions of the folds. The ore bodies are inclined pods, veins, saddles, and lenses that lie within the Homestake Formation along the crests of the Pierce anticline and its attendant dragfolds. There are also ore bodies along shear zones within the Homestake Formation.

The gold is found in coarse white quartz associated with cummingtonite, chlorite, ambroite, and minor amounts of garnet, mica, pyrrhotite, and arsenopyrite. The ore is uniform in character at all levels in the mine.

The Homestake gold deposit was formed by hydrothermal replacement of the Homestake cummingtonite schist. Mineralization may have accompanied replacement of the Precambrian "Harvey Peak-type granite," or it may be related to the Tertiary intrusives. Kulp (1925) gives an age of 1.7 to 1.7 b.y. for lead associated with the ore in the Homestake Mine.
Figure 26.--Precambrian geology in the vicinity of the Homestake Gold Mine, Black Hills, South Dakota. Taken from Noble, Harder, and Slaughter, 1949.
STOP: The Caravan will return to Deadwood and examine the Deadwood sandstone and the underlying Precambrian schist. Pay particular attention to the relief of the unconformity and the lithology of the basal Deadwood.

From Deadwood the caravan will travel east on U.S. 14 to the intersection with U.S. 85. Turn north (left) on 85.

0.1 WYETHWOOD DOLOMITE in road cut to left. About 60 feet thick. North American occurrence of Mississippian graptolites; identified by Randemann. WYETHWOOD formation above.

0.4 To the right is one of the few faults in the Black Hills. Beds from Cambrian through Pennsylvanian are present, but the fault is probably Tertiary. The north side is upthrown 300 feet, probably by an intrusion of Tertiary porphyry.

1.1 Cross Slaughterhouse Gulch.

1.3 MINNELUSA FORMATION.

3.7 OGRESS AND MINNELUSA form cliff to right. Leave Black Hills National Forest.

4.3 MINNELUSA LIMESTONE. Quarried for aggregate; wide use in Black Hills region.

5.3 Elkorn Peak ahead to right. Tertiary laccolith which has not been completely unroofed. MINNELUSA is continuous over the top. Note small concentric outcrop on MINNELUSA and the OGRESS around base.

7.2 Junction with U.S. 14. Turn left.

7.7 SPEARFISH-SUNDANCE CONTACT on right. Road on alluvium; largely reworked Spearfish.

11.4 Lookout Peak ahead to right. SPEARFISH, JURASSIC, and LAKOTA.

12.1 SPEARFISH contact with JURASSIC.

15.0 Town of Spearfish. Follow U.S. 14 west out of Spearfish.

28.1 South Dakota-Wyoming border. SPEARFISH FORMATION along road.

48.1 SUNDAENCE. Lunch stop. Tertiary laccolith with Sundance Formation at base.

0.0 Follow Highway 14 out of Sundance.

22.3 Junction. Turn right for DEVIL'S TOWER.
Figure 25. -- Geologic map and stratigraphic section of Devil's Tower National Monument, Wyoming. Modified after Robinson, 1956.
DEVIL’S TOWER NATIONAL MONUMENT

(first national monument in United States; established in 1906)

Devil’s Tower is one of the more spectacular erosional remnants of the series of Eocene intrusives that characterize the northern and northwestern parts of the Black Hills. The tower rises as a nearly straight-sided, vertical column for more than 1,200 feet above the flood plain of the adjacent Belle Fourche River.

The rock in Devil’s Tower has been identified as phonolite porphyry, an alkaline-rich rock containing soda-rich orthoclase and augite. On a fresh surface the 1/4-inch-to-1/2-inch-long phenocrysts of white orthoclase stand out against the fine-grained light-to-dark-gray background. The rock weathers light gray or brownish gray.

Perhaps the most striking feature of Devil’s Tower is the well-formed columnar jointing. Most of the columns are five-sided, but some are four- or six-sided. The larger columns, which may measure as much as 8 feet across, are bounded by smooth joint planes in the middle part of the tower. Near the top of the tower some of the columns merge to form small, irregularly shaped blocks. The columns stand almost vertically in the middle and upper parts of the tower. Toward the base they flare outward and lose their identity in a massive zone that is broken into irregular, joint-bounded blocks.

The tower is encircled by sedimentary rocks of Triassic and Jurassic age. (See geologic map of area.) The formations have been only slightly deformed by faulting and folding; dips of 5° to 10° are common.

No agreement exists as to the origin of Devil’s Tower. It may be a volcanic neck, or it may be the eroded remnant of a laccolith.

Pick up mileage at bridge across Belle Fourche River 2 miles northwest of Moorcroft.

0.0 Bridge across Belle Fourche River.

1.0 Texas trail marker; 1966-97; old cattle trail.

10.6 Bonet; traveling over Eocene WASATCH FORMATION.

20.2 STOP. MINTURN COAL MINE. Wyodak Coal Co. Coal is basal member of WASATCH Formation (Eocene). Underlain by Paleocene PORT UNION. Coal 92 to 100 feet thick.

The Wyodak Coal Co. is a subsidiary of the Homestake Mining Co. Most of the coal mined here is too low grade to compete on the open market. Some of it is burned here to operate a small BFA power plant; the rest is shipped to the Homestake Mine and a little of it goes to Rapid City.

When exposed by erosion or by mining, this low grade (lignite) coal is highly combustible (usually spontaneously) and thus bakes the overlying strata. You will become accustomed to seeing these splashes of red color whenever we are in the Wasatch and Fort Union Formations.
Extreme vigilance must be exercised to prevent spontaneous combustion. The coal is soaked as soon as it is exposed and is inspected constantly for signs of smouldering.

21.0 Back on U.S. 1 and 16. Turn right (west) for Gillette.

27.0 Gillette, county seat of Campbell County.

From Gillette the route trends northwesterly across relatively flat country underlain by the WASATCH Formation.

62.4 Spotted Horse. Still in Eocene WASATCH. Burned shales (red color) can be seen on the hilltops.

77.8 Bridge across Powder River. The name “Powder River” is supposed to have come from the earliest explorers in the area who moved up the Powder River from its junction with the Missouri River in southern Montana into what is now the Powder River Basin. The red clinker beds which characterize much of the river’s drainage area resembled powder burns to them. Hence the name.

86.2 Letter Post Office.

95.0 Clearmont.

105.4 Bridge at U-Cross across Pinedy Creek. Eocene WASATCH at surface. Turn right (northwest) on U.S. 14.

135.6 (est.) SHERIDAN, WYOMING. Stay at the ROCK TRIM MOTEL.
Figure 30.--Geologic strip map, Bighorn Mountains and eastern Bighorn Basin. From geologic map of Wyoming, 1952.
SIXTH DAY: ROAD LOG FROM SHERIDAN, WYOMING, TO RED LODGE, MONTANA

Turn left off Interstate at Sioux Gas station onto old U.S. 87 and 14.

Mileage begins at the bridge across Big Goose River half a mile north of Sheridan on U.S. 87 and 14.

0.0 Bridge across Big Goose River.

0.4 Underpass under Interstate.

0.7 Old Star Mine on right. The coal which crops out on the bluff is the Roland bed, which marks the arbitrary division between the FORT UNION and WASATCH Formations.

1.0 Fort MacKenzie Veterans Hospital. Old Fort MacKenzie military post was established in 1899 and abandoned in 1918.

3.5 STOP. Channel sandstone in FORT UNION. Examine the sandstone carefully for indications of parent material.

1. What is the source of the sand in the channel deposit?
2. What does this exposure tell you concerning the origin of the Fort Union Formation for this part of the Powder River Basin?

4.6 Abandoned town of Dietz on right.

5.5 Tongue River sandstone (upper FORT UNION) in pine-covered ridge at right.

7.0 Cross Tongue River.

7.2 In cool weather steam can be seen rising from clinker beds in the making in the valley on right.

7.3 At right in road cut the clinker beds formed from the combustion of the Carney Coal (FORT UNION).

8.0 Monarch Mine tipple to left.

From Monarch to Dayton there is a gap of 11 miles in the road log. Resume log again in Dayton at the intersection of U. S. 14 and gravel county road from the south.

19.0 Intersection of U.S. 14 and county road. For the next 1.8 miles we shall travel across poorly exposed outcrops of the CLAIBORNE, EAGLE, TELEGRAPH CREEK, MOHARRA, CARLISLE, and FRONTIER FORMATIONS (UPPER CHEYOOSHOS) in that order. We shall be GOING DOWN IN THE STRATON as we approach the east front of the Bighorn Mountains.

20.1 Bridge across the Little Tongue River. East side of town.
20.8 Straight ahead is Tongue River canyon. At 2 o'clock is Amsden canyon. TENSLEEP Sandstone (Pennsylvanian) forms tree-covered flats from behind ridge of CLOVERLY sandstone (lower Cretaceous). Massive MADISON Limestone (Mississippian) forms the high mountain front. Type section of the AMERICAN Formation (Pennsylvanian?) lies in the red slope above the Madison and below the Tensleep.

21.0 CARLILE Shale (upper Cretaceous) exposed in road cut on right.

21.4 MAYDAY Shale (upper Cretaceous) at 10 o'clock. Note change of strike ahead, swinging from N50°W at 4 o'clock to N40°E at 1 o'clock. Travelling on THERMOPOLIS Shale (lower Cretaceous).

21.5 XL Ranch entrance at right. CLOVERLY sandstone (lower Cretaceous) on ridge marked by pine trees.

STOP: Stratigraphy, structure, physiography of the east flank of the Bighorn Mountains.

22.1 MERRILL Formations (Jurassic) in valley at left. Road is on SUNDANCE Formation (Jurassic) at this point. Four CLOVERLY sandstones are visible in hills to left and at 11 o'clock. At right hogback is GYPSUM SPRING (?) (Jurassic) or basal SUNDANCE.

23.1 At 9 o'clock ledge at base of slope is a highly fossiliferous, calcareous sandstone of the SUNDANCE. The shale slope above is MERRILL. Tree-covered CLOVERLY on skyline.

24.2 GYPSUM SPRING (?) dolomite capping ridge at right.

26.0 In road cut at left are red beds, platy dolomite, and gypseiferous dolomite of questionable age and correlation. These beds rest unconformably on the Tensleep Sandstone (Minnelusa equivalent, Pennsylvanian). This lower redbed sequence resembles the Minnelusa-Opaiche (Permian) of the Black Hills. The red coloration of the upper part of the Tensleep is suggestive of the Minnelusa of the Black Hills region. Road from here to 27.0 miles signags through lower red beds, TENSLEEP, and upper AMERICAN (Pennsylvanian-Mississippian).

STOP: Examine lithology of TENSLEEP Formation.

26.7 MADISON Formation, stained; note large solution cavity.

27.5 Enter Bighorn National Forest. Good AMERICAN exposures. From this point road signags in AMERICAN and MADISON Formations to 29.0 miles.

30.0 STOP: SAND TURN OBSERVATION POINT. Road cut at right consists of basal AMERICAN sandstone resting on a very irregular MADISON limestone erosion surface.

30.5 FALLEN CITY at 11 o'clock consisting of blocks of HIGHHORN Dolomite (Ordovician) slumped on underlying Cambrian shales.

31.1 Devonian. Thin-bedded; gray; purple; red carbonates.

32.8 Approximate contact between MADISON Limestone and HIGHHORN Dolomite
Approximate contact between HIGHBORN Dolomite and PLATEHEAD (DEADWOOD) (Cambrian) sandstone.

Steamboat point sign. Approximate contact between Cambrian and Precambrian.

Precambrian consists of coarse-grained augen gneiss that has fairly well-developed foliation and that dips about 25° north.

STOP. Party will examine Precambrian, Cambrian, and Ordovician rocks at this location. Foliation in granitic Precambrian gives it bedded appearance.

1. What is the nature of the Precambrian-Cambrian contact at this location?
2. How does the lower Paleozoic section on the east flank of the Bighorn uplift compare to the section in the Black Hills?
3. Are the structures within the Precambrian rocks Laramide or Precambrian in age?

For the next 12.7 miles we shall be travelling over gneiss and granite of Precambrian age. The rocks are well foliated, and the dominant trends are NSE to ENE and NNE to ESE.

37.3 At 2 o'clock, on skyline, broad U-shaped saddle is in CAMBRIDIAN flanked by HIGHBORN on tree-covered slopes dipping steeply northeasterly and gently westward.

37.5 Road at right leads to quarry in porphyritic diabase (Precambrian?).

39.6 At 2 o'clock, in distance, HIGHBORN dipping gently southwesterly.

40.2 Cutler Hill. Looking down old road at 1 o'clock is Bear Rock consisting of horizontal HIGHBORN resting on PLATEHEAD. Straight down highway on horizon is Bruce Mountain consisting of Precambrian.

44.5 Bridge over South Fork of Tongue River.

44.95 Arrowhead camp on left.

45.35 Gravel and ash-clay bed on left probably OLIGOCENE (WHITEHORSE).

46.85 Precambrian erosion surfaces at 11 o'clock are surrounded by horizontal CAMBRIDIAN sediments at road level and also in smooth hill on horizon at 3 o'clock.

47.95 At 4 o'clock Twin Buttes are HIGHBORN Dolomite dipping gently northward. Small rise just ahead is weathered CAMBRIDIAN shale.

48.3 JUNCTION. Keep straight ahead on Wyoming 16. If snow is still deep, we may be forced to take Shell Canyon road to the south.

48.85 Sign post on right: "Bear Lodge Resort."

49.55 Cross bridge over Big Willow Creek.

50.25 Granite knoll on the left. The prominent cliffs in the distance to the west and southwest are HIGHBORN Dolomite.
North Tongue River on right side of road for next 3 miles.

Cross cattle guard. The smooth grass-covered slopes beneath the HIG Horn Dolomite on both sides of road have been formed in Cambrian sediments which are not exposed.

Cross bridge over North Tongue River.

Cross bridge over Hideout Creek.

High cliff on right is HIG Horn Dolomite over CAMBRIAN shale and sandstone.

Cross bridge over Fish Hook Creek.


Sign on right: "Hunt Mountain Road." The Bighorn Basin may be seen through the canyon to the west. Bridge over Beaver Creek.

Sign on right: Observation Point--Scene View of the Bighorn Basin.

Turn left at this sign, off main road, to Observation Point.

STOP. Observation Point. The rounded knoll on which we are parked is underlain by a pebbly limestone in the lower part of the CAMBRIAN. Little Bald Mountain is to the southeast, and Bald Mountain lies about 2 miles to the northwest. Precambrian granite is exposed in the deep gorge of North Beaver Creek immediately west of us. The ridge forming the crest of Sheep Mountain Anticline can be seen 20 miles to the southwest. Turn around and return to main road.

Main road. Turn left (west).

Granite knoll on left.

Sign on right: "Sheep Mountain." Bald Mountain, capped by Cambrian rocks (10,330 feet elevation), on left. Medicine Mountain, capped by HIG Horn Dolomite, is ahead.

STOP. CAMBRIAN-PRECAMBRIAN contact exposed in meadow.

Sign on left: "Bald Mountain Camp Ground."

Five Springs Creek on left of road. To the southwest, in the distance, is the Sheep Mountain Anticline. The sharp canyon cut by the Bighorn River across the axis of this structure can be seen from here.

Note the flexure in the HIG Horn Dolomite on the left.

Medicine Mountain Lodge.

Cross cattle guard.

Straight ahead, to the north, is a good view of a HIG Horn Dolomite ledge, underlain by CAMBRIAN shales and sands and overlain by the MADISON limestone.
77.0 Curve in road. Granite crops out on left.

78.2 Five Springs resort.

79.4 On the south side of the road are vertical to overturned beds of the
    BIGHORN and MADISON formation, adjacent to the FIVE SPRINGS FAULT.

79.65 Sign on left: "Leaving Bighorn National Forest."

82.0 STOP. Park as directed. About 100 feet down the road to the west is
    a good view of the FIVE SPRINGS FAULT. (See the diagram below for a
    picture of this fault and the drags on either wall.)

Note on the ridge about half a mile south the black THERMOPOLIS Shale
    which is locally overturned. Lying above this shale and in fault
    contact with it is an overturned section with SUNDAKE at the base and
    HURON SPRING AND CHUCKWATER above. In the foreground, on the south
    side of Five Springs Creek, the interbedded limestones, sandstones,
    and red shales belong to the ANDESHEN Formation, immediately overlying
    the thick MADISON Limestone. The BIGHORN Dolomite forms the ledge
    farthest to the east.

83.8 Cross bridge over Five Springs Creek.

84.5 View of monoclinal flexure in limestone beds to the north. The black
    shale beds to the south of road are THERMOPOLIS.

86.1 Cross bridge over Five Springs Creek.

88.5 View of Little Sheep Mountain Anticline straight ahead. Note the canyon
    cut by the Bighorn River across the south end of the fold.

96.85 Cross bridge over Bighorn River.
Approximate axis of Little Sheep Mountain Anticline.

Escarpments at 9 o’clock are composed of THERMOPOLIS Shale at base with light-gray MOWRY at top.

Note slight arching in buff-colored Cody Shale beds at 3 o’clock. You are crossing Lowell Dome, a small feature at the north end of Little Sheep Mountain. Unsuccessfully drilled by Texas Co. and Ajax.

Intersection of Wyoming 14 and U. S. 310. Proceed into Lowell for lunch.

Road log will be picked up again at the bridge over the Shoshone River on the west side of Lowell.

Bridge over Shoshone River. Contact of the COLORADO GROUP (CODY shale) and the MONTANA GROUP (MESAVESDE) on the right. Basal sandstone members of the MONTANA GROUP to the left.

Junction. Turn left on Highway 14.

Terrace gravels on the left.

Terrace gravels. Sandstone of the MONTANA GROUP form the cliffs along the river valley.

Axis of BYRON ANTICLINE. Sandstones of the MONTANA GROUP can be seen flanking the structure with dips of 15° to 10° on the southwest flank.

Byron Anticline is a faulted structure with the Cody shale exposed at the crest. It has about 1,000 feet of closure. The field was discovered in 1938 when gas was found in the upper sand of the FRONTIER Formation at a depth of 2,470 feet. Since then, oil has been found in the SUNDANCE at about 4,200 feet and in EMBAR limestone and the THERMOPOLIS Sandstone at depths of 5,300 to 5,400 feet.

Entering Byron.

Approximately on the axis of the syncline between the Byron and Garland Anticlines.

Crossing the GARLAND ANTICLINE. The CODY Shale crops out along the axis of the anticline and is flanked by the MESAVESDE Formation. The Garland Anticline has approximately 2,600 feet of closure and is faulted. Beds dip from 30° to 40° on the northeast flank and 15° to 20° on the southeast flank. Oil was discovered in 1906 in the Peay sand of the FRONTIER Formation at a depth of 626 feet. Subsequent drilling led to the discovery of gas in the CLOVERLY Formation at about 1,850 feet; oil in EMBAR limestone at a depth of 3,050 feet; oil in the THERMOPOLIS Sandstone immediately below the Ebar; and oil in the MADISON at approximately 4,000 feet.

On the right, the contact between the CODY Shale and the MESAVESDE can be seen at the base of the sandstone.
Figure 32.--Geologic strip map, Bighorn Basin and Beartooth Uplift. Taken from the state geologic maps of Wyoming, 1952, and Montana, 1955.
The contact between the MONTANA GROUP and the overlying LANCE Formation is in the cliff across the river (left).

PORT UNION in the hills to the left.

The ridge in the distance to the right is the LANCE Formation. The regional dip in this area is from 90° to 15° SW.

Railroad.

Garland at road junction of Wyoming 14 and 114; turn left on 14 for Powell.

"Fort Union" Formation crops out in the escarpment on the right. Later work indicates that the term "Fort Union" is not applicable, and the formation is now known as the POLECAT BENCH Formation.

The long flat-topped escarpment on the skyline (right) is the south margin of POLECAT BENCH.

Intersection in town of Powell of Wyoming 14 and secondary road north to Elk Basin Oilfield. Turn right (north) toward Elk Basin.

POLECAT BENCH

Polecat Bench is the largest of a group of gravel-capped benches in the Bighorn Basin that have been formed through the action of stream piracy. The bench today appears as a mesa 200 to 500 feet above the surrounding lowlands. The bench is about 20 miles long and 2 to 5 miles wide. A thin veneer of gravel caps a smoothly planed surface that bevels inclined strata of differing hardness. A plan view and section view picture of the bench is given in Figure 33.

The surface of Polecat Bench slopes to the northeast at a constant rate of 25 feet to the mile—essentially the same slope as the present streams. The bench trends in a northeasterly direction in direct line with an abandoned stream-cut gap in the Pryor Mountains. Mackin (1937) proposed that both Polecat Bench and the Pryor gap are features that were produced by the ancestral Shoshone River in its course between these two points. Mackin showed the history of drainage for the Bighorn Basin in a series of three drawings that have been reproduced as Figure 34 on page 56.
Figure 33.—Polecat Bench, Wyoming. After Mackin, 1947.
The picture that evolves is one of successive piracy of basin streams by headward-eroding tributaries to the Yellowstone and Bighorn Rivers. In map 2 above the Polecat-Shoshone River is shown traversing the area now marked by Polecat Bench. At this time the bench was a gravel-covered terrace along the broad and flat valley of the river. In map 3 the Polecat-Shoshone River is captured upstream from Polecat Bench by a tributary to the Bighorn River. The drainage of the Shoshone is diverted away from Polecat Bench, which is now left behind "high and dry".

ELK BASIN OILFIELD

The Elk Basin Oilfield is in the north-central part of the Bighorn Basin in Park County, Wyoming, and Carbon County, Montana. Oil and gas are found along the crest and the flanks of a northeast-southeastward-trending anticline that involves upper Cretaceous and Paleocene rocks. The surface expression of this structure measures about 10 miles by 5 miles. See map on the next page.

Oil was discovered at Elk Basin in 1915 by Jim Hurst in a well on top of the structure in sec. 30, T.50N., R.99W. The producing zone was the First Wall Creek sand at a depth of 1,335 feet. Since then, gas has been discovered in the Dakota at 2,000 feet (1922); oil in the Pekosphere-Tenkilep sequence at depths of 3,900 to 6,000 feet (1942); and in the Madison Limestone at depths of 4,350 to 5,053 feet (1945).

The name "Elk Basin" derives from the fact that the crest of the anticline is a topographic low. The sandstone members of the Montana Group that underlie the surrounding hills have been breached at the axis of the structure, and the relatively soft Niobrara shales have been exposed. Maximum topographic relief is about 500 feet.
EXPLANATION
Tfu Fort Union formation
KI Lance formation
Kfs Lennep formation
Kbp Bearpaw formation
Kjr Judith River formation
Kc Cragget Formation
Ke Eagle sandstone
Ktc Telegraph Creek formation
Knc Niobrara and Carlile shales

Figure 35.—Surface geology of the Elk Basin Field, Wyoming-Montana. After Wetzel, 1954.
The Elk Basin fold is an asymmetric anticline whose steep limb is on the east. Surface dips on this limb average 35° to 45°. On the opposite or west limb surface dips average 15° to 25°.

A number of interesting faults cut the Elk Basin Anticline. The most prominent ones and economically the most important of these are the group of northeastward-trending cross faults that displace the strata along a series of miniature horsts and grabens near the center of the fold. Displacement along these faults dies out toward the nose of the structure, an indication that they may be formed by stretching of the beds during formation of the fold. Several diagonal faults with strike-slip (?) movement and at least one northeastward-trending thrust fault (northwest side up relative to the southeast side) are mapped. In general, the fold and the faults suggest a stress field in which the greatest principal stress axis is directed in a northeasterly-southwesterly direction.

The route through the Elk Basin structure follows the axis of the fold.

If time permits, we shall visit one of the sulfur plants in the field.

**RED LODGE, MONTANA. Stay at HARLEY'S COTTAGES.**

19.0 Park H. Travel N, on U.S. 12 East
20.2 Climbing Potash Beach; dipping beds (faint?)
23.4 Jet, Angles W; Continue straight ahead. Elk Basin on left hand.
27.1 Begin descent, to side of Elk Basin and
30.3 Jet W; Half way up angle W. Continue straight ahead.
32.1 Jet, Angles E, cross gravel
crossing and Continue straight ahead per grade
34.1 Turn L. Travel to Elk Park (Historic drive, which was owned by)
35.8 Travel, Turn L (E) in backstop
52.1 Turn R (S) along edge Belt
61.3 Boar Mnt. 30' contour ahead on 30' Bear Creek. Mts. behind
67.2 Bear Creek beyond. Hill ends when from here turn right uphill.
70.0 Climbing out of valley
71.9 Travel (E) View sheer front of Cerro.
SEVENTH DAY: ROAD LOG FROM RED LODGE TO COOKE CITY AND YELLOWSTONE PARK

0.0 Start at "See 'Em Alive" zoo at south side of Red Lodge. Drive Southwestward on Cooke City Highway along east side of Rock Creek.

1.5 Bridge over west fork of Rock Creek.

3.4 Pass vertically dipping outcrop of Madison Limestone on right. Madison reddened in places by Ammonites shells infiltrating into solution cavities.

3.8 Road to left leads to Yellowstone-Bighorn Research Association camp.

3.9 STOP. Examine the eastern front of the Beartooth Uplift. A discussion will be held at this stop on the structure of the Beartooth Uplift.

4.6 Custer National Forest boundary.

9.4 Bridge over Rock Creek. Begin ascent toward switchbacks and the Beartooth Plateau. The Precambrian rocks along the route consist of granites, granite gneisses, migmatites, various metasediments, amphibolites, mafic and ultramafic intrusions, and basic dikes.

Many excellent views of landforms sculptured by alpine glaciation.

12.5 View up Rock Creek ahead is a good example of U-shaped glaciated valley.

14.7 First major switchback. Note near-vertical dike outcropping across creek.

16.0 Second major switchback. The secondary road visible across the creek climbs the Hellingroaring Plateau. This is the area where "Little Martin", a miner from the Colorado camps, discovered chrome deposits that were worked during the Second World War.

17.8 Third major switchback. At this curve paleoglacial ice was uncovered during construction of the highway in the 1930's.

20.1 Fourth switchback and vista point.

20.8 Mae West Curve switchback. Elevation 9290 feet.

21.2 Know Point switchback.

22.3 Approaching the top of the Beartooth Plateau. Gabbro outcrop on left in road cut. Note steep glaciated valleys cut into the plateau.

25.5 Observation point overlooking Twin Lakes to right.

30.9 Beartooth summit. Elevation 10,942 feet. Long Lake is to the southwest, and beyond is a west-northwest-east-southeastward-trending valley occupied by Cambrian shales. Granite fault scarp visibly exposed southwest of valley. As one descends from the summit, one can see Beartooth Butte to the west.
36.8 Bridge over outlet of Long Lake. Sawtooth Mountain is to the east.

37.6 Pass southeast end of Little Bear Lake and cross over divide into valley. For the next 1-1/2 miles the road parallels the strike of a wedge of Cambrian shales. The ridge to the left is Precambrian rock and is separated from the shales by a fault paralleling the road.

39.1 Bridge over Little Bear Creek. Ledge of Flathead sandstone immediately to right of road dipping gently under road; excellent jointing. The contact of the Flathead with the Precambrian can be seen approximately 100 yards up Little Bear Creek from the bridge. Best exposures are near the water level. A good outcrop of the Cambrian shales is visible in the bed of Little Bear Creek to the left beyond the bridge.

39.9 Re-cross Little Bear Creek.

41.3 Excellent view of Beartooth Butte to right. It is a lower Paleozoic remnant resting on the Precambrian of the Beartooth Mountains.

41.7 Road to Beartooth Lake Camp.

42.0 Bridge over outlet of Beartooth Lake.

42.4 Beartooth Falls on left. Note jointing in road cut.

43.3 Junction with Clay Butte Fire Tower road. Turn right for approximately 3 miles. The road rises through a section of Cambrian shales; the prominent cliff-forming limestone part way up the slope is either Cambrian Meagher or a Meagher equivalent.

46.3 STOP. Top of Clay Butte. Elevation 9,811 feet. Discussion of Precambrian, Paleozoic, and volcanic rocks that are visible from this point. Top of Clay Butte affords an excellent panoramic view of the Absaroka Mountains, Clarks Fork Valley, Beartooth Mountains, and the west slope of the Beartooth Butte.

47.3 Return to highway. Turn right.

50.4 Sharp curve to left at Inspiration Point. Glacial moraine can be seen in the valley of the Clarks Fork for the next 6 miles. Excellent exposures in road cuts.

51.0 Muddy Creek road camp on left.

53.0 Bridge over Muddy Creek. During the last century Muddy Creek and Lake Creek were favorites of fur trappers. Beaver, fox, and mink pelts were obtained.

56.4 Bridge over Lake Creek.

57.9 Junction with Sunlight Basin Road. Continue straight ahead to Cook City and Silver Gate. From this point west, the road remains on a vast exposure of Precambrian rocks. The view to the south shows a complex section of Tertiary volcanic rocks resting on rocks of Paleozoic and Cambrian age.
The charred brown rock capping the ridge is of volcanic origin, and the resistant sedimentary bed halfway down the slope is Cambrian Pilgrim Limestone. The ledge below the Pilgrim is formed by the Meagher Limestone.

58.8 Gilbert Creek.

60.5 Crazy Creek.

60.9 Excellent view of Pilot and Index Peaks. Pilot Peak is to the south and is a sharp glacial horn. The lower part of the mountain mass is composed of the early basic breccias resting on Paleozoic limestones. The sharp horn itself is cut from the essentially flat-lying early basalt flows series of the Tertiary Absaroka volcanic rocks. These peaks and the surrounding country were first seen by a white man in the winter of 1807-08, when John Colter made his famous trek eastward through the Yellowstone Park area. Colter called them "Pilot" and "Finger" peaks and stated that "one of them deserves its name from its shape, like a closed hand with the index-finger extending upward." Much controversy existed in the literature between 1872 and 1952 as to which is actually Index Peak and which is Pilot Peak. Library research forces one to conclude that Index Peak is to the north and Pilot Peak to the south.

61.2 Note columnar jointing in volcanic rocks across river.

62.4 Bridge over Clarks Fork River.

63.9 Outcrop of Cambrian limestone and shale exposed in road cut at left. For the next two miles one can glimpse the prominent profile on the skyline ahead to the west. This outcrop shows the Tertiary early basic breccia resting on Cambrian limestones. Ordovician and Mississippian rocks are missing at this exposure.

65.0 Bridge over Fox Creek.

65.9 Bridge over Index Creek.

66.1 Road cut showing Cambrian shales to south.

66.2 Montana-Wyoming State line.

67.2 Cooke Pass. Elevation 8,066 feet. This pass, first crossed by Colter, was known as Colter Pass until the highway was built. Since that time it has been referred to as Cooke Pass.

67.6 Road to Chief Joseph Camp. From here to Lamar River inside the Yellowstone Park boundary, gentle southwesterly dips prevail as shown by slopes of Paleozoic beds which are visible along the highway.

68.0 Cooke Pass Camp.

68.9 Secondary road leading north. This road goes into the Henderson Mountain and Sheep Mountain mining areas.
70.4 Secondary road to right leads to Henderson Mountain and Daisy Pass mining areas. The Cooke City or New World Mining District became active in the early 1870’s. Activities ceased between 1886 and 1893. Oxidized gold ore from Henderson Mountain revived activity for a year or two, and then no major operations were carried on until about 1904. From 1904 until about 1925 mining activities continued at a moderate pace. There is no active mining in the area at the present time.

71.0 Cooke City, Montana. Stop for lunch.

0.0 Post Office at Cooke Montana. Granite and evidence of former glaciation may be seen on entering valley of Soda Butte Creek.

0.9 Republic Peak on left (south). Good section of Cambrian rocks resting on Archean granite. The prominent cliff-forming formation is the Gallatin Limestone of late Cambrian age.

2.9 Silver Peak on right (north). Mineralized area. Silver, lead, zinc ores are found in this area; also some gold, copper and platinum are found in the general area. Prospecting and some mining have been in progress in the area since the 1860’s. (See “New World Mining District” by T. S. Lovering; U.S.G.S. Bull. 514-A).

3.0 Silver Gate Lodge and Camp. Meridian Peak on right (north).

4.1 Northeast entrance to Yellowstone Park, the largest wildlife sanctuary in the United States. Established in 1872, it is the oldest and largest of our National Parks.

4.7 Cutoff Peak straight ahead.

6.0 Fine Paleozoic section exposed to the southeast (left). Formations and thicknesses are about as follows:

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary volcanic rocks</td>
<td>1600 feet</td>
</tr>
<tr>
<td>(lava and breccia)</td>
<td></td>
</tr>
</tbody>
</table>
| Madison Limestone (Mississippian) | 290 feet |}
| Threeforks shale (upper Devonian) | 200 feet |
| red and purple streaks     |           |
| Jefferson Limestone (middle Devonian) | 115 feet |
| Bighorn Dolomite (upper Ordovician) | 175 feet |
| thin-bedded                |           |
| Gallatin shale (upper Cambrian) | 275 feet |
| Gallatin Limestone (middle Cambrian) | 175 feet |
| prominent cliff            |           |
| Gros Ventre Fm. (middle Cambrian) | 500 feet |
| greenish gray              |           |
| Flathead Quartzite (middle Cambrian) | 100 feet |
| Granite and gneiss (Precambrian) |         |

6.3 Cross Montana-Wyoming State Line.

6.6 Cross Soda Butte Creek bridge.

7.5 Abishar Peak on left (southeast).
Figure 36.--Geologic strip map, Yellowstone National Park, Wyoming. Taken from geologic map of Wyoming, 1952.
8.2 Paleozoic limestones and shales exposed beneath volcanic breccias on right across Soda Butte Creek. Note dip of strata is greater than stream gradient.

8.5 Baronet Peak (best view).

10.2 Soda Butte Creek bridge.

11.4 Agglomerate and breccia on right. Ice Box Canyon on left (east). Canyon cut in volcanic breccias. Paleozoic rocks not exposed. Note that many volcanic rock fragments are rounded.

12.1 The Thunderer on left (east).

12.8 Paleozoic limestones on right (west). Good exposures. (Madison or Devonian)

13.3 Bridge over Pebble Creek.

14.1 Mt. Norris on left (east). Druid Peak on right (west).

15.6 Ranger station on right. Soda Butte on left—hot springs deposits.

17.2 Limestone on right (Devonian or Madison).

18.7 Road cut in limestone on right. Junction of Soda Butte Creek and Lamar River on left.

19.6 Fossil forests in cliffs to the south.

20.6 Buffalo Ranch on right.

25.1 Lamar River Canyon cuts through granite (Archean).

27.4 Cross bridge over Lamar River.

27.9 Note granite outcrop on right (north).

28.4 Large granite erratics—glacial boulders—scattered over valley. Petrified tree stumps in Specimen Ridge, to southeast, visible with field glasses.

29.3 Trumpeter Lake.

31.4 Pass Junction Butte (capped with basalt flows).

32.4 Cross bridge over Yellowstone River. Effect of gases and hot water on rocks very evident. Sulphur deposited on boulders in streams.

33.0 TOWER JUNCTION on left.
(For the 2-mile side trip to Tower Falls, turn left at Tower Junction and follow Grand Loop)

0.0 Tower Junction.

0.2 Pass Roosevelt Camp on right (south)

0.5 Road passes through an ancient glacial spillway, through which the waters of Yellowstone River flowed for a time while ice still occupied the valley farther north. Remnants of a large number of these spillways may be viewed between this point and Mammoth Hot Springs.

1.5 Pass "Overhanging Cliff" of basalt on right. Across the canyon the columnar structure of two basalt flows may be seen separated by ancient river gravel. On the near side of the canyon, needle-like spires of volcanic breccia, left by erosion of the surrounding material, may be seen.

2.0 CROSS TOWER CREEK and park. Walk about 300 yards for view of Tower Falls and Canyon. Return to Tower Junction.

TOWER JUNCTION TO CANYON JUNCTION

0.0 Tower Junction. Turn left on road to Canyon Junction. The road heads directly to Dunraven Pass on the east slope of Mt. Washburn and traverses early andesite breccias, basalt, Yellowstone Tuff, Quaternary hot spring deposits, basalt, Yellowstone Tuff, and early andesite breccia in that order.

0.5 North end of glacial spillway.

1.6 South end of glacial spillway.

1.7 The Narrows lookout -- gorge of the Yellowstone River.

1.85 Below the highway near the west wall of the canyon is the Needle, a spire of volcanic breccia -- 250 feet high.

2.10 Overhang cliff; 150 feet high; columnar basalt near base -- Yellowstone Tuff on top. The base of the section shows river gravel and finer grained stream deposits.

2.25 View of wall of Grand Canyon of the Yellowstone. The stratigraphic section is:

<table>
<thead>
<tr>
<th>Top of section</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacial deposits</td>
<td>5 to 30 feet thick</td>
</tr>
<tr>
<td>Lake deposits</td>
<td>0 to 20 feet thick</td>
</tr>
<tr>
<td>Columnar basalt</td>
<td>5 to 25 feet thick</td>
</tr>
<tr>
<td>Stream gravels</td>
<td>130 feet thick</td>
</tr>
<tr>
<td>Columnar basalt</td>
<td>5 to 35 feet thick</td>
</tr>
<tr>
<td>Breccia</td>
<td>thickness unknown</td>
</tr>
</tbody>
</table>

2.45 Cross Tower Creek.
2.50 Tower Fall Parking area. The Fall is 132 feet high.

3.15 Basalt cliff west of road, early andesite breccia to east.

4.60 Antelope Creek to east. Yellowstone Tuff.

6.8 To the southeast at a distance of about 8 miles are Joseph's Cost Springs, a thermal area on Broad Creek at the contact between early andesite breccia and preplateau flows.

7.8 Volcanic breccia.

8.0 Volcanic ash deposits. To the northeast are peaks of the Beartooth Mountains and the north end of the Absaroka Range. Cutoff Peak (10,300 feet) is near Silver Gate, the northeast entrance to the park.

8.6 Road to Mt. Washburn summit.

8.7 Early andesite breccia that makes up Mt. Washburn.

10.1 Dunraven Peak -- named after the Earl of Dunraven, an explorer in this region.

11.3 Junction of Mt. Washburn loop road.

11.7 Carmelian Creek. Breccia that makes up Mt. Washburn is exposed in bank.

13.6 Junction at Dunraven Pass. View from this point is worth a stop.

14.9 View of Mt. Washburn, named after Henry Dana Washburn, Surveyor General of the Territory of Montana, who, in 1870, organized and led an expedition for the purpose of determining the truth or falsity of the stories pertaining to the wonders of the Yellowstone National Park region.

15.1 The Grand Canyon of the Yellowstone River may be seen from here.

15.8 Volcanic conglomerate.

19.4 Grand View Junction. The river is nearly 800 feet below.

19.9 Lookout Point.

20.9 Canyon Junction.

CANYON JUNCTION TO LAKE JUNCTION

0.0 Canyon Junction.

0.3 Trail to Upper Falls of the Yellowstone River. The Falls are cut in the Canyon Flow Unit of the Plateau flows. The predominant color of the rocks in the gorge near here is believed to have inspired the name given to river. The rhyolite in the gorge is intensely altered. Feldspars have been largely replaced by clay minerals. The altered rock is stained various shades of red and brown by iron oxide.
Chittenden Bridge; road to trail to Lower Falls, and to Artist Point.

2.80 North edge of Hayden Valley, which is underlain by Quaternary gravels. The valley was named in honor of Dr. Hayden, leader of early U.S.G.S. parties in the Park region. In this region, the Yellowstone River also flows on Quaternary gravels. Trail to the southwest goes to Highland Hot Springs near Mary Mountain and Mary Lake.

3.35 Alum Spring.

3.50 Sulphur Mountain, (7,800 feet) to the south.

7.7 South edge of Hayden Valley.

7.8 Mudpots west of the road.

8.0 Sulphur cauldron -- contains large amounts of free sulphur.

8.30 Side road to Mud Volcano, and Dragon's Mouth. The road is on Quaternary gravels but to the southwest are the rhyolite flows of the Elephant Back segment of the Central Plateau.

9.40 Elephant Back -- rhyolite flows.

11.10 Yellowstone River rapids.

13.15 Eastward across the Yellowstone River at a distance of about 4 miles are the Sulphur Hills, a hot springs and mudpot area.

14.0 Lake Junction -- elevation 7,792.

LAKE JUNCTION TO WEST THUMB

For most of the distance from Lake Junction to West Thumb the road is on Quaternary gravels and skirts Yellowstone Lake on the east. Along the western side of the road for nearly nine-tenths of the distance to West Thumb are the rhyolite flows of the Central Plateau. For the last part of the distance to West Thumb the road is on the flows.

0.0 Lake Junction.

1.9 Boathouse and dock.

3.8 To the northeast, beyond the lake are the peaks of the Absaroka Range.

3.9 West spur of road to Natural Bridge.

3.95 Cross Bridge Creek.

5.95 Weasel Creek.

10.30 Pumice Point, West Thumb Bay.

12.60 To the south, beyond the south shore of West Thumb Bay are the Red Mountains.
The highest peak in the Red Mts. is Mt. Sheridan at 10,250 feet (fire lookout on summit). The Red Mts. are the type locality for Boyd's Red Mountain Rhyolite unit (flows and flow breccias) of Eocene age. To the east and southwest of Red Mountains are outcrops of Yellowstone Tuff and to the south are Paleozoic and Mesozoic sedimentary rocks.

14.40 Sandbar (wave-built) in lake.

19.40 North end of West Thumb geyser basin. The geyser basin is developed in Plateau Flows.

20.8 West Thumb Junction.

WEST THUMB TO UPPER GEYSER BASIN

Along the entire route, the road is on rhyolite flows of the Central Plateau and Madison Plateau.

0.0 West Thumb Junction -- 7,784 feet.

1.0 Lake View -- to the east is Yellowstone Lake and beyond is the Absaroka Range.

3.35 The Continental Divide, 8,522 feet high.

8.0 Cross Dry Creek

8.5 Shoshone Point -- view of Shoshone Lake to the south. The Teton Range is about 50 miles to the south.

9.1 DeLacy Creek.

9.4 Herron Creek

10.20 Isa Lake, Craig Pass, on Continental Divide, 8,262 feet.

10.65 Norris Pass to southeast.

10.8 Altered rhyolite; resembles that found in the Yellowstone River Canyon.

12.9 Glacial lake to north.

15.3 Side spur to Lone Star Geyser.

15.4 Kepler Cascades of Firehole River.

16.0 The western skyline is the Madison Plateau, underlain by Plateau Flows.

16.35 Trail to Mallard Lake -- 3.5 miles to northeast.

17.0 OLD FAITHFUL. Stay at OLD FAITHFUL LODGE.
EIGHTH DAY: ROAD LOG FOR YELLOWSTONE PARK AND JACKSON HOLE

Retrace route across rhyolite flows of the central Plateau and Madison Plateau to West Thumb.

WEST THUMB TO SOUTH ENTRANCE

The road is on Plateau Flows for some distance, but crosses over onto Quaternary gravels just north of Lewis Lake. South of Lewis Lake the road travels over Plateau Flows, Yellowstone Tuff (to the west are the rhyolite flows of the Pitchstone Plateau), and the Pliocene Jackson rhyolite flows.

0.0 West Thumb Junction.
0.15 Village of West Thumb.
1.5 Leave Quaternary gravel, road now on Plateau Flows.
2.7 Continental Divide.
7.45 Trail to east to Heart Lake and Heart Lake Geyser Basin.
11.3 South end of Lewis Lake.
11.4 Aster Creek.
11.6 Lewis Falls, contact, Yellowstone Tuff, Madison-Central Plateau unit of the Plateau Flows, and the Pitchstone unit of the Plateau Flows. For the next 2 miles the road is on Yellowstone Tuff.
13.8 North end of Lewis Canyon. The Jackson flow unit is in contact with the Yellowstone Tuff in the Canyon opposite.
13.95 View of Lewis Canyon.
17.50 South end of Lewis Canyon; near here the river flows on Quaternary alluvium and the road which has been along the contact Yellowstone Tuff to the west, Jackson unit, Plateau Flows to the east, cuts across the Jackson unit and then crosses Quaternary alluvium and Quaternary gravels.
17.8 The Tetons Range in the distance to the south.
20.3 Crawfish Creek. Moose Falls to the east are on the Jackson unit of the Plateau Flows.
21.7 South entrance to the Park.

The road log has a 22 mile gap from the south gate of Yellowstone Park to the intersection of U.S. 287, 89 and 187 near Moran, Wyoming.

"CONFUSION CORNER" TO JACKSON HOLE

0.0 "Confusion Corner". Proceed south on U.S. Highway 187, 26, and 89, toward Moran and Jackson.
Figure 37.--Geologic strip map, Jackson Hole and the Teton Mountains, Wyoming. After geologic map of Wyoming, 1952.
1.2 Moran. Signal Mountain at 11:00 o’clock is the type locality for the Bivouac Formation, probably of late Pliocene age. The rocks are tilted 5° westward. The welded tuff, which superficially resembles a lava flow, is overlain and underlain by conglomerate, pumice, and sandstone of the Bivouac Formation, and extends continuously along the north and east sides of Signal Mountain. The top of the mountain is capped by glacial deposits of the Buffalo glacial stage.

2.2 Jackson Lake at 3:00 o’clock is the largest of many glacial lakes on the floor of Jackson Hole. The water of all these lakes was impounded behind moraines of the Pinedale glacial stage.

4.7 Highway crosses terraces developed along one of many former temporary outlets of Jackson Lake. This outlet was cut through outwash and morainal debris of the Pinedale glacial stage.

7.5 Knob and kettle topography. Highway passes between Jackson Lake Moraine (Pinedale glacial stage) and Burned Ridge Moraine (Bull Lake glacial stage).

14.1 Highway skirts Jenny Lake Moraine (Pinedale glacial stage) at 3:00 o’clock. Large angular erratics are of Precambrian rocks carried eastward from the Teton Range by ice.


15.1 Grand Teton (13,766 feet) at 3:00 o’clock. The Matterhorn-like facets are caused by alpine glaciation. Part of the superior elevation of this and adjacent peaks is the result of upward movement of this block along the Buck Mountain Fault west of the peaks. A dark-colored basic dike cuts the south shoulder of the Grand Teton and separates the pinnacle known as Tepee Pillar from the main mass of the mountain. This dike also extends through the north side of the saddle between the Grand and Middle Teton peaks and crops out to the west along the wall of South Cascade Canyon. This dike is one of many such intrusives of Precambrian age in the range.

19.4 Mileage check point. Entrance road to Grand Teton National Park Headquarters turns off to west. Continue straight ahead.

20.2 Optional stop. Panoramic view of southeastern part of Jackson Hole. Enter National Park Service turnout on east side of Highway. Consider 12:00 o’clock position to be straight ahead.

Gros Ventre River valley emerges from north flank of Gros Ventre Range at 10:40 o’clock. Pinkish hues in big landslide scar are red shale in ANDEEN Formation (Pennsylvanian). Redbeds along river valley are rocks of Triassic age.

In middle distance, at 11:00 o’clock, Blacktail Butte rises 1,000 feet above the floor of Jackson Hole. The shape of the butte is thought to have been formed by the southward-moving Buffalo ice sheet which once completely covered the butte. The East and West Gros Ventre Buttes, visible at 2:00 o’clock in the south-central part of the valley, are similar complexly faulted and westward-tilted blocks of Paleozoic and Tertiary rocks. A modified Bull Lake outwash plain comprises most of the flat area of the
valley within view at this point. Moraines deposited by both Bull Lake and Pinedale Glaciers form wooded hill at 5:00 o'clock.

20.5 "Windy Point", a locality of deep winter snowdrifts. Highway descends from modified Bull Lake outwash plain to a series of terraces slightly higher than the present flood plain of the Snake River.

21.8 Gravel road to left goes to Elk post office. Keep on main highway.

22.0 Blacktail Butte at 9:00 o'clock. Ledges of MADISON Limestone (Mississippian) stand nearly vertical at north end. The higher part of the butte is white limestone, pumice, and other tuffaceous rocks of the Terminot Formation of middle Pliocene age dipping westward and down-faulted against the MADISON Limestone.

23.3 Death Canyon is cut through the east front of the Teton Range at 3:00 o'clock. The type section of the Death Canyon Limestone of middle Cambrian age is near the head of this canyon and is barely visible in a cliff face. Note other cliffs of Cambrian, Ordovician, Devonian, and Mississippian rocks forming the crest of the Teton Range.

Granite Canyon, directly south of Open Canyon, is the farthest south of the canyons cutting the main part of the Teton Range.

24.3 Cross-roads. The highway here is on one of the outwash plains of the Bull Lake glacial stage. The loess- and silt-covered surface extending south from Blacktail Butte is thought to be older than the Bull Lake glacial stage and younger than the Buffalo.

26.1 At 9:30 o'clock on the skyline is the "Sleeping Indian" or Sheep Mountain. The cliffs are formed of gently-dipping Cambrian, Ordovician, Devonian, and Mississippian rocks. At 11:00 o'clock is Jackson Peak (10,707 feet), composed of Precambrian rocks in the core of the Gros Ventre Range. At 12:00 o'clock is East Gros Ventre Butte. The ski run on the north face of Snow King Mountain south of Jackson are visible in the background. At 1:00 o'clock is West Gros Ventre Butte, composed of Paleozoic rocks capped and intruded by volcanic rocks of late Tertiary age. At 2:00 o'clock on skyline, Paleozoic rocks can be seen dragged upward on the south side of the Rendezvous Peak fault. The bare peak with snow patch on north side is Housetop Mountain.

26.5 Main channel of Gros Ventre River.

30.4 Leaving Grand Teton National Park.

30.5 Valley of Flat Creek ahead. Note how much lower it is than that of the Gros Ventre River, just crossed.

30.6 Note loess deposit on terrace gravel on both sides of road.

30.8 Cliff of andesite porphyry at 3:00 o'clock.
32.1 At 5:00 o'clock, across Flat Creek Valley is part of the west flank of the Gros Ventre Range. The heavily timbered upper slopes are of north-west-dipping conglomerate at the base of the TRESNITOT Formation of middle Pliocene age and in part glacial debris of the Buffalo glacial stage. The canyons are cut into Cambrian, Ordovician, Devonian, and Mississippian rocks. The prominent surfaces extending along the bare slopes are ice grooves excavated by the Buffalo ice sheet as it moved southward down the valley. In this area the ice must have been more than 1,500 feet thick.

At 10:00 o'clock on the skyline is Jackson Peak. Curtis Canyon is the prominent canyon in line with the peak. Precambrian rocks extend to the valley floor directly east of the ranch buildings at the mouth of Curtis Canyon.

32.1 Turnoff to Chuck Wagon at right. Lower ledges at 2:00 o'clock are cherty dolomites in the PHOSPHORIA Formation of middle Permian age, overlain by andesite porphyry. The low butte in Flat Creek valley at 9:00 o'clock is a fault block of west-dipping MADISON Limestone and ANSDEIN Formation. The red rocks at the north end are red shales of CHESTER age underlain by the MADISON limestone, whereas those at the south end are red shales in the ANSDEIN Formation, underlain by the Darwin Sandstone member.

33.1 At 2:00 o'clock, lower ledges are of Mississippian limestone overlain by red Darwin Sandstone member of the ANSDEIN Formation. The TENSENLEB Sandstone (Pennsylvanian) forms weak ledges near top of hill just south of the pass. The park ledge at the top of the hill is the basal chert and phosphate bed of the PHOSPHORIA Formation.

The fields on the east side of the road are part of the Jackson Hole National Elk Refuge winter feed ground.

34.5 Cross bridge over Flat Creek and enter town of Jackson (population 1,250 in the winter time), county seat of Teton County. The high west-sloping hill at 9:00 o'clock is composed of the TENSENLEB Sandstone on the overriding block of the Cache thrust, thought to be of early Pliocene age. This west-sloping surface, 1,500 feet above the valley floor, contains glacial debris of the Buffalo glacial stage.

At 10:00 o'clock is the valley of Cache Creek, cut in CODY Shale of late Cretaceous age. The low hill with the road curling around the top is composed of south-west-dipping fossiliferous marine sandstone in the FRONTIER Formation.

Snow King Mountain is straight ahead. The upper half is composed of MADISON Limestone. Wells and pits dug in the lower slopes have encountered CODY Shale and BACON RIDGE Sandstone (upper Cretaceous). There is a difference of opinion as to whether the Cache thrust extends under Snow King Mountain, thereby making it a klippe, or whether the mountain is part of a north-moving thrust called the Jackson thrust. On the south side of Snow King Mountain there is evidence of some southward movement of the overriding block.
At 10:00 o'clock on the skyline is a notch through which the uppermost part of the Buffalo ice sheet passed. This ice filled Leek's Canyon on the south side of Snow King Mountain. At 2:00 o'clock are ledges of MADISON Limestone that bend over sharply in an asymmetric anticline with the southwest flank the steepest, again suggesting southward movement.

Lunch in Jackson.

From Jackson we retrace our route north along U.S. Highways 26, 89 and 187 to the turnoff for Kelley.

6.90 Turn right. Blacktail Butte ahead and to left.

6.95 Village of Kelley. The store is one of two buildings that survived the Gros Ventre River flood in 1927. The MADISON Limestone forms cliffs directly east of Kelley at the mouth of the Gros Ventre River Canyon. Turn left across bridge.

7.3 At 9:00 o'clock the structure of Blacktail Butte is visible. The down-faulted rocks of middle Pliocene age on the southeast corner are easily seen. The steep east face, which may have been sculptured by the Buffalo ice sheet, has rocks ranging in age from Cambrian to Mississippian.

7.95 Cross-roads. Turn right on Gros Ventre River road.

8.1 Cross big irrigation ditch. Just east of ditch on left side is Pleistocene or Recent travertine. On right, 50 feet inside fence is a warm spring from which a considerable amount of gas of unknown composition emanates. The TERENIOT Formation underlies this locality. The source of the warm water is not known, nor why it appears at this particular spot. Other warm springs emerge from the MADISON Limestone along the Gros Ventre River about a mile to the southeast.

Side road enters from left. Keep straight ahead.

9.0 Hill at 11:00 o'clock is pumice, limestone, and claystone in TERENIOT Formation dipping about 20° to the west. The hill is capped with glacial debris, probably of the Buffalo glacial stage.

11.1 Cattle guard. Mileage check point.

11.2 Leave Grand Teton National Park, enter Teton National Forest. Rocks at 9:00 o'clock are PHOSPHORIA, DIGWOODY, and CRICKWATER Formations, as are those at 12:00 o'clock. Looking back at 4:00 o'clock, rising out of deep trout pool in Gros Ventre River is a cliff of TENSILEP Sandstone capped by a dark-colored ledge of chert and phosphate rocks that is the basal bed of the PHOSPHORIA Formation. A somewhat similar chert bed, but with no phosphate in it, occurs here just below the TENSILEP-PHOSPHORIA contact and contains abundant fusulindos of Des Moines (Middle Pennsylvanian) age. The Darwin Sandstone Member, comprising the basal part of the Asmussen Formation crops out in red ledges and slopes farther down the river.
11.6 Note debris from the 1927 Gros Ventre River flood at 3:00 o'clock.

11.9 Cross Turpin Creek. A complete section of the red CHUGWATER Formation, capped by the cliff-forming salmon-red NUGGET Sandstone can be seen up Turpin Creek. The NUGGET Sandstone, here about 100 feet thick, pinches out northward and is gone in the section on Ditch Creek about five miles to the north.

12.2 Black phosphatic, slightly radioactive shale and silt stone in PHOSPHORIA Formation in road cut on left.

12.7 Lower Gros Ventre Slide straight ahead.

13.3 At 4:00 o'clock is a complete section of the PHOSPHORIA Formation just above river level. This section was washed clean in the 1927 Gros Ventre flood and is one of the best in the region.

13.4 DINWOODY and CHUGWATER Formations (Triassic) are exposed on north edge of slide. Note how high the slide debris was thrown on the north side of the canyon.

14.3 Stop. The entire slide can be seen at this stop.

The red and purple beds are plastic shales in the AMENSEN Formation and these served as the slide planes. The large light-colored blocks are TERNSTEEP Sandstone. Directly to the east of the slide on the south side of the lake is an outcrop of black shale in the PHOSPHORIA Formation. Upstream from the slide, steeply dipping red beds in the CHUGWATER Formation are exposed on the flanks of the Red Hills Anticline. Red ledges directly north of the slide are likewise in the CHUGWATER Formation. The Alova Limestone Member forms the top of the prominent cliff 300 feet northeast of the turnout on the slide.

Lower Gros Ventre Slide. At 4:20 on the afternoon of June 23, 1925, a section of earth 2000 feet wide and a mile long slide more than 1-1/2 miles down the north slope of Sheep Mountain and into Gros Ventre Canyon. The momentum of the mass carried water and debris almost 400 feet up the far side of the canyon. A dam 285 feet high was formed which blocked the Gros Ventre River and created a lake 5 miles long. Alden (1925) estimated the volume of the slide to be 50 million cubic yards. The section on page 76 shows the relationship of the slide to the bedrock in Gros Ventre Canyon.
Several factors combined to produce the Lower Gros Ventre Slide.

1. The north slope of Sheep Mountain is faced with the resistant Tenaleep Sandstone. This sandstone is underlain by soft shale of the Amsden Formation.

2. The dip of the beds and the slope of the mountain are essentially conformable - 50' north.

3. There is a relief of slightly more than 2000 feet in a horizontal distance of a mile and a half.

4. The Gros Ventre River had cut completely through the Tenaleep at the toe of the slope.

5. There had been a prolonged period of exceptionally heavy precipitation immediately preceding the slide.

Relatively little destruction accompanied the slide itself. One ranch and a ranger station were destroyed by the rising water behind the dam, but no lives were lost. In May of 1927 two years after the slide, however, the slide lake created the slide dam, creating a calamitous flood and wiping out the village of Kelley 1/2 miles down the canyon. Six lives were lost during this flood.

Examination of the Gros Ventre Valley east of the Lower Gros Ventre Slide shows numerous slide scars, some of them quite recent. The map of the Gros Ventre River on the next page shows the location of some of the more prominent slides. Keefer and Love (1956) believed that landslides are the chief mechanism of mass wastage in the valley of the Gros Ventre River.
The route from the Lower Gros Ventre Slide back to Yellowstone Park passes north along the east side of Jackson Hole and rejoins U.S. Highways 89 and 287 just north of Moran. You should try to distinguish the deposits of the various glacial stages on the way back to Yellowstone.

Return via gravel road to Kelley.

0.0 Intersection of Kelley road and U.S. Highway 89 and 287 on Pinedale Outwash plain. Turn right (north).

1.2 Ascending terrace front onto Bull Lake Outwash plain. Valley of Snake River to left. Pinedale and Bull Lake terrace nicely developed on west side of river.

2.5 Picnic area. Fishing road (sign).

3.9 Teton Point Turnout.

7.0 Pass onto Bull Lake Moraine.

7.5 Travelling over Pinedale Outwash. Pothole area. Bull Lake Outwash surface to right.

10.7 Sign. Cunningham cabin.

12.2 Cross Cache Creek.

15.7 Cross Buffalo River.

15.8 Intersection U.S. 26 and 287. Turn northwest to Park Station and continue on highway 26 and 287.

16.7 Cross river.

19.8 Intersection. Turn right toward Jackson Lake Lodge.

20.4 Turn right to Jackson Lake Lodge.

Retrace route to West Thumb and thence to OLD FAITHFUL. Stay at OLD FAITHFUL LODGE.
NINTH DAY: ROAD LOG FROM OLD FAITHFUL TO INDIANA UNIVERSITY GEOLOGIC FIELD STATION

OLD FAITHFUL TO MADISON JUNCTION

0.0 Leave Old Faithful (Upper Geyser Basin) region. Travel northwestward on Grand Loop. The road follows the valley of the Firehole River past Midway Geyser Basin and Lower Geyser Basin. Upper Geyser Basin is underlain by Quaternary hot springs deposits, apparently laid down on Plateau Flows. Famous hot springs such as Sapphire, Morning Glory, and Mirror Pools. Old Faithful, the most famous of all geysers, is here as well. The hot springs and geysers here are depositing a hydrous silica sinter (geyserite). Some springs (Hillside Springs for example) are depositing a mixture of calcareous sinter as well.

1.15 Road on left to Black Sand Basin.

2.3 Approximately the north edge of the Upper Geyser Basin. The rocks along the Firehole River are Plateau Flows.

4.5 A group of small hot springs; the south edge of the Midway Geyser Basin.

4.6 Service road from Lower Geyser Basin.

6.0 Midway Geyser Basin. Among the many geysers of the Midway Geyser Basin are the Imperial, Spray, and Excelsior -- the latter was last active in 1888. When active it erupted at 1- to 4-hour intervals; eruptions lasted from 4 minutes to 1-1/2 hours, and reached a height of 300 feet. The overflow from the Excelsior Geyser Crater in 1934 was 500,000,000 gallons of scalding hot water. Turquoise and Opal pools as well as Indigo Hot Spring are in this basin.

8.1 Firehole Lake Loop.

8.75 Lower Geyser Basin. The Fountain Paint Pot, a large hot cauldron of clay, quartz, opal, and enough hot water to make a mud mixture, is situated in this basin. The colors of the mud range from white to pale orange and pink.

10.0 Cross Nez Perce Creek.

10.55 Service Road.

12.00 South End, Firehole Canyon. The river got its name from the fact that the early-day trappers found a large burn-out area here and named it "burnt-hole". From this developed the present name, Firehole River. For many miles, hot springs and geysers along the banks of the Firehole River pour their hot water into the stream; nevertheless, the water is cold and the river is inhabited by trout.

13.6 To the north the Summit of Purple Mountain (Yellowstone Tuff) may be seen (the lower part of Purple Mountain is composed of rhyolite pumice breccia).
13.85 Service road to Madison Junction.

15.10 Firehole Falls -- 40 feet high -- also a geological exhibit.

15.75 The rock pinnacle near here is the site of an Osprey (fish hawk) nest.

15.90 North end of Firehole Canyon.

15.90 The steep face of National Park Mountain (Plateau Flow) may be seen from here.

16.10 Cross Gibbon River.

16.2 Madison Junction

MAIDSON JUNCTION TO NORRIS JUNCTION

From Madison Junction to Norris Geyser Basin the road follows the Gibbon River. For the first mile and a half, the road is on Quaternary alluvium deposited in the valley formed along the northern edge of the Plateau Flow where it is in contact with the older Yellowstone Tuff. For 3 miles the north wall of the valley is made up of Purple Mountain Pumice Breccia. The south wall of the valley is Plateau Flow of the Madison Plateau. Thereafter we travel along the contact of the Yellowstone Tuff and the Plateau Flow.

0.0 Madison Junction.

0.5 Basalt outcrop on north side of valley.

1.0 Terrace Spring.

4.3 Service road to Cascades of the Firehole River.

5.2 Gibbon Falls -- Yellowstone Tuff.

5.55 Secret River Valley -- Underlain by Quaternary glacial gravel.

5.7 Iron Spring (sodium bicarbonate, sodium sulphate, ferric oxide, cold water) -- no law against drinking this.

6.8 Cross Gibbon River.

7.8 Cross Gibbon River.

8.15 Rhyolite in the high cliff to the south -- In Gibbon River Canyon the road follows more or less the contact between Yellowstone Tuff on the west and a rhyolite flow -- The Gibbon River unit of the Plateau Flows.

8.65 Beryl Spring -- one of the hottest springs in the region.

9.0 Cross Gibbon River.

9.4 Road to Monument Geyser Basin -- 1 1/2 hours by trail -- (deposits include realgar and orpiment).
9.5 North end of Gibbon Canyon.
9.8 Parking area: Artists Paintpots -- 0.5 mi.
10.5 Gibbon Geyser basin near the northern edge of Quarternary alluvial deposits.
11.0 Chocolate Pots: Beyond this point, for the next three-fourths mile, the road is on Yellowstone Tuff.
11.25 Gibbon River rapids.
12.40 South edge of Norris Geyser Basin. Mt. Holmes in Gallatin Range is to the northwest (Fire tower). It is an early Tertiary intrusive.
13.4 Parking area -- Norris Geyser Basin: Locale of Locomotive Springs, the Black Growler, Steamboat Geyser, etc. 100 feet east of the road is the site of an exploratory drill hole 250 feet deep. Temperature at that depth was 205°C, steam pressure 300 lbs. per square inch. (Allen and Day, 1935, Hot Springs of the Yellowstone National Park).
14.0 Norris Junction.

NORRIS JUNCTION TO GARDNER, MONTANA

0.0 Norris Junction: Northward the road is mainly on the Quarternary alluvium of the Gibbon River, whose valley is cut in Yellowstone Tuff.
0.3 Cross Gibbon River.
2.1 Frying Pan Spring -- the "frying" action is due to gas vents submerged in shallow water.
2.2 Nymph Lake to west (left side of road).
2.3 Fumaroles on east side of road; beyond is an outcrop of Tertiary basalt.
3.1) to
4.1) Twin Lakes.
4.5 Roaring Mountain: The rock undergoing alteration is the Yellowstone Tuff.
4.9 Sand and gravel of stream and lake deposits.
6.8 Lemonade Creek.
7.1 150 yards east of the road is a solfatara area.
7.50 Beaver Lake to the west -- on the east are outcrops of the Obsidian Cliff unit of the Plateau Flows. Enter Obsidian Canyon -- on the west bank of the river are outcrops of the Yellowstone Tuff.
8.10 STOP. Obsidian Canyon Parking area.
8.6 North end of Obsidian Canyon -- Crystal Spring.
9.3 Obsidian Creek -- The valley of Obsidian Creek is flanked by Yellowstone Tuff. Extensive basalt flows occur to the east, beyond the thin, elongated outcrop of Yellowstone Tuff.
9.4 Apollinaris Spring (calcium bicarbonate, silica, magnesium and sodium bicarbonates, sodium sulphate and potassium chloride -- makes excellent chocolate soda, if you bring the chocolate syrup.)
12.20 Indian Creek campground. Obsidian Creek.
12.60 Cross Gardiner River -- the rocks to the northwest are basalt; to the southeast is Yellowstone Tuff.
13.40 To the west is Antler Peak, 10,200 feet.
15.10 Swan Lake -- from here a view may be had of Bannock Peak; Quadrant Mountain (Paleozoic rocks) to the west, and Peaks of the Washburn Range, (early andesite breccia) to the east (Prospect; Cook; and Folsom Peaks, 9,300; 9,300; and 9,200 feet respectively).
15.7 Swan Lake: To the west is the Gallatin Range with views of Antler Peak (10,900 feet), Mt. Holmes (10,300 feet, with fire lookout tower), and Dome Mountain (9,900 feet) in addition to Quadrant Mountain (10,200 feet). To the north is Electric Peak (11,155 feet). Mammoth Springs Junction is 1.30 miles from here.
15.9 Cathedral Rock, on the face of Bunsen Peak. Bunsen Peak is a Tertiary intrusive of dacitic composition.
16.1 Glacial deposits on both sides of the road. The glacial deposits are on Yellowstone Tuff.
16.35 Jupiter Terrace -- calcareous hot spring deposits.
16.9 Liberty Cap, an extinct hot springs cone. Capitol Hill; glacial deposit (kame).
17.5 To the right of the road is a fine view of Mt. Everts, named after Truman C. Everts, a member of the Washburn Exploration party of 1870 who was lost in this region for 37 days. A good section of sedimentary rocks of late Cretaceous age is exposed in Mt. Everts.

The south end of Mt. Everts is capped with a rhyolite flow underneath which can be seen several feet of volcanic ash. This in turn lies on the upper Cretaceous shales and sandstones. Immediately beneath the north end of this flow as seen on the face of Mt. Everts is CLAGGETT shale. Further north to the left is the PARKMAN Sandstone, which caps the face of the cliff. The section from the Parkman or lower part of the JUDITH RIVER Formation is as follows:
Parkman Sandstone
Claggett shale (marine). Dark gray mudstones, yellowish-green shales, and thin dark gray sandstones
Eagle Sandstone (terrestrial).
Alternating sandstones, shales, and coal beds. Basal sandstone sometimes referred to as Virgella Member.
Telegraph Creek (partly marine). Thin bedded, light gray shales and buff sandstones, transitional between base of Montana Group, top of Colorado Group
Carlile-Miobrara (marine). Dark shale, containing fossiliferous concretions
Frontier (partly marine). Black sandy shale, with light gray, ledge-forming sandstone near top and some bentonite beds.
Mowry (marine). Hard siliceous black shale that weathers light gray. Contains fish scales and a six-foot bed of quartzitic sandstone 80 feet below the top

18.2 On the right near the level of Gardiner River issues a full grown stream known as Hot River, which is doubtless the overflow from the Mammoth Hot Springs. This empties into Gardiner River after flowing for about 200 yards parallel to it. Its flow is 21.5 second feet, and from analyses made by the Carnegie Institution it has been computed that this stream puts 100 tons of dissolved lime into Gardiner River every 24 hours. Temperature is about 137°F.

18.9 Cross Wyoming-Montana State Line.
19.0 Cross bridge over Gardiner River.
19.6 On right, high on the cliff, are river gravels and glacial drift deposited in the old channel of Gardiner River.
20.0 On right, cliffs of TELEGRAPH CREEK Formation. On left, a slowly moving slump or mud flow which is half a mile wide and about 2-1/2 miles long, extends from the flanks of Sepulcher Mountain.
21.1 Unconformity of volcanic agglomerate on Cretaceous shale.
21.3 On right, Eagle Nest Rock. Ospreys have been continuous summer residents at this place since the park was established.
21.4 Cross bridge over Gardiner River.
21.5 On right can be seen a monocinal flexure which is probably the drag of a fault paralleling the river at this place. The dip of the sediments in Mt. Everts is toward the northeast at an average angle of 15°.
Figure 40.--Geologic strip map, Gardiner, Montana, to Bozeman, Montana. Taken from the geologic map of Montana, 1955.
22.1 On the left is Sepulcher Mountain composed of early acid and early basic breccia. Beyond is Electric Peak, (11,355 feet), made up largely of Jurassic and Cretaceous sedimentary rocks intruded by numerous dikes and sills of andesite and andesite porphyry.

23.0 "CHECK OUT" at North Entrance of Yellowstone Park. First entrance used. Arch constructed in 1903 and dedicated to the "benefit and enjoyment of the people" by President Theodore Roosevelt.

23.5 Gardiner bridge over Yellowstone River.

GARDINER, MONTANA, TO LIVINGSTON, MONTANA

0.0 Road fork at north end of Gardiner bridge.

1.5 On right, basalts and travertine deposits overlie old erosion surface to cutting across Gardiner thrust fault and overturned Cretaceous beds southwest of it.

3.5 Ridge of REESE Formation (age uncertain) opposite, across river.

3.7 Overturned stream channel conglomerates in LARGE Formation visible to right of road.

4.2 Coals in slightly overturned EAGLE formation, visible to right. Precambrian rocks visible just beyond.

5.2 (STOP 3) EAGLE coal-measures visible in syncline to west. The Devil's slide consists of upturned beds, above which the crystalline rocks to the northeast have been thrust. The trace of this thrust fault is covered by volcanic breccias for several miles, but reappears again and has been mapped in the Three Forks Quadrangle to the Northwest. In the Devil's Slide (Cinnabar Mt.) section, the crest of the ridge is made by the Permian PROSERPINA Formation and Pennsylvanian CHELEEPE Sandstone, and the "slide" itself is formed by the CHUGWATER Formation which here shows a yellowish upper phase in addition to more common red beds in its lower part. From this point the overturning of the EAGLE coal measures in the ridge to the southeast (half way from Cinnabar Mountain to Gardiner) and the Precambrian complex and some "fault intrusions" just to the east are also clearly visible. (Several basalt and porphyry intrusions follow fault trace - both east of Cinnabar Mountain, and thence southeastward.)

5.75 Pass silicified breccia and spring at road side, approximately on thrust trace.

7.5 Store at Corwin Hot Springs, to right of road.

10.05 Pass road turning off to Dude Ranch.

11.9 Cross Slip and Slide Creek.

13.2 Pass signs "Winding Road" and "Yankee Jim Canyon". Banded gneisses, with steeply-dipping foliation extensively exposed in (Dome Mountain) ridge through which canyon is cut.
16.25 Emerge from lower portal of Yankee Jim Canyon into open valley.

16.85 Continue North on highway. Sign-post for road to left reads, "Cartella 1 mile" and "To Ox-Yoke Ranch". Light-colored tuff bed is visible high up in volcanic breccias forming ridge to northwest of the Yellowstone.

18.0 Note possible young fault scarp which cuts alluvial fan to right (southeast).

19.3 The agglomerates visible 100 yards to right of road surround a small volcanic vent and contain numerous large bombs and vertical tree stumps. Present valley floor is essentially at the level of the pre-volcanic valley floor.

19.6 Basalt flow which caps Chalk Cliffs begins to be visible to right—presumably at or near locus of extrusion.

19.75 to Acid porphyrite plugs exposed near or at right of roadside.

20.5 Basalt reappears to right of road and continues to Chalk Cliffs. Varied volcanic rocks and dikes visible across river.

23.95 Chalk Cliff ("Bozeman Lake Beds") consists of ashy materials containing late Miocene or early Pliocene vertebrates, and is overlain first by river gravels and then by basalt flow.

24.4 to Best exposures of Chalk Cliffs, "lake beds".

24.7 Re-worked material and river fill show to the right at curve.

25.4 Curve. Other basalt flows show in valley across river.

26.0 Chalk Cliffs basalt flow ends.

27.65 Cross Bridge over Six-Mile Creek.

28.6 Pass "Historic Sign" regarding Emigrant Creek gold discovery.

28.75 Cross Bridge over Emigrant Creek.

30.25 Pass Wanigan Store and filling Station.

30.45 "Lake beds" again visible in right road-bank, and are overlain by river to gravel. May continue as far as 31.0

30.6

31.7 Side road turns off to left to Emigrant Station and bridge.

32.5 Side road turns off to right to Chico Hot Springs.
35.2 Pass school (down lane to left). Wind gap leading from Yellowstone Valley into Trail Creek Valley, visible toward northwest from this point.

36.5 Road descends from prominent gravel terrace.

37.1 Cross Bridge over Mill Creek.

37.5 Side road turn-off to left to Pray.

37.6 Side road turn-off to right at Snowy Range Ranch sign.

38.2 Pass schoolhouse on left.

39.45 Cross bridge over Elbow Creek.

41.7 Pass sign "Livingston 1.5 miles".

43.75 Cross bridge over Barney Creek.

45.25 Cross bridge over Pine Creek.

45.45 Turn left onto side road, just beyond houses.

46.4 Cross bridge over Yellowstone River.

47.8 Turn north.

48.5 Cross Northern Pacific Railway tracks.

48.65 Pass Brisbin station.

49.55 Road Junction. MADISON LIMESTONE crops out on right. Old ranch on left. TURN RIGHT.

49.65 Cross crest of "hogback" anticline.

50.35 Opposite MADISON outlier.

51.0 Pass schoolhouse.

51.15 Outcrop of CLOVERLY conglomerate to left.

51.5 Upper CLOVERLY sandstone outcrop.

52.4 Pass GALLATIN Limestone "Headland" to left of road, and note red CLOVERLY (lower Cretaceous) clays and associated sandstones, which underlie green-gray Cambrian beds in "half-window" to left of road.

52.75 Road corner opposite basal CLOVERLY conglomerate (Lakota) outcrop. Repeated GALLATIN Cliff visible in lower part of mountain scarp to north.

53.7 Pass end of GALLATIN Limestone ridge (at old gate by roadside.) Tipped syncline (in MADISON Limestone) visible in top of Canyon Mountain to the northeast.
55.2 Cross Northern Pacific Railway tracks.
55.7 Junction with main highway. To east-southeast strong anticlinal crumpling in BIGHORN limestone visible a little beyond highway bridge.
56.4 BIGHORN Dolomite forms lower cliff across river. Overlain by DEVONIAN limestones and shales. Some minor thrust slicing in MADISON Limestone visible in cliffs west of road, between 56.4 and 56.8.
56.5 Pass contact between AMMON (red shales) and TENSLEEP Sandstone, which here comes to road level.
56.65 Livingston city limits.
57.1 Junction of routes 87-W and 10.

LIVINGSTON, MONTANA, TO BOZEMAN, MONTANA

The route turns west at Livingston, and follows the valley of Billman Creek as far as Bozeman Pass. We are beginning the last leg of our route to the I. U. Field Station, located in the northern part of the Tobacco Root Mountains. The road (U. S. Highway 10) is on Quaternary Alluvium for about the first mile west of Livingston, after which it enters the Valley of Billman Creek and at the same time crosses the contact of the Alluvium and the Cretaceous LIVINGSTON Formation. From this point westward to Bozeman Pass the underlying rocks belong to the LIVINGSTON Formation (volcanics and sedimentary rocks). The long ridge to the south is Canyon Mountain, composed of an Archean core flanked by Paleozoic and Mesozoic sedimentary and pyroclastic rocks. West of Bozeman Pass, the route follows the valley of the East Gallatin River and continues to traverse Cretaceous LIVINGSTON Formation rocks until we reach Chestnut Mountain at the eastern portal of Rocky Canyon. Rocky Canyon has been cut by the East Gallatin River in Chestnut Mountain, a southeasterly trending, dissected anticline. The formations exposed in the Chestnut Anticline range in age from Cretaceous to Mississippian. They appear in the following order as we drive westward through Rocky Canyon:

Cretaceous
   Eagle and Telegraph Creek Formations
   Upper Colorado Group (Carlile and Niobrara Formations)
   Lower Colorado Group (Frontier, Mowry, and Thermopolis Formations)

Jurassic
   Morrison Formation
   Ellis Group

Pennsylvanian
   Tensleep Sandstone

Mississippian
   Madison Limestone *(Center of the anticline; the Archean rocks are not exposed here)*
Watch carefully and see if you can spot the axis of the anticline. Thereafter, the section will be repeated in reverse order and at Gordon, about 21 miles west of Livingston, the rocks of the Upper Cretaceous COLORADO Group will be exposed on the north side (right) of the road. Shortly thereafter, near the west portal of Rocky Canyon, the road is once again on rocks of the Cretaceous, LIVINGSTON Formation. About 22 miles west of Livingston, the road leaves the Cretaceous LIVINGSTON Formation and travels over Quaternary Alluvium and strata of the Tertiary "BOZEMAN GROUP".

**BOZEMAN, MONTANA, TO INDIANA UNIVERSITY GEOLOGIC FIELD STATION**

0.0 Pick up the road log at the intersection of Main and Wilson Streets in Bozeman. Baxter Hotel (excellent food) on the northwest corner.

0.3 Junction of U. S. Highway 10 and 191. Turn sharply to right on U. S. 10.

1.3 Bozeman city limits. Bridger Range at 12:00 to 3:00 o'clock.

1.6 Overpass across Northern Pacific Railroad.

2.5 In the distance the Madison Range can be seen at 9:00 o'clock, and the Tobacco Root Mountains at 10:00 o'clock. The highway is on alluvium covered Bozeman "lake beds".

3.6 Bridge. From Bozeman to near Logan U. S. 10 has an almost straight course through the lower Gallatin Valley.

7.7 Cross Northern Pacific Railroad.

9.1 Side road to Gallatin Field.

9.7 Enter Belgrade (alt. 4,667 feet). The town was named in 1883 by a Serbian who was with the party accompanying President Villard of the Northern Pacific to Gold Creek to drive the last spike.

10.8 Bridge across West Gallatin River.

19.2 Enter Manhattan (alt. 4,258 feet). Named by New York land speculators who operated here under the name of the Manhattan Company.

20.1 Leave Manhattan. The low range to the right across the river is composed of the Precambrian BELT series overlain by early Paleozoic sediments.

22.5 Contact between ledge-forming FLATHEAD Formation and underlying BELT series can be seen in hills across river at 3:00 o'clock.

24.2 The rocks exposed to the right across the river range from Cambrian to Mississippian in age, dip to the northwest, and represent the east limb of a northeastward-trending syncline.

24.8 Logan.

25.5 Overpass. MADISON Limestone to right across Gallatin River.
27.9 Bridge across Ray Creek.

28.6 Side road to Trident. Three miles to the north are the three forks of the Missouri River. The Jefferson River, flowing northeastward, is joined from the south by the Madison River and less than a mile downstream the Gallatin River makes its confluence from the southeast. All three rivers named by Lewis and Clark in 1805. Note the series of folds in the low hills on the right.

29.4 Bridge across part of the Madison River.

30.0 Main bridge across Madison River.

30.5 The low range straight ahead has rocks from Cambrian to lower Cretaceous exposed along it. The Cambrian rocks form the south end of the range and progressively younger units make their appearance northward. The mountains at 1100 o'clock to 1130 o'clock in the distance are the Tobacco Roots.

31.2 Enter Three Forks (alt. 4,081 feet). After a series of false starts Three Forks more or less came into existence with the advent of the rail line that came through in 1905.

32.6 Overpass across the Milwaukee Railroad.

34.3 Bridge across the Jefferson River. Leave Gallatin county, enter Broadwater County.

34.5 Junction of U. S. Highways 10N and 10S. Turn left on U. S. 10S.

35.4 Middle Cambrian MEAGER Limestone in road cuts. Named by Weed for exposures in Meagher County to the northeast.

37.0 Upper Cambrian PILGRIM limestone on right.

38.0 PILGRIM limestone repeated by faulting.

39.1 Crossroads. Leave Broadwater County, enter Jefferson County. The entire Cambrian succession with the exception of the DRY CREEK shale, which here is cut off by the valley, is exposed in the low range at 2300 o'clock. The FLATHEAD is poorly exposed at the base of the hill because of talus from the overlying WULSEY shale.

45.9 The low ridge to the left is basal KOOTENAI; about 500 feet thick.

47.2 LIVINGSTON formation exposed in road cut.

48.0 LIVINGSTON formation in low ridge on right. High hills in the background are BELT series. Paleozoic rocks absent between the two by faulting.

49.4 Enter Lewis and Clark Cavern State Park. Main feature is cave discovered by Mr. Dan A. Morrison in 1902. In 1911 it was declared a National Monument.
50.0 Good view of Cave Mountain at right. KOOTENAI in road cuts.

50.3 In the valley to left across the Jefferson River landslide topography is developed on the ELLIS and KOOTENAI, which are in fault contact with the MADISON and AMERICAN formations, forming the west wall of the valley. Enter Jefferson Canyon.

51.9 MADISON limestone (Mission Canyon) on both sides of river.

52.3 Limestone quarry in MADISON.

53.2 Precambrian BELT arkose forms mountain ahead and on the right. LABOOD formation.

54.1 Leave Lewis and Clark State Park.

54.7 La Hood Park.

56.4 Bridge across North Boulder River.

57.2 Cardwell Junction. Turn left on gravel road leading to South Boulder road.


58.5 Bridge across Jefferson River. Leave Jefferson County, enter Madison County.

58.6 Cross Milwaukee Railroad.

59.1 Jefferson Island.

59.5 North end of the Tobacco Root Mountains at 1:00 o'clock.

60.1 Travelling on Bozeman "lake beds".

62.5 Bridge across South Boulder Creek.

63.0 Turn right on gravel road paralleling South Boulder River. Tobacco Root Mountains at 2:00 o'clock. The mountains were named for a variety of bitterroot that occurs in the mountains. The Shoshone Indians ate these roots which, when cooked, smelled like tobacco. A few whites attempted to add these roots to their diet, but gave it up.

63.7 Lava flows (ELEKORN MOUNTAINS volcanics) capping hills on both sides of valley.

65.9 Side road left to London Hills. Keep straight ahead. Gastropod limestone member of KOOTENAI is poorly exposed at left.

66.6 Northward-dipping QUADRANT, PHOSPHORIA and ELLIS exposed in rounded hill across river.

67.0 Bridge across South Boulder River. Base of MISSION CANYON limestone of MADISON group is the gray ledge-forming limestone in lower part of hill at right.
67.5 SAPPINGTON formation forms a bench on the grassy slope at the right. The little valley below the bench is THREEFUGS shale, and the evergreen-covered dip slope on the south side of the valley is JEFFERSON formation.

67.6 Pole Canyon at right. JEFFERSON formation immediately to right.

67.8 PILGRIM limestone at right.

67.9 PARK shale (valley) at right.

68.0 MOKAGHEE limestone at right.

68.2 Pit at right is in WOLFEY shale.

68.4 FLATHEAD sandstone at right rests on Precambrian PONY gneiss.

69.5 Turn left to Indiana University Geologic Field Station.

69.7 INDIANA UNIVERSITY GEOLOGIC FIELD STATION. Located on a narrow alluvial apron along the east side of South Boulder River. The bedrock at the camp is the PONY gneiss of Precambrian age. About 100 yards south of the camp the Carmichael Creek Fault crosses the road in a southeasterly direction.

75.4 Jef. 257 and Hubenhalde Road

97.9 Horse Creek Valley. Excellent terraces downstream. In a short distance upstream

96.2 RT. gravel pit, terrace on hill across river (R). Main Fault, Hubenhalde Road

99.7 Indian Creek Bridge. Road (L) crosses river. Sphend 111 (R).

100.5 Atop upper terrace. Sphend 111 (R).

100.5☽ Carson Creek. In the first bend there the base of the Madison Range (R), at the upper edge of the large fault scarp.

117.8 Madison River bridge. Enter Ennis

118.5 Jef. 34. Continue N on 257.

120.8 Atop terrace. Forr. lake (R) in distance. Madison River upstream. From the large valley the rocks are nearly level for the Alpine.

127.5 Assumed to be the middle terrace in these areas, with 150' vertical.

135.6 0 R. xing. Norris

142.3 0 Upper terrace approximately 1250' altitude.

150.4 0 R. xing. garment. Left road to PONY. Turn 135°

152.8 PONY fork and. Turn left

155.5 Upper North Fork road at PONY dirt road

156.7 Turn left. Take it to Camp
GEOLOGY OF THE CENTRAL STABLE REGION

There is a vast stretch of country between the Appalachians and the Rockies where the rocks of the post-Pre cambrian sedimentary veneer are horizontal or only slightly tilted, relatively thin, and relatively rich in carbonate. This is the Central Stable Region. We see in figures 42 and 46 on pages 94 and 95 that the Central Stable Region is subdivided into several units, such as the Great Plains, Interior Lowlands, and Canadian Shield, and that these units contain distinct structural, stratigraphic, and physiographic subunits.

The part of the Central Stable Region that is discussed in this resume is limited, more or less, to the area shown on the figure below. The reader is referred to P. B. King's excellent books, "The Tectonics of Middle North America" and "The Evolution of North America" for a more complete summary of the geology of the Central Stable Region.

![Figure 42. Map of the Central Stable Region. After Raisz, E., 1957.](image)
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Figure 44. - Generalized Paleozoic stratigraphy of the Central Stable Region. From C. S. A. correlation charts and other sources.
PALEOZOIC STRATIGRAPHY

CAMBRIAN

Rocks of lower and middle Cambrian age are not found in the Central Stable Region. See the stratigraphic chart on page 96. The upper Cambrian consists of less than 1,000 feet of sandstone and some interbedded carbonates. These rocks are best exposed along the margins of the Canadian Shield in Wisconsin and Minnesota and along the edge of the Ozark Uplift in Missouri and Oklahoma.

The upper Cambrian sands were deposited in shallow water by seas that encroached slowly onto the continental platform from the Appalachian and the ancestral Cordilleran troughs.

ORDOVICIAN, SILURIAN, AND DEVONIAN

Limestones and dolomites are the dominant lithology in the Ordovician, Silurian, and Devonian rocks of the Central Stable Region. These rocks are well exposed along the axis of the Cincinnati Arch, Nashville Dome, Kankakee Arch, and other positive structures in Ohio, Indiana, Illinois, and Iowa; along the margins of the Shield in the upper Mississippi valley; and along the edges of the Ozark region of Missouri and Oklahoma. These rocks are noted for their prolific fossil content, including the upper Ordovician (Cincinnatian) fossil-bearing beds of the Cincinnati region, the Silurian fossil reefs of the Chicago region, and the Devonian coral reefs of Michigan. A widespread black shale, known in different areas as the Antrim, New Albany, and Chattanooga, occurs at the top of the Devonian and appears to continue on into the Mississippian.

The environment of deposition of these rocks was once again shallow water marine. Scattered evaporite deposits in the Silurian and Devonian (particularly in the Michigan Basin) attest to the fact that certain parts of the shallow seas had a restricted circulation at times.

MISSISSIPPINIAN

Mississippian and Pennsylvanian rocks of the Central Stable Region contain a higher percentage of clastics than the lower and middle Paleozoic. In general, the Mississippian can be divided into three units: (1) a lower unit rich in shale and minor amounts of carbonate, (2) a middle limestone unit, and (3) an upper sandstone and shale unit and some interbedded carbonate. Exposures of rocks of Mississippian age are widespread in the Interior Lowlands.

The Mississippian is thicker in most places than the preceding Paleozoic formation and indicates by its lithology that the continental platform was experiencing some slight epeirogenic effects from the initial pulses of the Appalachian orogeny to the east and south.

PENNsylvanian

Pennsylvanian rocks are now confined mostly to the basin areas, such as the Illinois Basin and the Michigan Basin, but there is reason to believe that they were deposited over much of the Central Stable Region. The Pennsylvanian is predominantly clastic but exhibits a great variety of lithologies, including
the economically important coal measures, and cyclothems—those rhythmic alterations of continental and marine sediments that attest to minor but widespread fluctuation in land areas and sea areas at this time. There is a gradual but progressive change in the relative amounts of land-deposited and sea-deposited units from east to west. In Pennsylvania the Pennsylvanian is almost wholly land deposited. Westward in Illinois there is an almost equal proportion of continental and marine beds, whereas in Kansas the sequence is almost wholly marine.

**PERMIAN**

Rocks of the Permian System are restricted to the southwestern part of the Interior Lowlands in Nebraska, Kansas, Oklahoma, and Texas, and it is doubted if they even were much more extensive. Most of the Central Stable Region was land area and was being eroded by the end of the Pennsylvanian.

The Permian is characterized by carbonates in the lower part and by red beds and evaporites in the upper part. The edges of the evaporite basins were fringed by limestone barrier reefs and banks (King, 1940).

**TECTONIC DIVISIONS**

Figure 46 on page 99 shows in sketch form the size, shape, and location of the more prominent structural elements in the Central Stable Region. In the whole of the Central Stable Region there are no truly orogenic belts such as we find in the Appalachian and Cordilleran region. Here the structures are broad and gentle and result in a series of basinlike negative areas and a number of arch or dome-like positive structures. We consider first the basins or negative structures.

**ILLINOIS BASIN**

Figure 45 below is a cross section of the Illinois Basin from the Kankakee Arch on the northeast to the Stark Dome on the Southwest.

![Geologic cross section of the Illinois Basin](image)

Figure 45.—Geologic cross section of the Illinois Basin. Taken from King, 1951.

Paleozoic rocks attain a maximum thickness of about 10,000 feet in the basin, but this thickness cannot be measured in any one vertical section. Furthermore, some of the time-rock units thin toward the center of the basin rather than thicken.
This thinning toward the center indicates that the Illinois Basin is a structural basin rather than a sedimentary one. The basin contains a number of smaller folds, such as the La Salle Anticline, the Du Clos Flexure, and the Lincoln fold, and its southern end is crossed by a complex system of normal faults that carry important fluorspar mineralization.

MICHIGAN BASIN

Figure 47 below is a north-south cross section through the Michigan Basin.

![Cross section of the Michigan Basin]

Figure 47.—Geologic cross section of the Michigan Basin. Taken from King, 1951.

This basin, like the Illinois Basin, is an intracratonic basin, but there are some important differences. The Michigan Basin is a symmetrical basin. Rock units thicken toward the center of the basin and thus it is a sedimentary as well as a structural basin. The maximum thickness of Paleozoic sediments in the basin is somewhat in excess of 10,000 feet and the approximate geographic center of the basin contains the thickest rock section. Also, the Michigan Basin is less compartmented by minor folds and faults than the Illinois Basin.

FOREST CITY AND SALINA BASINS

Figure 48 on page 101 shows a cross section of the Forest City and Salina Basins and includes the Nemaha Ridge. Both basins are rather shallow. They are separated by a very sharp and very strong positive element known as the Nemaha Ridge. The development of the Forest City Basin on the east and the Salina Basin on the west is closely allied with the upwelling, by folding or faulting, of the basement along the Nemaha Ridge in late Mississippian and early Pennsylvanian time and with its subsequent erosion and final burial by sediments in later Pennsylvanian time.

There are numerous places in the Central Stable Region where the rock section is thinner than usual or where Precambrian basement is found closer to the surface than normal. These are the so-called positive areas. Only two of the largest of these positive structures—the Cincinnati Arch and the Ozark Dome—will be treated here.

CINCINNATI ARCH

The Cincinnati Arch is a poorly defined positive structure near the eastern margin of the Central Stable Region in Tennessee, Kentucky, Ohio, and Indiana. Northward from this point the arch splits into a northeastward-trending high known as the Findlay Arch and a northwestward-trending branch known as the Kankakee Arch.
Figure 40.--Geologic cross section of the Salina Basin, Nemaha Ridge, and Forest City Basin. After Hardley, 1951, p. 39.
Rocks of middle Ordovician age are exposed at the center of the Nashville and Jessamine Domes. Evidence on hand suggests that the Cincinnati Arch was active as a positive element from early Ordovician, but most of the actual upwarp probably took place after deposition of the Paleozoic strata.

OZARK DOME

The Ozark Dome is a broad plateau-like uplift that occupies most of the southern half of Missouri and spills over into Arkansas and Oklahoma. Its central part exposes a circular area of Precambrian, Cambrian, and Ordovician rocks nearly surrounded by outward-dipping Mississippian and Pennsylvanian rocks. Near the eastern part of the uplift a roughly circular mass of Precambrian crystallines, the St. Francis Mountains, projects above the general level of the dome.

Like the other major structures of the Interior Lowlands, the Ozark Dome has developed through most of the Paleozoic era. Early Paleozoic strata thin toward the crest of the uplift, and both Mississippian and Pennsylvanian rocks are unconformable on older rocks.

GLACIAL GEOLOGY OF THE CENTRAL STABLE REGION

The surface of much of the Central Stable Region is mantled with a cover of glacial drift of varying age and thickness. Figure 49 on page 103 shows the distribution of this drift. Notice the lobate character of the moraines as they sweep southward into the Central Lowlands.

Four fairly distinct periods of ice advance, or glacial ages, separated by periods of ice retreat, or interglacial ages, are recognized for North America, as classified below:

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Age</th>
<th>Subage</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Valders?</td>
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<td></td>
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<td>Mankato?</td>
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<td>Cary</td>
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<tr>
<td></td>
<td></td>
<td>Tazewell</td>
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<tr>
<td></td>
<td></td>
<td>Iowan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Farmdale</td>
</tr>
</tbody>
</table>

Wisconsin glacial
Sangamon interglacial
Illinoian glacial
Pleistocene
Yarmouth interglacial
Kansan glacial
Aftonian interglacial
Nebraskan glacial

A study of the deposits of the latest glacial age, the Wisconsin, shows that it is not a single great ice advance but a number of individual advances and retreats, each with its characteristic drift and moraine pattern. These individual ice advances moved from two or more centers in Canada and were controlled in large
Figure 49.—Generalized glacial geology of the Central Stable Region. Modified from U.S.A. glacial map of the United States east of the Rocky Mountains, 1939.
measure by the preglacial bedrock topography. They left a distinct series of
drift lobes which include from east to west:

a. Ontario-Erie Lobe -- northwestern Pennsylvania, Ohio and
   eastern Indiana.

b. Lake Michigan Lobe (including Green Bay and Saginaw sublobes) --
   Michigan, Wisconsin, Illinois, and Indiana.

c. Lake Superior Lobe -- northwestern Wisconsin and northeastern
   Minnesota.

d. Red-Iowa Lobe -- western Minnesota and Iowa.

e. Dakota Lobe -- North and South Dakota.

In the northern part of the Interior Lowlands the surface is modified by
both glacial scour and by glacial deposition. To the south the modifications
are largely the result of glacial deposition alone. In this latter area in
Ohio, Indiana, Illinois, and Iowa glacial deposits range in thickness from a
few feet to more than 300 feet. The bedrock surface is effectively buried
under a relatively smooth-surfaced layer of drift, and it is only through
drilling and geophysical methods that we are able to reconstruct the pre-
glacial drainage patterns.

The various drift layers are dated on the basis of the law of superposition,
distribution of the drift to known ice centers and lines of ice advance,
character of the drift, topographic expression, and, for the latest glacial
age, radiocarbon methods. In general, the deposits of the Wisconsin Stage are
fresher than those of preceding glacial stages. Also, the moraines and other
depositional topographic features of Wisconsin age are more distinct than
similar features left by earlier ice sheets.
GEOLOGY OF THE BLOOMINGTON, INDIANA, REGION

Bloomington, Indiana, and the campus of Indiana University are underlain by limestones of Mississippian age. Figure 53 on page 107 is a generalized stratigraphic column showing the Mississippian rocks exposed in the region. The middle Mississippian (largely Meramecian) limestones average about 300 feet in thickness. Their exposure is limited to a lowland area known as the Mitchell Plain. (See figure 50 below and figures 54 and 55 on pages 108 and 109.)

Figure 50.--Diagrammatic cross section of the Bloomington area. From Indiana Geological survey, 1950.

The Salem Limestone is commercially the most important rock unit in the region. It is extensively quarried for building stone, and because of its uniform texture and color, ease of working, and great strength, it is the most widely used natural building stone in the United States. Figure 51 below gives a view of one of the numerous limestone quarries in this area.

Figure 51.--Photograph of a limestone quarry near Bloomington, Indiana. Courtesy R. Dee Barick.
The Bloomington, Indiana, region is also well known for its excellently developed karst topography. The Mitchell Plain west and south of Bloomington is literally riddled with sinkholes, caves, sink valleys, and other features of bedrock solution. These features are most numerous near the St. Louis-Ste. Genevieve contact.

Bloomington lies in the eastern part of the Illinois Basin. The rocks in this region dip at about 30 feet per mile to the west-southwest. The structure in the region then is essentially a very gently dipping monocline. Younger rocks are exposed up section to the west. Notice on figures 53 and 54 how nicely the physiography is adjusted to the bedrock and the regional structure. This is not the case for central and northern Indiana, where till sheets cover and obscure the bedrock surface.

Several smaller structures are found within the Illinois Basin. See figure 52 below.) They are (1) the LaSalle Anticline; (2) the Duquoin Monocline; (3) the Moorman Syncline; and (4) the Rough Creek, Shamrock, and Ste. Genevieve Fault Zones.

Figure 52.—Structural features of the Illinois Basin. Modified after Clark and Roys, 1948, and Swann and Bell, 1958.
**Figure 53.**--Generalized stratigraphic column of Mississippian rocks exposed in the Bloomington region. From Ferry, Smith and Wayne, 1954, pl. 1.
"Magnificent ruins of a great silent city painted in delicate shades of cream, and pink, and buff, and green! Domes, towers, minarets, and spires decorate gorgeous cathedrals and palaces and present dimensions little dreamed of by the architects of the ancients."

Cleophas C. O'Haara
South Dakota School of Mines Bulletin No. 13

The White River Badlands are the erosional remnants of a once-extensive blanket of sediment that surrounded and partially covered the Black Hills in Oligocene time and extended eastward as far as eastern South Dakota. The sediments are believed to be nonmarine and fluviatile (flood plain and channel fill) in origin. The source for the sediments appears to have been the Black Hills. Several large stream channels have been found in the Chadron Formation—all trending in a general east-west direction. Sands and gravels become coarser and more abundant in these channels to the west; the gravels contain many of the more resistant materials found in the rocks of the Black Hills.
The Badlands are geologically famous for two reasons:

1. They are the classic vertebrate fossil collecting ground in America.
2. They are the type example for Badlands topography.

Paleontologists have collected more than 150 different species of land animals and a few plants from the Oligocene beds of the Badlands. Some of the more common or important vertebrate fossils are listed below:

- Titanotherium - large rhinoceros
- Metaxyodon - rhinoceros
- Poebrotherium - ancestral camel
- Proceratops - six-horned deerlike herbivore
- Creodons - the ruminating ancestral hog (?)
- Stylonyx - dryland turtle
- Crocodilus - Oligocene crocodile
- Leptocerchaenio - (?)

Plant fossils (maple, oak, and walnut) indicate a warm, moist climate for the Black Hills during Chadron time. The climate was somewhat drier during Brule time.

The complex dendritic drainage pattern of the Badlands has been produced by headward erosion into the tablelands. Rainwash and creep are believed to be the two most important mechanisms of slope retreat. The Chadron, with its somewhat more permeable clays soaking in the water, erodes principally by creep. Rounded "haystack" hills with broad convex tops and average slope angles of 33° are common erosion forms. The Brule Formation erodes by rainwash into sharp, angular forms.

The light-gray sediments of the Chadron Formation rest disconformably over the Pierre shale. A fairly rugged topography was developed on the Pierre (Cretaceous) by the time of Chadron deposition (Oligocene). The unconformity in places has a relief of 100 feet. The uppermost 30 to 40 feet of the Pierre shale below the unconformity is deeply stained in red, purple, yellow, and brown. Many think that this coloration originated in pre-Oligocene time and represents a "laterization" of the Pierre.

The Brule Formation overlies the Chadron conformably and is differentiated from it on the basis of the color (buffs and pink) and the weathering forms (steep, angular). The Brule in turn is overlain by fine clastics of the Arikaree Formation (Miocene). See figure 37 on page 112.

Near the northwest corner of the Badlands Monument peculiar narrow wall-like bodies are found standing above the general surface of the Brule and Chadron. These are the clastic dikes and chaledony veins which have evoked so much speculation. The dikes and veins are numerous in nearly all parts of the Badlands. They vary greatly in strike, but most of them are vertical. They commonly cross-cut with no apparent offset. Common thicknesses range from a quarter of an inch to 1 inch, but many of the dikes and veins are smaller, and some reach a width of 3 feet.

We shall have a chance to examine several of these bodies. Study their lithology and their relations to the surrounding sediments. Can you suggest an origin for these dikes and veins?
LOWER KIIOCENE

Arikaree Formation
Rosedale Member - light-colored clays and sand with discontinuous layers, lenses, etc; ash near top.
Basal Arikaree White ash

OLIGOCENE

Brule Formation:

Poleslade Member - Protoceras beds - type 8-1/2 miles south of Scenic, South Dakota.

Upper Zone (Rosedale of Matthew)
85 feet - Gray silty ash. Weathers in vertical walls and columns.

Middle Zone
111 feet - Buff and gray clays. Protoceras channel sandstone in upper 40 feet. Sandstones highly fossiliferous.

Lower Zone (light weathering of Wanless)
17 feet - Light-gray clay with narrow brown bands above and below.
30 feet - Gray clays with brown hue. Not very fossiliferous.

(Orellan-Whitney contact)

Scenic Member - Oredon beds - type 2-1/2 miles south of Scenic, South Dakota

Upper Nodular Zone (easily recognized)
12 feet - Light-creamy clays with narrow layer of fossiliferous clay-lime concretions.

22 feet - Gray clays with scattered and rounded silt concretions (few fossils)

Vertical weathering.

39 feet - Mostly gray clays but with irregularly spaced brown banding.

Siltstone concretions. Fossils rare.

Lower Nodular Zone (easily recognized)
36 feet - Pink-gray clays; brown-gray weathering; clay-lime concretions which oxidize rusty color. Highly fossiliferous.

Chadron Formation

Upper Member
20-40 feet - Mainly clays with few sand layers; fossils scarce.

Middle Member
40-70 feet - Gray clays with silts and sandstones; basal 10 feet of gray-brown fossiliferous sandstone; scattered conglomerate.

Lower Member
10-90 feet - Variable lithology; blue-green clays; chalky sand, red clay, and gravel; fossils scarce.

Disconformity (relief as much as 100 feet)

UPPER CRETAaceous

Pierre Formation - Gray shales; upper 30 to 40 feet stained red, purple, brown, and yellow.

Figure 57.--Tertiary stratigraphic section of the White River Badlands, South Dakota. After Bump, 1956.
GEOLOGY OF THE BLACK HILLS

The Black Hills rise from the plains of western South Dakota as though to greet the westward-bound traveller to the great Rocky Mountains. Lying as they do some 100 miles east of the main front of the mountains, the Black Hills give us our first glimpse of Rocky Mountain stratigraphy and structure. Your field study of the Rocky Mountains, then, begins with your first glimpse of these famous hills. Observe carefully:

The Black Hills are an elliptical uplift about 110 miles long and 50 miles wide. Four geomorphic units are recognized: (1) a rugged central core composed predominantly of Precambrian crystalline rocks; (2) a prominent upper Paleozoic plateau surrounding the inner mountains and on the west side rising over the Precambrian; (3) the Red Valley or "race track," underlain by Triassic (periodic) red shales; (4) the hogback ridge of Cretaceous sandstone, which presents a bold inward escarpment to the Red Valley and declines down its own dip slope into the surrounding plains. We will enter the Black Hills at Rapid City, where Rapid Creek has cut a shallow gorge through the hogback ridge.

Figure 50.—Diagrammatic map and section of the Black Hills, South Dakota. After Grunder, 1911, p. 246.

Rocks ranging in age from middle Precambrian to late Cretaceous are exposed within the uplift. The Precambrian core consists of metamorphosed igneous and sedimentary rocks, highly distorted and intruded by granite and pegmatite (Precambrian) and by porphyry stocks, plugs, and laccoliths (Tertiary). The figures on Mt. Rushmore are carved from the Harney Peak Granite, one of the late-middle Precambrian intrusives in the central core. Pegmatites famous for their
large spodumene, feldspar, and mica crystals are associated with the granite at Keystone in the southern Black Hills. In the northern hills the important gold deposits at Lead are found within the metamorphosed and disturbed Precambrian schists.

About 1500 feet of Paleozoic rocks (upper Cambrian to Permian) are exposed in the belt immediately surrounding the central crystalline area. See figure 59. The lower 10 to 500 feet of the section (Deadwood Formation) is predominantly clastic. The upper part of the section is characterized by massive ledges of limestone (Pahoaapa) and sandstone (Minneluza). Silurian and Devonian rocks are entirely absent from the Black Hills section, and only a relatively thin formation marks the Ordovician.

The Mesozoic section measures as much as 11,000 feet, but only the lower 2,500 feet is well exposed. Red shales and sandstones, with gypsum members, characterise the lower part of the exposed Mesozoic section. Green shales and massive sandstones constitute the upper part.

In the southern and eastern part of the Black Hills the long axis of the uplift trends about N10°W. In the northwestern part of the uplift the axis has a more westerly trend, striking about N45°W.

Paleozoic and Mesozoic rocks appear to be draped over the broad-backed central crystalline region. On the east side where erosion has removed the post-Precambrian sheet, the Paleozoic and Mesozoic strata appear turned up in eastward-dipping hogback ridges. Paleozoic rocks ascend the west side of the uplift by a series of step-like folds and extend out over the crest of the uplift, where they can be seen resting horizontally on deformed schists and gneisses.

The geologic history of the Black Hills is much longer, although certainly no less interesting, than its modern history. The more pertinent details of the geologic story are summarised on pages 116 to 118.
<table>
<thead>
<tr>
<th>QUATERNARY</th>
<th>FORMATION</th>
<th>LITHOLOGY</th>
<th>THICKNESS IN FEET</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Badlands, formations</td>
<td></td>
<td>0-30</td>
<td>Sandstones, and breccias</td>
</tr>
</tbody>
</table>

| MIOCENE AND Oligocene | Ft. Union formation |            | 0-250 | Dark grey gravel and sandstone, yellowish to grey sandstone, shale, siltstone |

| PALEOCENE | Hell Creek formation |            | 425   | Orange, yellow, and grey sandstone with intercalated gravelly lenses in upper part, lower half more sandy, clay, fine gravel and sandstone |

| FOR HILLS S. |            |            | 85-100 | Gray, white to yellow sandstones |

| UPPPER | Pierre shale |            | 1200-2500 | Principal occurrence of limestone lenses giving loose surface |

| CRETACEOUS | Niobrara s.s. |            | 100-225 | Orange, yellow, and grey sandstone |

|    | Carli shale |            | 400-800 | Light grey shale with numerous cavities and sandstone beds |

|    | Spartanburg s.s. |            | 20-225 | Dark grey sandstone, weathered limestone |

|    | Newcastle (Mud) s.s. |            | 150-300 | Dark grey sandstone, weathered limestone |

|    | Skull Creek sandstone |            | 0-500 | Orange sandstone, weathered limestone |

|    | Dakota sandstone |            | 0-998 | Yellow to purple sandstone, weathered limestone |

|    | Middle beds |            | 0-253 | Weathered brown sandstone |

|    | Lullahoma s.s. |            | 25-398 | Weathered brown sandstone, weathered buff sandstone, conglomerate, sandy sandstone, siltstone, shale, sandstone, and breccia |

| JURASSIC | Morrison s.f. |            | 0-225 | Orange to grey sandstone, shale, siltstone |

|    | Uinta s.s. |            | 0-225 | Weathered fine-grained sandstone |

|    | Eocene Springs s.s. |            | 70-450 | Weathered fine-grained sandstone, and small sandstones and siltstones, siltstone, and shale |

|    | Uinta s.s. |            | 0-450 | Weathered fine-grained sandstone, siltstone, and shale |

|    | Uinta s.s. |            | 0-60 | Weathered fine-grained sandstone |

| TRIASSIC | Spearfish formation |            | 350-700 | Red sandstone, siltstone, and shale with pumice and breccia |

| PERMIAN | Wwllowood s.s. |            | 50-500 | Red sandstone and siltstone |

|    | Missoula s.s. |            | 50-500 | Red sandstone and siltstone |

| PENNSYLVANIAN | Wwllowood s.s. |            | 300-450 | Red sandstone and siltstone, weathered, and siltstone |

|    | Missoula s.s. |            | 300-450 | Red sandstone and siltstone, weathered, and siltstone |

| MISSISSIPPIAN | Wwllowood s.s. |            | 0-650 | Red sandstone and siltstone, weathered, and siltstone |

|    | Muddy Creek s.s. |            | 0-650 | Red sandstone and siltstone, weathered, and siltstone |

|    | Blackwood s.s. |            | 0-900 | Red sandstone and siltstone, weathered, and siltstone |

| ORDOVICIAN | Blackwood s.s. |            | 0-650 | Red sandstone and siltstone, weathered, and siltstone |

|    | Deadwood s.s. |            | 0-900 | Red sandstone and siltstone, weathered, and siltstone |

|    | Manganese and iron formations |            | 0-900 | Red sandstone and siltstone, weathered, and siltstone |

|    | Precambrian |            | 0-900 | Red sandstone and siltstone, weathered, and siltstone |

*Figure 59.—Generalized columnar section of the Black Hills, South Dakota. From South Dakota School of Mines, 1970.*
Summary of Geological History of the Black Hills, South Dakota

Tuff and Obsidian (southeast of Deadwood)

Pleistocene
Regional uplifts resulting in erosion and reworking of older Tertiary sediments; Pleistocene terraces in valleys and large areas along divides radiating out from foothills.

Miocene
Folding and faulting (south of Black Hills) into Pliocene.

Erosion of Oligocene over Black Hills area.

At close of Oligocene over 6,500 feet of sediments eroded. Hills appeared as low range of Precambrian rocks nearly engulfed by White River sediments.

White River Group—clays, sands, and volcanic ash and sluggish streams and temporary lakes; important vertebrate fauna, also plants and seeds.

Active Erosion

Early Tertiary intrusions in northern Black Hills; intrusion of rhyolite, rhyolite porphyry, monzonite, quartz monzonite, phonolite, and other types in form of dikes, sill, plugs, batholiths, stocks, and laccoliths producing marked deformation; mineralization in Deadwood Formation.

Paleocene
Port Union Formation (Cannonball clays, shales, marine member silts, sands, Ludlow Lignite lignites, Member)

Clay, vertical uplift and doming

Hell Creek-sand along marshes; large brackish and fresh water basins

FOX HILLS-withdrawal of sea; brackish and fresh water basins

PERSIRE SHALE—clay, minor subsiding trough on west side of Hills shelf to east

Laminated limestone with bentonites, sandstone

sand, gravel, and gravel dolomite

Laminae with limestone intercalation, bentonite, sandstone
NIAGARA LIMESTONE
briefly
inter-
rupt-
ions
of
DAXOTA SANDSTONE (earliest American dicotyledon
flora (flowering plants); coarse
(strong currents);
FUSION SHALE - Deeper quiet marine waters
MINNOSAUG LIMESTONE
LAXODA SANDSTONE (indurated); prominent bogback;
shallow seas and estuaries along coastal plain

MORRISON FORMATION (dinosaur beds);
invertebrates; stable shelf conditions;
UPPER CAMPAS SANDSTONE - uplift
SUNDANCE SANDSTONE, shale and fossiliferous limestone, marine
local downwarping; exceptional thickness of Jurassic sediments in southeast part of area.

SPEARFISH FORMATION - red sandy clay unstable shelf during redbed and evaporite deposition
700 feet and gypsum as much as 30 feet

PERMIAN 
MINNOKATA LIMESTONE (late Permain Black Hills weak but distinct unstable shelf; evaporites
OPHELIE SHALE - red, thin early Permain positive element

PENNSYLVANIAN -
MINNOKUSA FORMATION - marine sandstone, shale, and limestone early Pennsylvanian-Lusk Embayment
Seas no longer invade from northwest
Penn - Pre-Penn ) thumblike projection
Post-Madison uplift extending northward from Siouxi

MISSISSIPPIAN -
PARKSAPA LIMESTONE widespread marine conditions
EAGLEWOOD FORMATION
DEVONIAN - absent
SIURIAN - absent
C
ORDOVICIAN

Late
Richmond

WHITWOOD FORMATION

enroachment of seas
stable shelf
Sioux Arch

CAMBRIAN

DEADWOOD FORMATION-marine submergence
transgressive seas
Peneplanation
few local shallow channels
and low ridges

Granite and pegmatite intrusion - Harney Peak Granite with associated pegmatites; mineralization at Homestake; concentric deformation of earlier structures around margin of Harney Peak Granite.

Shear folding superimposed on earlier folds at small angles; may be related to Tertiary intrusion.

Orogeny - complex fowlage folds trending north-northwest; planes dip steeply eastward; axes plunge southeastward; metamorphism of sediments and basic intrusion.

PRECAMBRIAN

--Top not exposed--

GREZZLY FORMATION-3,000 feet

ARGILLACEOUS;

FLAG ROCK FORMATION-5,000 feet

SOME QUARTZITE

NORTHEASTERN FORMATION-4,000 feet

AND CARBONATES;

ELLISON FORMATION-5,000 feet

ANKERITE

HOMESTAKE FORMATION-200-300 feet

POORMAN FORMATION-2,000 feet

Metamorphism -- Scottish Highlands Type.
Staurolite, garnet, biotite.

Igneous rocks -- Diorite and gabbro intrusives.
Metamorphosed to amphibolite.

--Base not exposed--

Undefined geosyncline -- over 20,000 feet of sediments.
North-northwest axis inferred.
THE POWDER RIVER BASIN

The Powder River Basin occupies approximately 32,000 square miles in northeastern Wyoming and southeastern Montana. The basin is bounded by the Black Hills on the east, the Bighorn Mountains on the west, and the Laramie and Hartville Uplifts on the south. The basin merges into the Montana Plains to the north.

The Powder River Basin contains a maximum thickness of approximately 16,000 feet of sedimentary rocks, ranging in age from middle Cambrian to Eocene. Waasitch and Ft. Union beds of Tertiary age cover the central part of the basin, and older Paleozoic strata are found in the foothills of the surrounding uplifts.

The Powder River Basin is the largest intermontane basin in the Central Rocky Mountain region, except for the shallow Williston Basin to the northeast. It is also one of the least deformed of the basins, as large portions of the central and deeper parts are relatively undisturbed. The basin is consistent with the other intermontane basins in the region in its asymmetry; the steep limb is adjacent to the mountain front on the west. Deformation within the basin is also more severe on the west side. Near Sheridan this marginal zone has been steepened and locally overthrust to the east. Large overthrusts that have lateral displacements of about 3 miles have been formed. Farther south the west margin of the basin is characterized by northwest-southeastward-trending anticlines arranged in an en echelon fashion. Included in this zone of marginal folding are many of the important oilfields in eastern Wyoming. Teapot Dome, the subject of the famous government scandals of the early 1920's, and Salt Creek Field, perhaps the largest oilfield in the Rocky Mountain Province, are found in this part of the Powder River basin.

The geologic inception of the Powder River Basin as we know it today, probably began in the late Cretaceous. On the west flank of the basin Kingsbury conglomerate of Eocene age rests unconformably on deformed rocks of Mesozoic age. Later conglomerate, named by Sharp (1942) the Moncrief gravels (Eocene), lying unconformably on the Kingsbury indicates a renewed stage in the deformation. Remnants of Oligocene (?) sediments are found near the center of the basin; this indicates that uplift again occurred in the Bighorn Mountains in post-Eocene time.
Figure 61.—Cross section on the west side of the Powder River Basin, Wyoming. From a photograph by Hoppin, 1961.
GEOLOGIC HISTORY OF THE CENTRAL ROCKY MOUNTAINS

INTRODUCTION

For the sake of convenience this discussion will be limited to those parts of the Central Rocky Mountains which we will see on the trip west to the Geologic Field Station. This part of the Rocky Mountains is characterized by a series of north-southward-trending to northwest-southeastward-trending mountain ranges (Bighorn Range, Pryor Mountains, Beartooth Plateau, Absaroka Range) and adjoining intermontane basins (Powder River Basin, Bighorn Basin, Wind River Basin). See the map on page 122 for the location of these ranges and basins.

Precambrian crystallines constituting the "basement rocks" are exposed in the cores of the mountain ranges at elevations which range from 4,000 feet to more than 13,000 feet. The present relief on the basement surface is great -- 20,000 feet between the Bighorn Range and the Bighorn Basin. An even greater relief exists on the Precambrian surface between the Beartooth Plateau and the Bighorn Basin. (See the diagram below.)

Figure 62. --Section across the Bighorn Basin along the 45th parallel.
After Poldervaart and Bentley, 1955.

The Paleozoic and Mesozoic strata which originally overlay these basement areas have largely been removed from the crests of the uplifts, but are preserved around their flanks, where they are upturned in a series of striking hogback ridges. In many places these flexures surrounding the uplifts are broken and displaced by faults which parallel the strata in strike and also serve to bound the uplift.

Deformation in the post-Precambrian sedimentary rocks dies out basinward. Strata in the central part of the intermontane basins are essentially flat lying.

Structures within the crystalline cores of the uplifts are mostly Precambrian in age. The two dominant trends of these Precambrian structures are north-south and northwest-southeast.
GEOLOGIC HISTORY

The geologic history of the Central Rocky Mountains is treated in five stages:

1. Precambrian stage
2. Paleozoic and early Mesozoic stage
3. Laramide stage
4. Post-Laramide stage
5. Recent stage.

PRECAMBRIAN STAGE

The Precambrian stage is by far the longest and least well-known stage in the geologic history of the region. Thom (1958), Fanshawe (1958), and Poldevaert (1956) recognize three general phases, in order of their occurrence from oldest to youngest:

A. Deposition of argillite, siltstone, quartzite, and iron formation in an Archeozoic "geosyncline" that had a north-easterly trend. Accurate measurements of the thickness of the ancient sequence is wholly lacking because of the intense deformation, although Poldevaert reports a minimum thickness of 10,000 feet for the Archean rocks exposed in the core of the Beartooth Uplift. Mafic and ultramafic dikes, sills, and plugs were intruded into the sediments.

B. Folding, metamorphism, and granitization of the Archean rocks. Gast, Kulp, and Long, (1958) date this period of Precambrian orogeny at 2750± 150 m.y.--definitely Early Precambrian in age. Two dominant structural trends were established at this time--north-south and northwest-southeast. The first trend is expressed by fold axes within the Archeozoic rocks (Beartoth-Wise, 1957) and by cleavage, foliation, and shearing, jointing, and faulting in the cores of the uplifts. Orogenic movements during the later Laramide Revolution are believed to have followed these two Precambrian trends.

Stillwater complex emplaced in the Beartooth region.

C. Erosion and peneplanation during late Precambrian and early Cambrian. A regional surface of low relief was bevelled over the roots of the Precambrian mountains.

PALEozoIC AND EARLY MESozoIC STAGE

The Paleozoic and early Mesozoic eras were a time of relative crustal stability for the Eastern Rocky Mountain region. Regional warping of the Precambrian surface during the period from Cambrian to Jurassic formed the broad Cordilleran geosyncline. Eastern and Central Wyoming and eastern Montana lay well to the east of the axis of the geosyncline during this time. They were part of the broad eastern shelf or platform and so received a relatively thin layer of carbonate and clastics. These shelf areas were featured from time to time by local islands and peninsulas, recurrently produced by minor vertical crustal readjustments along one or more of the early Precambrian rifts.
LARAMIDE STAGE

From Triassic to early Cretaceous time the Cordilleran geosyncline underwent a series of orogenic convulsions. The first pulse of the Laramide was felt near the Pacific coast in Triassic time. Explosive volcanism, intense deformation, and batholithic emplacement characterize the rocks of this region. Throughout Jurassic and Cretaceous time the zone of maximum Laramide orogeny shifted slowly eastward until it reached culmination in the Eastern Rockies at the end of the Paleocene.

With the eastward advance of the orogeny, Paleozoic and Mesozoic rocks were intensely folded, uplifted, and thrust from the deeper parts of the Cordilleran geosyncline. These became the source rocks for younger sediments to be deposited ahead of the advancing front of deformation. The diagram to the right clearly shows the effects of this eastward-migrating tectogene and attendant cannibalism on the Cretaceous sediments of the Eastern Rockies.

In eastern and central Wyoming where the sedimentary cover was relatively thin, the Laramide was expressed mainly by vertical movements in the Precambrian basement. These movements, which occurred along the subrectangular mosaic of Precambrian fractures, served to "block out" the major structural units in the region. Some blocks rose relative to others; all were bounded by the fracture system inherent from the Precambrian. See the diagram on the next page.

Attention is focused to early Tertiary as the time for maximum deformation in the Wyoming Rockies. The story of the Laramide orogeny in this region is read principally from the sediments. The early Tertiary (Paleocene and Eocene) sediments may be characterized as follows: (See next page, below diagram.)
Figure 65.--Idealized section from the Beartooth Mountains to the Powder River Basin. After Thom and others, 1933.

1. They are confined largely to the intermontane basins.
2. They are deposited by streams.
3. The streams that were depositing sediments in the intermontane basins were also eroding on the plains to the east.
4. The sediments attain thicknesses of 5,000 feet at the basin margins.
5. They are strongly to moderately deformed at the basin margins.

Early Tertiary time in the Central Rocky Mountain region was a time of active erosion on the upthrown mountain blocks and equally active deposition in the downthrown basin blocks. The climate of the region was humid and mild to subtropical (Mackin, 1937). The numerous streams that coursed off the mountains carried great volumes of detritus, most of which was deposited in those great sediment traps--the intermontane basins. These same streams continued eastward over the Great Plains, where, now released of their loads, they began to erode again. Hence we find little or no evidence of early Tertiary sediments on the plains.

Many of the Paleocene and Eocene sediments are strongly deformed, especially near the margins of the basins. This indicates that the orogenic phase of the Laramide orogeny continued into Eocene time in the Central Rocky Mountain region.

Unconformities representing early Tertiary erosion surfaces show moderate to high relief. The mountains at this time were probably not more than 1,000 to 5,000 feet above the basin floors, or not more than 4,000 to 6,000 feet above sea level--approximately half their present altitude (Mackin, 1937).

**POST-LARAMIDE STAGE**

The suggestion that the Laramide Revolution is over leaves the student with the feeling that things have been pretty quiet, pretty dull since the Great Uplift. No so, say the geomorphologists! In fact, according to Mackin (1947), Bradley (1936), and others, it would be hard to find any time since the Cretaceous when the Rockies have been stable. The Rockies, according to these workers, are not the degenerating, third-stage mountains some geologists would have us believe, but are still first-stage mountains, higher and more spectacular than they have ever been. This view, although not accepted by all American geologists, has the balance of recent evidence in its favor and certainly is to be recommended to the geologist who is impressed with the majesty of the western scenery.
The post-Laramide history of the Central Rocky Mountain region can be separated (arbitrarily, of course) into two substages. The first substage is the period of mid-Tertiary (Oligocene, Miocene, early Pliocene) uplift (epiregression) and pedimentation. The second substage is late Tertiary (Pliocene, Pleistocene) uplift (epiregression), glaciation, and altiplanation.

During the late Eocene and early Oligocene epochs the climate changed from subtropical to semiarid (MacKin, 1947). Streams which had had low gradients in the early Tertiary (1 foot to 1 mile as an average) began to steepen their gradient by aggradation, spreading as they did sheets of coarse gravel across previously bevelled bedrock surfaces, and forming the moderate to steeply sloping "Subsummit surface" at 6,000 to 11,000 feet in the Central Rockies. Equipped with increased energy furnished by the increased gradient and supplied with abundant detritus from relatively enhanced mechanical weathering processes, the streams (diminished in number because of the decreased moisture) now spread extensive sheets of silt, sand, and gravel all along their courses across the basins, and out into the plains. Uplift of about 4,000 to 5,000 feet accompanied the mid-Tertiary climate change. This uplift was regional in extent, elevating basins as well as mountains, and, although diminished in magnitude, even extended to the plains. The overall effect was a steepening of the slope from the mountains to the plains, a condition which undoubtedly aided the easterly spread of detritus.

If this picture of pedimentation, gradational uplift, and stream aggradation is true, it means that the Subsummit surface and the mid-Tertiary plains surface were part of the same system of high gradient stream profiles, as shown below in the generalized sketch.

![Diagram showing Subsummit surface and Plains surface](image)

**Figure 66.--Early Tertiary Subsummit and Plains Surface.**

Because of these new sets of conditions, we find that the mid-Tertiary sediments differ in thickness, pattern, and degree of deformation from the early Tertiary sediments, as follows:

1. The mid-Tertiary sediments are widespread over plains and intermontane basins alike.
2. They are a few hundred feet to 1,000 feet thick.
3. They overlap the front range structure and generally are undeformed.
The second post-Laramide substage involves continued regional uplift (about 1,000 to 2,000 feet), local plioclastation, and altiplanation (a special accelerated form of solifluction which reduces irregularities on an upland surface to a rubble-strewn terrace). Altiplanation is called upon by Mackin (1947) to produce the "Summit Surface"—that broad, meadow-covered surface found at the crests of many of the ranges in the Central Rockies at elevations of 11,000 to 13,000 feet. The summit surface of the Beartooth uplift is a good example.

The combined mid-Tertiary-late Tertiary regional uplift is estimated by Mackin (1947) to be about 5,000 to 7,000 feet. Thus, many of the basin-fill beds are now at a higher elevation than they were at the time of their deposition.

RECENT STAGE

The recent geologic history of the Central Rockies is characterized by upwarpment and uparching, with consequent tensional faulting, canyon cutting, reexcavation of basin fill, and local volcanic activity. Streams are lowering their channels across the intermontane basins, leaving beautifully formed paired or unpaired terraces, and in general etching out the mountain fronts in bold relief. Polecat Bench, an extensive gravel-capped terrace on the interflue between the Shoshone and Clark Fork drainages, is one of the more prominent products of this latest bit of geologic frivolity.
GEOLOGY OF THE BIGHORN REGION

INTRODUCTION

The Bighorn region as here defined includes the Bighorn Basin and five positive structural units arranged clockwise around the basin as follows: Pryor Mountains, Bighorn Mountains, Owl Creek Uplift, Beartooth Mountains, and the Nye-Bowler Lineament. See the tectonic map of the northern Bighorn Basin on the next page. The geology of the Bighorn region will be handled by a brief discussion of each of these areas. On the sixth and seventh days of the trip west we shall travel across three of the six areas described—Bighorn Mountains, Bighorn Basin, and Beartooth Mountains. We shall see the Owl Creek Mountains on the trip back to Bloomington at the end of the summer.

PRYOR MOUNTAINS

The Pryor Mountains are north and northeast of the Bighorn Basin in Carbon County, Montana. They are depicted on some maps as a northwest extension of the Bighorn Range, but Blackstone (1940) shows that they are a separate structural and orographic unit.

Topographically the Pryor Mountains are moderately dissected block mountains with gentle dip slopes of Madison limestone to the west and steep scarplike slopes to the east. A series of moderate to steeply dipping reverse faults bound the east front of the mountains and bring Precambrian crystallines into fault contact with deformed and locally overturned Paleozoic and Mesozoic rocks. Vertical movements were greatest on the northeastern part of the mountain block so that in addition to being uplifted, the Pryor block has been tilted to the southwest.

BIGHORN MOUNTAINS

The Bighorn Mountains are a northwest-southeastward-trending range of mountains that border the Bighorn Basin on the east. The mountains consist of an elevated core of Precambrian crystallines that have remnants of nearly flat-lying lower Paleozoic strata on top and overturned Paleozoic and Mesozoic strata around the margins.

The Bighorn Range is divisible into three units. The northern unit extends northward from near the Montana-Wyoming border to the vicinity of the Bighorn River. This segment of the Bighorn Range is about 30 miles wide. Its surface has a gently northerly slope. The west flank of the range is marked by a monocline fold in the Paleozoic and Mesozoic strata which dip westward at about 70°. To the south this monocline steepens and passes along strike into an eastward-dipping thrust fault.
The central segment extends southward from the Tongue River area to Tensleep Canyon. Our route from Sheridan to Red Lodge will cross the central segment of the Bighorn Range near its north edge. The range here is fairly symmetrical. The core consists of highly deformed metamorphic and igneous rocks (Precambrian) overlain by nearly horizontal Lower Paleozoic strata. On the west flank of the range the Paleozoic and Mesozoic rocks are steepened and locally overturned above the eastward-dipping thrust that serves to bound the Bighorn Uplift on the west. The Paleozoic and Mesozoic rocks are also upturned along the east flank of the range and presumably are separated from the Precambrian core by another reverse fault.

![Diagram of Bighorn Mountains]

Figure 68.—Generalized section through the Bighorn Mountains.

The southern segment of the Bighorn Range is separated from the central segment by the large tear fault that parallels Tensleep Canyon. This southern segment is essentially a southerly extension of the Bighorn Range that is elevated along its west and southwest margins by a thrust fault.

**BIGHORN BASIN**

The Bighorn Basin occupies approximately 3,000 square miles in northwestern Wyoming. It is bounded on all sides by mountain ranges. See tectonic map of northern Bighorn Basin.

The basin is asymmetrical in section; the steep western limb lies adjacent to, and partly under, the east margin of the Beartooth Uplift. The axis of the basin hugs the west margin also. The Paleozoic and Mesozoic rocks of the basin are thrown into a series of anticlinal structures. Many of the oil and gas fields are in these structures.

The Bighorn Basin contains about 17,000 feet of marine and nonmarine sediments. The center of the basin is underlain by Paleocene and Eocene sediments that attest to mountain building in nearby areas.

**NYE-BOWLER LINEAMENT**

The Nye-Bowler Lineament is a continuous zone of structural disturbance extending for a distance of at least 115 miles from Livingston, Montana, to the Pryor Mountains. Across the northern part of the Bighorn Basin the lineament is featured by numerous northeast-ward-trending en echelon faults. Elsewhere there is thrust faulting, wrench faulting, and local volcanism associated with the lineament. Thom (1947) believes that the Nye-Bowler Lineament is an extensive rift in the crust along which there has been scissors-type movement during which the southern block rotated in a clockwise fashion relative to the northern block.
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<td></td>
<td>Capulin</td>
<td>Marine green, grey and grey glauconitic shale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chugwater</td>
<td>Red sandstone and sandy shale, some thin limestones</td>
</tr>
<tr>
<td>PRECAMBRIAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frontier</td>
<td>Grey shale and underlying grey glauconitic sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mowry</td>
<td>Dark grey shale, weathered grey brown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermopolis</td>
<td>Black shales, middle grey sandstones (Mowry member)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clover</td>
<td>Red sandstones, local conglomerates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Morrison</td>
<td>Grey to green sandstone and shale/chertaceous sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sundance</td>
<td>Grey to black shales, locally marine or fossiliferous</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capulin</td>
<td>Marine green, grey and grey glauconitic shale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chugwater</td>
<td>Red sandstone and sandy shale, some thin limestones</td>
</tr>
</tbody>
</table>

Figure 69.—Generalized stratigraphy of the Bighorn region.
<table>
<thead>
<tr>
<th>Age</th>
<th>Black Hills</th>
<th>Bighorns</th>
<th>Field Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligocene</td>
<td>Brule</td>
<td>Wasatch</td>
<td>Boxeman Group</td>
</tr>
<tr>
<td>Eocene</td>
<td>Ft. Union</td>
<td>Ft. Union</td>
<td></td>
</tr>
<tr>
<td>Paleocene</td>
<td>Hell Creek</td>
<td>Lance M</td>
<td>Elkhorn Mt.</td>
</tr>
<tr>
<td></td>
<td>Fox Hills</td>
<td>Lensen N O G</td>
<td>Volcanic</td>
</tr>
<tr>
<td></td>
<td>Pierre</td>
<td>Bear Paw T N R</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hishbura</td>
<td>Judith R T O</td>
<td></td>
</tr>
<tr>
<td>E Upper</td>
<td>Carlile</td>
<td>Claggett A U</td>
<td></td>
</tr>
<tr>
<td>S E</td>
<td>Greenhorn</td>
<td>N P</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Dakota</td>
<td>Eagle O G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kirtland</td>
<td>Telegraph L R</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Frontier</td>
<td>Cr. O O</td>
<td>Colorado Group</td>
</tr>
<tr>
<td>C</td>
<td>Mowry</td>
<td>Moris A P</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>Tiberia</td>
<td>Thermo- D</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>Pine Creek</td>
<td>Polis O</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Lower</td>
<td>Cloverly</td>
<td>Kootenai</td>
</tr>
<tr>
<td></td>
<td>Fossil</td>
<td>Lakota</td>
<td></td>
</tr>
<tr>
<td>Jurassic</td>
<td>Morrison</td>
<td>Morrison</td>
<td>Morrison</td>
</tr>
<tr>
<td></td>
<td>Unkapa</td>
<td>Sundance</td>
<td>Ellis</td>
</tr>
<tr>
<td>Triassic</td>
<td>Spearfish</td>
<td>Cheyenne</td>
<td></td>
</tr>
<tr>
<td>Permin</td>
<td>Minnekahda</td>
<td>Embry</td>
<td>Phosphoria</td>
</tr>
<tr>
<td></td>
<td>Opisie</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minnelusa</td>
<td>Tensleep</td>
<td>Quadrant</td>
</tr>
<tr>
<td></td>
<td>Minnelusa</td>
<td>Amaden</td>
<td>Amaden</td>
</tr>
<tr>
<td></td>
<td>Pennsylvania</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mississippian</td>
<td>Madison</td>
<td>Mission Canyon</td>
</tr>
<tr>
<td></td>
<td>Pahsapa</td>
<td>Lodgepole</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Englewood</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Devonian</td>
<td>Three Forks</td>
<td>Three Forks</td>
</tr>
<tr>
<td></td>
<td>Jefferson</td>
<td>Jefferson</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bighorn</td>
<td>Dry Creek Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gallatin</td>
<td>Pilgrim La.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grov Ventre</td>
<td>Park Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flathead</td>
<td>Meagher La.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deadwood</td>
<td>Welsey Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deadwood</td>
<td>Flathead as.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precambrian</td>
<td></td>
<td>Pony Series</td>
</tr>
<tr>
<td></td>
<td>Granites, schists, gneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basic Intrusives, etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 70.--Stratigraphic columns for the Black Hills, Bighorn, and Field Station regions.
Figure 7: Tectonic map of the northern part of the Big Horn Basin. Redrawn from Alpaugh and Pecosky, 1954.
GEOLoGY OF THE BEARTOOTH UPLIFT

The Beartooth Mountains is a rectangular uplift that measures about 70 miles in a N65°W direction and is about 30 miles wide. This uplift is cored with Precambrian granite, granite gneiss, metamorphics, and ultrabasic rocks. These rocks are folded into a series of broad north-southward-trending anticlines and synclines and are broken by joints, cleavage, and shears that are oriented in all directions of the compass but that are concentrated into two master directions that trend N45°E and N45°W to 65°W.

The uplift is somewhat asymmetric in profile. The east and northeast sides rise abruptly out of the Bighorn Basin to altitudes in excess of 10,000 feet. The west and southwest sides of the uplift are covered by later volcanic rocks. This part of the uplift rises gently up the dip slope of these volcanic rocks to the Beartooth summit. Alpine glaciation has cut the upland surface east of the summit into a series of deep U-shaped valleys. West and south of the summit the surface of the uplift is a rubble-strewn plateau capped with remnants of Paleozoic sedimentary rocks and is partially enlapped by the Absaroka Volcanics.

The Beartooth Uplift is bounded on all sides by faults. Just southwest of Red Lodge the bounding fault is a thrust fault dipping into the mountain mass. Displacement along this fault is not known with certainty, but it is estimated to be several miles. Movement is southwest side up and northeastward relative to the northeast side. To the south this fault--known as the Beartooth Fault--steepens until it is vertical at Clarks Fork Canyon. (See the block diagram below.)

Figure 73.--Block diagram of the southeast corner of the Beartooth Uplift. Taken from Wise, 1950.
The southwest corner of the uplift is formed by the intersection of two vertical faults—the Beartooth Fault coming in from the northeast and the Clarks Fork Fault, a complex series of normal faults that come in from the northwest. The Clarks Fork Fault is believed to continue to the northwest under the Absaroka Volcanics as the Cocke City Sag (Wise, 1957).

The northeast side of the Beartooths is bounded by a fault that dips steeply northeastward from Nye to Livingston, Montana. The west side of the uplift is marked by a northeastward-dipping thrust fault north of Gardiner, Montana.

The shape of the Beartooth block and its behavior during the Laramide Revolution are thought to be controlled by the master Precambrian structural trends. Wise (1957) has shown that the trend of the Beartooth Fault is controlled by a northeastward-trending set of "fracture cleavage."

The geologic chronology of the Beartooth Mountains is summarized below in a chart taken from Poldervaart (1958).

<table>
<thead>
<tr>
<th>GEOLOGIC EVENT</th>
<th>DESCRIPTION</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-Laramide</td>
<td>Pleistocene glaciation</td>
<td>alpine on northeast</td>
</tr>
<tr>
<td></td>
<td>Tertiary volcanism</td>
<td>continental on south-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>west</td>
</tr>
<tr>
<td>Laramide</td>
<td>Thrusting</td>
<td></td>
</tr>
<tr>
<td>Revolution</td>
<td>Emplacement of porphyry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sills, stocks, and dikes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uplift</td>
<td></td>
</tr>
<tr>
<td>Subsidence and</td>
<td>Deposition of Flathead</td>
<td>middle Cambrian to</td>
</tr>
<tr>
<td>deposition</td>
<td>sandstone and younger</td>
<td>Laramide Revolution</td>
</tr>
<tr>
<td></td>
<td>sediments</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UNKNOWN TIME INTERVAL</th>
<th>PENEPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proterozoic uplift</td>
<td>Emplacement of dolerite dikes</td>
</tr>
<tr>
<td></td>
<td>Absolute age unknown</td>
</tr>
<tr>
<td></td>
<td>Uplift and formation of Precambrian joint systems</td>
</tr>
<tr>
<td></td>
<td>Faulting and cataclasis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UNKNOWN TIME INTERVAL</th>
<th>INTERVAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metamorphism and</td>
<td>Stillwater Complex?</td>
</tr>
<tr>
<td>granitization</td>
<td>2750± 150 million years</td>
</tr>
<tr>
<td></td>
<td>(high amphibolite)</td>
</tr>
<tr>
<td>Folding</td>
<td>Open Folds with north-south fold axes in southern part</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Emplacement of mafic and ultramafic rocks</td>
<td>Thick and abundant north of Beartooth Butte; thin and less abundant elsewhere</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UNKNOWN</th>
<th>TIME</th>
<th>INTERVAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition of Archean sediments</td>
<td>Mainly argillites and siltites; minor quartzites. Preserved as metamorphic rocks in belt below. Stillwater Complex mainly.</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

The Yellowstone National Park region, which is in the northern part of the central Rocky Mountains, is noted for such geologic features as spectacular stream erosion, rock alteration, evidence of volcanism, and end-stage igneous activity. The region is composed of part of the Beartooth Mountains, the Absaroka Range, and the Snake River Basin. The Yellowstone Plateau occupies a topographic basin that is rimmed on all sides but the southwest by high mountains. Its surface rocks are the rhyolites of Pliocene age and minor amounts of associated basalt. These are unmatched anywhere for volume, rapidity of eruption, uniformity of composition, and magnitude of modern thermal features. The neighboring part of the Snake River Basin to the west is underlain dominantly by basalts and minor amounts of rhyolite. The rhyolites and the associated basalts are considered to be closely related in their origin, and it has been suggested that the rhyolites of the Yellowstone are silicic differentiates of a basaltic magma which gave rise to the basalt of the Snake River Basin. The situation is somewhat similar to that of the capping granophyres of the Wichita and Bushveld lopoliths. The park and its immediate environs is sometimes referred to as the Absaroka-Yellowstone-Beartooth region. The geologic history of this region is complex and is part of the overall igneous and tectonic evolution of western Wyoming, Montana, and southeastern Idaho.

The "park" is famous for its deposits of volcanic rock, but here and there, in scattered outcrops in the border of the region, Precambrian to Cretaceous metamorphic and sedimentary rocks are exposed. The latter are similar to the rocks that you have been seeing since you started to climb the steep east face of the Big Horn Mountains. You will undoubtedly be familiar with many of these rocks by this time.

The structure and petrology of the volcanic and associated plutonic rocks of the "park" are the result of volcanism and tectonic deformation which began near the end of Cretaceous time, a volcanism expressed by: (1) major igneous intrusives, such as the Idaho and Boulder Batholiths, and (2) small intrusives and extrusives, such as the Devil's Tower in the vicinity of the Black Hills. According to Parsons, most of the igneous activity in the Absaroka-Yellowstone-Beartooth region belongs to the second category, but the amount of volcanic ejecta involved in the Absaroka volcanic field and in the Yellowstone rhyolites perhaps justifies calling these major extrusives.

Igneous activity in the "park" region has occurred in two main periods. These may be dated roughly on the basis of their time relationship to the major thrust faulting in the Beartooth Mountains. The earlier period of igneous activity is Cretaceous or early Laramide in age. It preceded the main thrust faulting in the Beartooth Mountains. The Livingston volcanic rocks (north of the Beartooth Mountain uplift) and a number of minor intrusives, such as the porphyry dikes exposed in the road cuts along the switchbacks of the Red Lodge-Coope City highway and in the chromite prospect on top of the Beartooth Mountains, represent this igneous epoch. The later period of igneous activity is Tertiary, or late Laramide in age, and the rocks involved were emplaced after the main period of thrust faulting in the Beartooth
Figure 7A.—Generalized geologic map of the Yellowstone National Park region. After Hamilton, 1960.
Mountains. The Absaroka volcanic field, the Yellowstone Park rhyolites, many small scattered intrusive and extrusive masses in central and western Montana, and the Boulder Batholith belong to this period of volcanism.

The emplacement of the igneous rock bodies and the vast quantities of volcanic rocks of the Absaroka-Yellowstone-Beartooth region have been controlled by structural features, such as (1) axes of depressions, (2) axes of old uplifts, and (3) major structural lineaments or basement rifts.

Locally the volcanic rocks have been subjected to continuous attack by hydrothermal waters. The visible effects of this phase of volcanism are the geysers and hot springs. More subtle effects of this hydrothermal attack are the large-scale alterations of the host volcanic rock.

LATE CRETACEOUS VOLCANIC ROCKS OF THE YELLOWSTONE-
ABSAROKA-BEARTOOTH REGION

The Livingston volcanic rocks, andesitic breccias, agglomerates, and tuffs are the most noteworthy products of the early Laramide (premain thrust faulting) igneous activity in southwestern Montana. These rocks grade laterally into volcanic sandstone and conglomerate, which in turn grade into Cretaceous sedimentary rocks. The pyroclastic rocks of the Livingston Formation were spewed out from a large number of small breccia vents. The breccias were exploded to the surface and then spread by mudflow and by water action. The volcanic conglomerates and sandstones were formed in similar manner.

In this region the base of the Livingston Formation is partly Judith River in age; it overlies with unconformity upturned Cretaceous sedimentary rocks of the Eagle Sandstone and Claggett Formation and associated intrusive rocks. The Livingston Formation is dated by fossil plants. It can be traced laterally into Cretaceous, Judith River, Bear Paw, Lenape and Lower Lance rocks, and it is unconformably overlain by the Hell Creek Formation.

SUMMARY OF LATE CRETACEOUS EVENTS

1. Deformation of sediments, including Cretaceous Eagle and Claggett, in late Claggett time. Deformation was followed by erosion.

2. First extrusions of volcanic rocks in early Judith River time. Locally, these volcanic rocks were deposited across the upturned bedding of the earlier rocks.

3. Continued alternation of local uplift, erosion, extrusion and intrusions of igneous rocks, and warping, all during Judith River, Bear Paw, Lenape, and early Lance time. Thus the later pyroclastic rocks unconformably overlap the earlier ones.

4. Deposition of the Hell Creek Formation. The rocks of this formation are conformable to the upper part of the Livingston volcanic series in the region south of the Yellowstone River.

5. Beginning of the period of main doming and thrusting in the Beartooth-Bighorn region. Deformation of this age still continuing during and at the close of Paleocene time.
CENOZOIC VOLCANIC ROCKS OF THE YELLOWSTONE-
ABSAROKA-BEAUTOOTH REGION

EARLY CENOZOIC VOLCANIC ACTIVITY

The early Tertiary or late Laramide volcanic rocks, the Absaroka Volcanics, are chiefly pyroclastic. They cover an extensive southeastward-trending area beginning north of Gardiner, Montana, and continuing nearly to Thermopolis, Wyoming. They are exposed in the high peaks of the rugged Absaroka Mountains and in the southwestern part of the Beartooth Uplift. They form the east boundary of Yellowstone National Park. See the map below.

![Map of Yellowstone National Park](image)

Figure 75.--The Absaroka Volcanic Field. Re-drawn from Parsons, 1958.

The Absaroka Volcanics were first studied in 1899 by Arnold Hague, who divided them into six units. The following stratigraphic column for the Absaroka Volcanics as presently known includes refinements on his original classification.
Andesite Flows  Overlie the late acid and late basic breccias in the southpess part of the park. Occur on the higher  peaks. Thickness 250 to 500 feet. NOTE: The total  amount of volcanic rocks extruded between the close  of the Laramide Revolution and the beginning of the  great rhyolite floods may exceed 13,000 feet. Depo-  sition was intermittent as shown by (1) buried forests  and (2) volcanic conglomerates at base of some units.

Late Basic  Deposition of 2,000 feet of late basic breccias on  Breccias  an irregular erosional surface of late acid breccias.  These basic breccias are similar in lithology and  mode of occurrence to the early basic breccias.  Abundant in the southeastern part of Yellowstone Park,  forming great plateaus and making up almost the entire  south half of the Absaroka Range. Restricted in area.  Lie on either the late acid breccias or on the early  basalt flows.

MIOCENE

Late Acid  2,000 feet; similar in lithology and mode of occurrence  Breccias  to earlier acid breccias; restricted to Absaroka Range  Early Basalt  1,000 feet thick; form higher flat top summits in the  Flows  Absaroka Range but are overlain by younger rocks in  the southern part of the park; poured over early  basic breccias but not over Lost Creek Trachyte.

Lost Creek  A trachytic rhyolite extruded as scattered patches  Trachyte  along the Yellowstone Valley and in parts of the  Absaroka Range.

Early Basic  4,000 feet of tuffs, breccias, agglomerates, and flows;  Breccias  widely distributed in the northern part of the park.

Early Acid  At present 1,000 feet thick; original thickness unknown  Breccias  owing to erosion; light-colored andesite breccias,  agglomerates, tuffs, and flows now remain; exposed  at only a few localities, for example, in the Absarokas.  A long period of quiet followed the deposition of these  early acid breccias.

Figure 76.—Stratigraphic column for the Absaroka Volcanics. Modified after  Hague, 1959.

Although the total thickness of these rocks may exceed 13,000 feet, the  maximum thickness in any continuous exposure ranges from a maximum of 6,500  feet in the central part of the Absaroka Range to a minimum of a few hundred  feet in the foothills.

The pyroclastic rocks contain a variety of breccias, tuff-breccias, tuffs,  agglomerates, volcanic conglomerates, and volcanic sandstones. These materials  were extruded from many small vents or fissures and perhaps a few larger volcanoes.
Some of the vents have been located. Many of these, especially in the northern part of the Absaroka Range, are filled with intrusive breccia or vent agglomerate. (See figure 75 on page 140.)

The pyroclastic material was deposited upon a surface having a relief of 1,000 to 2,000 feet. This prevolcanic topography is well shown along the south side of the Clarke Fork Valley between Cooke City and Sunlight Valley.

In addition to the volcanic vents, many intrusive centers have been recognized. These contain small stocks, necks, laccoliths, and ring dike complexes; several contain sets of radiating dikes. The intrusive centers appear to be aligned in north-northwestward and west-northwestward-trending zones.

The pyroclastic rocks of the central Absaroka region that are near known vents or intrusive centers are very poorly bedded and are composed of angular fragments typical of volcanic breccias. Outward from the center of the range the pyroclastic rocks are very well bedded and are obviously water deposited. This is particularly true along the east and southeast margins of the Absaroka Range. These rocks are classified as volcanic conglomerates and volcanic sandstones. The Aycross, Wiggins, and Pitchfork Formations, as described by Love (1939) and Hay (1956), for example, are typical deposits of this type.

Professor Earling Duff, of Princeton University, is studying the well-bedded pyroclastic rocks and their fossil flora from exposures near Tower Falls and on Specimen Ridge in Yellowstone National Park. He feels that the fine-grained pyroclastic rocks in the area include river-deposited tuffaceous sands and lake sediments. Some of the fine-grained beds he considers actually air-deposited tufts.

The coarser pyroclastic rocks are in part volcanic conglomerates of alluvial origin. Many of them are heterogeneous in character and have angular or subangular fragments probably representing mudflows or lahars. On Specimen Ridge petrified tree stumps are preserved upright in the coarse-grained mudflow material. In some of the breccias from the central Absaroka Range sorting and bedding are completely absent. Beds 100 feet or more thick have no layering within the beds. The rocks are made up of fragments of all size and composition, and some of the fragments are many feet in diameter. Elsewhere the fragment size in the breccias is fairly uniform within a zone. The fragments are dacitic, andesitic, and basaltic in composition, and most of them are porphyritic; vesicular or scoriaceous material is lacking. The fragments contain hornblende, augite, or plagioclase phenocrysts.

The breccias of the Absaroka volcanic series are heterolithic and as such cannot be considered as flow breccias or autobrecciated flow rocks. They do not appear to be of the nuée ardente type of eruption because of the conspicuous variation in size of the fragments. It has been suggested that the breccias were derived by simultaneous explosive eruption from many vents. Although this kind of eruption would cause a mixing of the fragment types, this idea does not seem to fit the situation, because it has not been possible to find remnants of vent structures in which all the fragments are uniform in composition.

Thorough mixing of fragments could be accomplished by mudflows or lahars. Newly deposited, loose pyroclastic material on becoming saturated with water could flow downslope and cause intermixing from many vents. Furthermore, it would not be necessary that the fragments in any particular vent be of uniform composition. Parsons (1950) favors this mechanism for the Absaroka breccias.
Still another manner in which the breccias of the Absaroka Range may have been deposited has been suggested by recent fieldwork (Hay, 1954). A variety of intrusive breccias, occurring in irregular dike-like and sill-like bodies as well as in vertical pipes, has been disclosed. The breccias in these intrusive masses, especially in the pipes, are just as heterogeneous in composition and texture as the extrusive breccias. Some of the vent structures contain breccias of varied fragment sizes, but in other vent structures the fragments are rather uniform in size. In a number of vents there are Precambrian gneiss and Paleozoic limestone fragments derived from rocks beneath the pyroclastic series. Some of the fragments, therefore, appear to have been torn from the wall rock of the vents and fissures and brought up from below. Apparently, some of the brecciation and mixing of fragment types occurred prior to extrusion.

In a number of localities, the breccias contain blocks of limestone as much as 500 feet in length surrounded by pyroclastic rocks containing much smaller igneous rock fragments. As the limestone blocks show no heat effects along their contacts, the pyroclastic rocks were probably relatively cold when emplaced. The limestone blocks are not badly fractured either, and it has been suggested that the blocks were: (1) possibly torn from the rim of a vent and more or less "floated" in the breccia being extruded; (2) torn from the edge of limestone cliffs by the passing breccia as it flowed or traveled out from the vent; or (3) picked up or torn loose by lahars.

The associated basalt sheets have been interpreted as fissure eruptions and not as flows from central vents. The early basalt sheets in the northern half of the Absaroka Range have been domed. They reach their greatest elevation, 1,600 feet above sea level, over Trout and Dead Indian Peaks. Rouse (1937) considered this fact as evidence for deformation that followed Absaroka volcanic activity.

LATE CENOZOIC VOLCANIC ACTIVITY

Miocene and post-Miocene pyroclastic flows* and associated rocks.—During middle Tertiary time the Yellowstone-Sierran-Bearooth region was subjected to renewed faulting, by means of which the block-fault mountains present in the region today were produced. In this manner a structural basin, the Snake River Basin, was formed in what is today the Yellowstone Park-Snake River region. The basin was formed chiefly during Miocene time. The Yellowstone Plateau represents the high, lava-filled end of the basin. It is underlain by a central mass of rhyolite flows of Quaternary age, virtually surrounded by rhyolite tuffs of Pliocene age. Basalt is a subordinate rock type in the post-Miocene deposits of the Yellowstone Plateau region. The Snake River Basin, on the other hand, is formed of olivine basalt flows, and here rhyolite flows and tuffs are subordinate.

*Pyroclastic flow: an eruption in which fragmented lava buoyed by escaping gas is emplaced at high temperature in avalanches. The products of some pyroclastic flows can be classified into types exemplified by historic eruptions, such as nuées ardentes and panic flows. Applied to Yellowstone National Park, the term "welded tuff" refers to that part of the Yellowstone Tuff or any other tuff in which the shards and fragments of pumice have been deformed and welded at high temperature so that the rock is indurated. The degree of welding varies with depth in the Yellowstone Tuff, and some parts have partially or wholly crystal-lized after welding.
<table>
<thead>
<tr>
<th>Age</th>
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<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent and Pleistocene</td>
<td>Hot Springs Quaternary</td>
<td>Remarkable, very young rhyolite flows of the Madison, Pilotstone, and Central Plateaus. Some of the flows are preglacial, and others postglacial. Lava of the plateaus fill basins that are possible collapse caldera sites.</td>
</tr>
<tr>
<td></td>
<td>Rhyolite flows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alluvium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lacustrine deposits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glacial deposits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late Canyon basalts</td>
<td>The most recent basalt flows in the park. Found mainly in the northern part of the area in the Lamar and Yellowstone valleys and near Gardiner. These are presumably the same age as the basalt of the Snake River Plateau, which crowns against the western scarp of the rhyolite plateau.</td>
</tr>
<tr>
<td>Middle Pliocene</td>
<td>Post- Yellowstone rhyolite erosion:</td>
<td>Start of the carving of the Grand Canyon of Yellowstone. Lamar Valley may have started at this time. Post-rhyolite faulting probably due to settling as result of withdrawal of vast quantities of magma from chambers below earth's surface. Faulting at this time may also have been important in the localization of lake and hot spring basins in the park area.</td>
</tr>
<tr>
<td></td>
<td>Rhyolite</td>
<td>Enormous outbursts of rhyolite pyroclastic deposits or pyroclastic flows; total thickness of 1,000 feet; sea of pyroclastic flows lapped up against foothills of encircling ranges; to the west the pyroclastic flow plateau ends in a steep scarp which drops sharply to the lower plateau of the Snake River Basin.</td>
</tr>
<tr>
<td></td>
<td>Early Canyon Basalts</td>
<td>Found locally under the rhyolite; probably followed the faulting and erosion period; patches found in Yellowstone Canyon and in the northwestern part of the park.</td>
</tr>
<tr>
<td>Pliocene and possibly early Pleistocene</td>
<td>Period of Postbreccia Faulting:</td>
<td>Extensive faulting and erosion: Mt. Washburn and Washburn Range formed. Erosion caused gently undulating topography in the park; at close of this period the basin was now ready to receive the tremendous floods of rhyolite pyroclastic rocks. In places the rhyolite pyroclastic rocks were preceded by basalt flows.</td>
</tr>
</tbody>
</table>

Figure 77.--Stratigraphic column of the Pliocene-Pleistocene deposits in Yellowstone Park.
The outer part of the Yellowstone Plateau, on all sides but the southwest, consists of huge sheets of rhyolite ignimbrite (the Yellowstone Tuff of Boyd, 1951) and subordinate flows of alkaline rhyolite and basalt. See the figure on page 136. At the present time, these rocks crop out in a circular ring of tuff whose width is about 10 miles. See the figure on page 130. The Yellowstone Tuff is welded to obsidian at its base and grades upward through interbedded, lithoidal rhyolite to loose ash at the top of an uneroded section. The ignimbrites are commonly devitrified and carry crystals and fragments of clear sanidine and less plagioclase and some clinopyroxene; biotite and hornblende are scarce. The subordinate rhyolite flows are similar mineralogically to the pyroclastic rocks. These rocks have been dated as Pliocene. Probably all the Yellowstone Tuff was erupted in a single rapid series of eruptions from discrete vents. Textural and structural evidence suggests that the Yellowstone Tuff was emplaced as pyroclastic flows (Boyd, 1951).

Small flows of olivine basalt and subordinate olivine andesite lie beneath and above the older rhyolites. The age of these basic rocks is not known with certainty, but they have all been termed Pliocene by Boyd (1951).

Pliocene flows of the Madison and Pitchstone Plateaus.—The Yellowstone Plateau within Yellowstone Park is divisible into three segments: the Madison, Central, and Pitchstone Plateaus. The Madison and Pitchstone Plateaus, which form the west-central part of the composite Yellowstone Plateau, are composed of great viscous flows of rhyolite lava that were erupted from a northwestern-trending fissure zone along the crest of the plateau and a number of minor flows of basalt. The flows are greater than 100 cubic miles in volume, and they occupy a tectonic basin rimmed by the Yellowstone Tuff and older rocks in central and southwestern Yellowstone Park. See the figure on page 130. The individual flows are as much as 1,000 feet thick and cover areas as large as 100 square miles. Surficial features, including vents and domes, are well preserved locally. Exposed portions of these flows are, for the most part, banded obsidian and perlite and brecias formed by incorporation of fragments of pumiceous crust in the moving flows. The flow which forms the northern part of the Madison Plateau is shaped like an irregular V, one arm of which extends northward to within 5 miles of West Yellowstone; the other extends almost to Madison Junction. The surface of the flow is marked by flow ridges concentric downstream to the lobate form of the flows. The steep front of the northeast arm forms the north margin of the Lower Geyser Basin, the west wall of Firehole Canyon, and the south side of Madison Canyon from Madison Junction almost to Mt. Haynes. Over most of its front the original surface and front of the flow can be seen, because the flow has been virtually untouched by erosion and has been ice accreted only near its east margin. A discontinuous narrow ridge, 3 miles long, trends southward along the western part of the flow near the topographic constriction through which the rhyolite flowed to form the northwestern lobe. It probably represents a fissure through which much of the lava was extruded.

Many other flows of comparable size are found on the Madison and Pitchstone Plateaus. The youngest of the big flows, those of the Pitchstone Plateau and those of the southern part of the Madison Plateau, lack vegetation over most of their surfaces, and, consequently, concentric flow ridges are clearly displayed on them. Along the crest of these flows a series of concentric flow ridges form a low, elongated, elliptical dome, which is believed to mark the site of the source fissure for the flows.
All the big lobate flows of the Madison and Pitchstone Plateaus were erupted from a major fissure zone that trends N, 30° W. The aligned vents are marked by a few steep knobs and by broad, low elliptical domes similar to the one mentioned above.

The flows are viscous, have convex profiles with a steep front, and consist of an upper zone of obsidian flow breccia that merges downward with flow-contorted rhyolite several hundred feet thick. The flow-contorted rhyolite in turn merges with massive rhyolite several to many hundred feet thick that rests on an obsidian breccia base.

The breccias have been altered locally by fumarolic activity, presumably contemporaneous with the cooling of the interiors of the flows. Siliceous sinter is widespread as thin coatings on obsidian blocks, and limonite, hematite, or sulphur is present locally.

The rhyolites have been so little eroded that only the upper-obsidian-breccia zone is exposed in most of them. Few gullies penetrate this zone. The interior of the big flow at the north end of the Madison Plateau, however, is exposed continuously along the Madison River and the lower Firehole River.

Study of air photos shows that near Mt. Ash Creek the big rhyolite flow capping the Pitchstone Plateau overrode an older flow which had been scoured by ice. The younger flow was scoured in turn along its northwest margin by a later valley glacier. Rhyolite flows still younger than this later valley glacier are found near the saddle between the Madison and the Pitchstone Plateaus.

Pliocene lavas of the Central Plateau.--Large elliptical to irregularly shaped flows of rhyolite and obsidian form the Central Plateau of Yellowstone National Park, a circular area about 25 miles in diameter, east of the Madison Plateau. See the figure on page 138. Like the flows described above, these also have steep fronts and surfaces formed of obsidian breccia and flow-contorted rhyolite. They were, however, extruded from diversely oriented vents scattered throughout the Plateau rather than from a single fissure system. Their mutual relations are accordingly more complex.

The flows of the Central Plateau are mostly less than a cubic mile or so in volume. They have been only slightly eroded, but in Gibbon Canyon erosion has gone deeper, and the interior faces of lithoid rhyolite is exposed. These flows are so fresh that they are classified as Quaternary rhyolite and are probably late Pleistocene in age. Some rhyolite domes, associated with the flows in the Central Plateau, are larger than any in the western areas. Other rhyolite domes, probably also of Quaternary age, lie within the rim of Pliocene welded tuffs elsewhere in the Yellowstone Plateau.

Pliocene lavas of the Snake River Basin.--The Snake River Basin, "downwarp," or "greben," also was the site of extensive Pliocene and Pleistocene volcanism. The older rocks of the basin are rhyolite welded tuffs, most of which have been buried beneath later basal flows. A large semicircular ridge of rhyolite that protrudes through the basalt and partly encircles the area is known as the Island Park Caldera. See the figure on page 138. It is reported to be composed of welded tuffs and of obsidian-breccia flows that have a radially outward dip.
The overlying basalts are dominantly blue to black. Many of them are vesicular, and most carry megascopically visible olivine and feldspar. The rocks are fresh and vesicles commonly are empty. The olivine is partly altered to iddingsite, and glassy crusts are still present in the pahoehoe surfaces.

The basalt plain contains numerous small cinder cones and other volcanic-vent features. The basalts were erupted from a series of closely spaced vents north of the center line of the basalt flows. The basalts largely preserve their constructional topography, except where they are overlain by till of the Buffalo Glaciation which extends as far west as Henry's Fork of the Snake River. Both the rhyolite welded tuff and the basalt have been overlapped from the northeast by the younger rhyolite flows of the Madison and the Pithstone Plateaus.

STRUCTURE OF THE YELLOWSTONE PARK-SNAKE RIVER BASIN REGION

SNAKE RIVER BASIN

The Yellowstone Plateau represents the high, laval-filled eastern part of the Snake River Basin. The Snake River Basin is the depression formed by a number of block-faulted mountains that were uplifted along normal faults. The mountain blocks generally tend to dip toward the basin. The Centennial and Teton Ranges, for example, dip under the upper Snake River Basin from the north and the southeast respectively. On the sides away from the basin, these ranges are bounded by high rugged scarps, along Centennial and Jackson Hole Valleys. The Madison and Gallatin Ranges also decrease in structural and topographic relief as they approach the Yellowstone Plateau. They are merely low lying blocks at the plateau, where they are buried beneath the rhyolites of Pliocene and Quaternary age. The older Tertiary volcanic rocks in these ranges have undergone considerable structural deformation, but the Pliocene rhyolites have been offset only about 500 feet. Differential deformation such as this strongly suggests that the mountain ranges, and hence the Snake River Basin, were largely formed in Miocene time. In the Teton Ranges, the Pliocene rhyolites have a structural relief of 2,000 feet, but here also both structural and topographic relief decrease toward the plateau. The Beartooth and the Absaroka Ranges dip generally under the Yellowstone Plateau. The Rocene and Oligocene volcanic rocks in these ranges dip inward, and the Precambrian rocks are widely exposed to the northeast. The rhyolites of Pliocene age, on the other hand, have been little affected by the deformation, and thus the suggested Miocene age of the basin is corroborated.

The Pliocene and Quaternary rhyolites of the Yellowstone Plateau thus fill the topographic and structural basin that was formed during Miocene time. In the Centennial and Teton Ranges deformation appears to have continued on a more active scale during the Pliocene and Quaternary than in the other ranges.
WASHBURN RANGE

Washburn is a horseshoe-shaped, block-fault mountain with the open end to the northeast. It is divisible into three sections, of which two, the northern and the southern, trend northeast-southwestward; the third, or western, trends roughly north-southward. The area within the horseshoe is drained by the northeastern-flowing Tower Creek and is called the Washburn amphitheatre.

The range is composed of prerhyolite breccias. The two northeast-southwest-trending sections present steep scarps to the southeast and to the northwest gentle slopes largely controlled by the dip of the breccias. In the north-south segment, a steep scarp faces eastward, and the slope to the west is more gentle.

The Washburn Range has been considered variously as a volcano, as a tilted fault block (Howard, 1937 and de Martonne, 1933), and as a monadnock (Jones and Field, 1929). All but the faulting hypotheses have been discarded. Field evidence indicates that the Washburn Range was faulted almost to its present height before the rhyolite was deposited. The range front was then eroded back from the fault line (the amount of retreat is measured by the width of the bench), and a pediment, possibly veneered with gravel, was left extending southward. Rhyolite flows then surrounded the old fault range and submerged the pediment. Renewed faulting along the old prerhyolite fault in post-rhyolite time raised the rhyolite-veneered pediment surface about 500 feet and caused the rhyolite field within the amphitheater to slope northward.

ISLAND PARK BASIN CALDERA

Island Park Basin is thought to represent the site of a huge caldera. The west rim of the basin, a semicircular ridge with an inner diameter of approximately 10 miles, is formed of rhyolite welded tuff with radial outward dips of a few degrees. The inner rim of the semicircle is a single arcuate northward-facing fault scarp in the north and a series of semicentric, arcuate scarps in the south. There is a suggestion, therefore, that the Pliocene rhyolite tuffs of the Island Park Basin have slump as a result of weakening caused by withdrawal of magma from an underlying source chamber. The interior of the semicircular basin has been filled with basalt flows, which presumably came from the underlying magma source.

THERMAL ACTIVITY

Yellowstone Park is unique for the intensity and extent of its hot springs and geysers. Hot water features are widespread over an area of 50 miles in diameter that coincides roughly with the rhyolite plateau. The thermal activity is thought to be produced by heating of large quantities of meteoric waters. On the Pitchstone, Madison, and Central Plateaus all of the major thermal features, and most of the minor ones, are in topographically low areas defined by high steep fronts of the big rhyolite flows. The Upper Basin, Midway Basin-Lower Basin, and Norris Basin are all low areas left between the edges of young rhyolite flows. The basins are floor with till, outwash gravels, and alluvium that are underlain by Quaternary rhyolite. Most of the thermal areas are in the Pliocene rhyolites.
Although the thermal activity postdates the deposition of the Pliocene rhyolites, these rocks cannot themselves be the source of much of the required heat, except for that involved in the minor hot springs on the crests of the youngest flows. Most of the heat for the thermal activity must be of deeper origin, and the abundance, temperature, and composition of the steam all seem to point to a magmatic source. The young rhyolites may actually block upward movement of magmatic steam and thus deflect it laterally, perhaps along buried glacial till, to the geyser basins, where it heats great quantities of ground water.

GLACIATION

Several times during the Pleistocene, large parts of Yellowstone Park were submerged by ice from the surrounding mountains. The Pleistocene glacial history of the park was controlled almost exclusively by the activities of two great trunk glaciers. One of these, the Lamar Glacier, occupied the Lamar Valley in the northern part of the park. The other, the Upper Yellowstone Glacier, occupied the valley of the Yellowstone River south of Yellowstone Lake. At times of maximum ice spread, a tongue of the Lamar Glacier extended as far south as Hayden Valley and spread over the western divide into the headwaters of the Madison River. At such times, the Upper Yellowstone Glacier filled the basin of Yellowstone Lake and advanced up Hayden Valley to merge with the Lamar Glacier. On the west side of the lake basin, the Upper Yellowstone Glacier filtered through the coals in the continental divide and advanced southward into the Snake River valley as far as the Teton Mountains.

The Lamar Glacier, during each of its southerly advances against the flow of the Yellowstone River, impounded a lake, which, with increasing thickness of the ice, eventually would completely submerge the canyon and stretch southward to the advancing front of the Upper Yellowstone Glacier. With continued approach of the two ice fronts, the confined lake would steadily decrease in size and finally disappear. With recession of the ice fronts the lake would re-form, and the area of the lake would steadily expand.

The behavior of the ice was probably similar in each glacial epoch, but only the events of the last epoch, particularly the recessional stage, are recorded by abundant deposits. Thus, during a pause in the retreat of the last ice, a lake, Hayden Lake, was confined in Hayden Valley; it drained to the west into the Madison River. This lake was eventually completely filled with sediment. During the Hayden Lake Stage, the basin of Yellowstone Lake lay buried beneath the ice of the Upper Yellowstone Glacier. When the ice retreated, the basin of Yellowstone Lake was occupied by a lake of greater height and extent than the modern lake, but by a lake lower in level than the sedimentary fill of Hayden Valley to the north. This lake, Greater Yellowstone Lake, probably drained into the Snake River and the Pacific Ocean until such time as the outlet to the north was reopened by breaching of the Hayden Valley sediments.

POSTGLACIAL HISTORY

The close of the Ice Age in Yellowstone Park is of relatively recent date, for the park lies at a high altitude and has a cool climate. Time has been sufficient, however, for the Yellowstone River to remove the greater part of the sedimentary fill inherited from the Ice Age and to cut down an additional 50 to 50 feet into bedrock. Pleistocene sediments of several ages within the
canyon of the Yellowstone River indicate that erosion of this canyon had begun no later than the middle Pleistocene.

Postglacial land sliding of parts of the canyon walls has in places littered the canyon floor with debris. The river now passes unhindered through this debris, which at one time may have caused ponding for short distances.

SUMMARY OF CENOZOIC EVENTS

The Tertiary tectonic and volcanic events in the Absaroka-Yellowstone-Beartooth region may be summarized as follows (from oldest to youngest):

(1) Major Beartooth thrusting and deformation; during Paleocene and post-Paleocene (Fort Union).

(2) Widespread erosion in uplifted areas, forming a topography with 1,000 to 4,000 feet of local relief. Wasatch time (Willwood Formation).

(3) First scattered volcanic eruptions in Absarokas (early acid breccias); late Willwood time (Tatman Formation in part).

(4) Erosion of some of the early acid breccias.

(5) Deposition of early basic breccias; Bridger time; Pitchfork and Ayresoss Formations deposited to the southeast and south.

(6) Local folding and tilting.

(7) Extrusion of early basalt sheets from many fissures; late Bridger and early Uinta time.

(8) Minor erosion.

(9) Extrusion of late breccia series and late basalt sheets; late Eocene and early Oligocene time.

(10) Widespread deposition of ash deposits; early Chahron time.

(11) By late Oligocene time the Bighorn Basin was filled with sediment, largely volcanic tuffs and sandstones, to a level approximately adjusted to the dominant "Subsummit" erosion surface in the Beartooth Mountains.

(12) Local doming in central and western Montana, for example, Castle Mountain area, and volcanic eruptions; Miocene time.

(13) Subsummit surface and related sediment system completed.

(14) Regional arching and widespread erosion; much of the late volcanic series in northern Absarokas and Yellowstone Park removed, and Snake River Basin formed.

(15) Inundation of Snake River Basin with Yellowstone rhyolites, welded tuffs; Pliocene to early Pleistocene age (Boya, 1959).
(16) Eruption of Quaternary rhyolites and subsidiary basalts to form the Yellowstone Plateau in the eastern part of Snake River Basin. Possible roof collapse of partially enclosed magma chamber. Late rhyolites appear to fill depressions created by such collapse in the Madison-Pitchstone-Central Plateau areas. In the western part of the present Snake River Basin the Quaternary extrusive rocks are basalt, and in the Island Park Basin these appear to fill a collapse caldera. Evidence of glaciation.

(17) First cutting of the Yellowstone Canyon; middle Pleistocene? time.

(18) Local basalt flows in Yellowstone Park (as at Tower Falls); late Pleistocene time both before and after the last glaciation (Howard, 1937).

(19) Recutting of the Yellowstone Canyon in postglacial time.
INTRODUCTION

The Teton Range of western Wyoming is one of the most spectacular physiographic features in the Rocky Mountains. Near the steep east flank of the uplift alpine glaciers have carved the bedrock into a series of picturesque horn peaks and deep U-shaped valleys, with sharp dividing arêtes and fringing arcs of glacial debris.

The Teton Range extends in a north-south direction for a distance of slightly more than 30 miles. Northward the range grades into the Pitchstone Plateau of Yellowstone Park, and to the south it merges with the low Teton Pass Mountains, which terminate against the transverse Snake River Range.

The uplift is noticeably asymmetric in profile. The gently sloping west side is capped with Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic rocks, but the east flank is a steep, fault-bounded face overlooking the Jackson Hole Intermontane Basin. The relief between the crest of the uplift and the present surface of Jackson Hole is about 7,000 feet.

BEDROCK

The Teton Uplift is cored with rocks of Precambrian age. Bradley (1956) recognized five distinct rock types within the Precambrian complex of the Central Teton Block:

1. Gneiss and schist; the bulk of the Precambrian.
2. Granite and leucogranite stocks.
3. Pegmatite, aplite, and quartz veins and dikes.
5. Epidote veins.

Rock unit 4, the black diorite dikes, are well exposed along the east face of the uplift in Mt. Moran, Grand Teton, and Middle Teton.

On the west flank of the uplift the Precambrian igneous and metamorphic complex is unconformably overlain by 8,000 to 10,000 feet of Paleozoic and Mesozoic strata. See the stratigraphic column on the next page for a summary of the Paleozoic and Mesozoic rocks.

The basal Tertiary deposit in the Tetons is the Pinyon Conglomerate of Paleocene(?) age. A slight angular unconformity between the Pinyon and the underlying rocks suggests that these lower beds were mildly deformed and uplifted prior to the deposition of the Pinyon Conglomerate. The Pinyon Conglomerate in turn is unconformably overlain by at least three groups of Tertiary volcanic rocks. The oldest of them has been dated as probable lower or middle Mioocene, (Colbert, 1943; Schultz and Falkenbach, 1947) from an oreadont skull and mandible and a camel's toe found in sediment associated with the andesite flows, agglomerates, and tuffs.
<table>
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</table>

Figure 78.—Stratigraphic column of the northern part of the Teton Range, Wyoming.
These volcanic rocks were deposited on a surface of variable relief and must have been preceded by an extended period of erosion as they lie locally on Precambrian rock.

The second eruptive unit consists largely of rhyolite flows. It has been given a tentative date of early or middle Pleistocene by Horberg, Edmund, and Fryxell, (1955).

This third and youngest volcanic unit is characterized by basalt flows and is limited to the northwestern part of the range. These volcanic rocks overlie the rhyolite and are confined to the valleys and other depressions of the present topography.

STRUCTURE

The dominant structural feature is the major normal fault that marks the east side of the Tetons and along which the range has been elevated and tilted to the west. Edmund (1956) estimated that the dip of this fault is at least 40° and possibly 70° to the east. The maximum throw may be as much as 14,000 feet. See the section below.

![Diagram](image_url)

Figure 79.—Section through the northern part of the Teton Range, Wyoming. After Edmund, 1956.

The uplift block is also broken by a number of steeply dipping normal faults and a few thrust faults. The major folds trend in a northwesterly direction. See the tectonic map on the next page.

GEOLoGIC HISTORY

PREcAMBRnAN IStory

1. Deposition of sediments, including sands and gravels and probably including muds and carbonates. Thickness unknown but probably in excess of 10,000 feet.
2. Metamorphism and metasomatism to schist and gneiss.
3. Emplacement of granite and leucogranite, pegmatite, aplite, and quartz veins and dikes.
4. Emplacement of black diorite dikes and epidote veins along east-west and north-south systems.
5. Truncation by erosion.
6. Deposition of Paleozoic and Mesozoic sediments; shelf environment.

**LARAMIDE HISTORY**

7. Folding of superincumbent Paleozoic and Mesozoic strata into a series of northwestern-trending anticlines and synclines. Some faulting.

8. Uplift and truncation of the folds. As much as 10,000 feet of rock removed in places.

9. Deposition of Pinyon Conglomerate and tilting to the west.


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*Figure 80.* Tectonic map of the Teton Range, Wyoming. After Edmund, 1990.
POST-LARAMIDE HISTORY

12. Tilting of the Teton Block to the west accompanying the outpouring of the volcanic rocks, so that the oldest unit dips west at 30° and the youngest unit dips in the same direction at about 10°.
13. Block faulting in the Teton Block; renewed uplift of the block. Late Miocene or Pliocene
15. Glaciation.

GLACIAL GEOLOGY

The striking features of glacial erosion dominate one's first impression of Jackson Hole Country. Probably no other mountains in the world display better evidence of erosion by alpine glaciers than do the Tetons. From time to time force yourself to take your eyes away from the mountain peaks and you also can see many features of glacial deposition. As the large tongues of ice in the valleys of the Tetons reached Jackson Hole, piedmont glaciers were formed, and drift was laid over much of the broad valley. End moraines, pitted outwash plains and terraces are present downstream from these moraines. The three glacial stages are summarised briefly below from oldest to youngest, and the map on page 197 shows the distribution of the drift of these stages.

BUFFALO GLACIATION

Many of the isolated buttes in Jackson Hole and the stream divides of the West Gros Ventre highland are covered with patches of thoroughly weathered drift. This drift is found at altitudes of about 7,500 feet. The distribution of the drift suggests that it was deposited by an extensive piedmont glacier that buried all but the highest mountains in Jackson Hole and that had its major source somewhere in southern Yellowstone Park.

BULL LAKE GLACIATION

Several piedmont glaciers invaded the Jackson Hole valley floor in Bull Lake time, and the distribution of the drift left by these glaciers is seen on the map on page 197. A large amount of the Bull Lake drift is buried beneath the youngest glacial deposits. Notice how the Burned Ridge Moraine appears to come out from under the younger Jackson Lake Moraine.

PINEDALE GLACIATION

The last episode of glaciation has left abundant material on the broad valley floor of Jackson Hole and in the narrow steep-walled canyons of the Tetons. Notice the distribution of this drift on the map. An excellent example of pitted outwash and knob and kettle topography is seen in "The Potholes."
Figure 81.—Glacial geology of Jackson Hole, Wyoming, After Fryxel, 1930.
REFERENCES CITED


Geol. Soc. America, 1959, Glacial map of the United States east of the Rocky Mountains, 111,730,000.


Illinois State Geol. Surv., 1945, Geologic map of Illinois, 1:500,000.

Indiana Geological Survey, 1953, Map of Indiana showing physiographic units, 1:2,000,000 (approx.).


———, 1956, Generalized geologic map of Indiana, 1:2,000,000


Iowa Geological Surv., 1937, Geologic map of Iowa, 1:500,000.


Raisz, E., 1957, Landforms of the United States, 6th Revised Ed.

Riggs, W. R., 1960, Major basins and structural features of United States (map); Hammond and Co.


South Dakota State Geol. Surv., 1953, Geologic map of South Dakota, 1:500,000.


