Geology of the Stanford-Hobson Area Central Montana

GEOLOGICAL SURVEY BULLETIN 1027-J

Prepared in cooperation with the U. S. Bureau of Reclamation, as a part of a program for the geologic mapping and investigation of mineral resources in the Missouri River basin

Geology of the Stanford-Hobson Area Central Montana

By JAMES D. VINE

A CONTRIBUTION TO ECONOMIC GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1027-J

Prepared in cooperation with the U. S. Bureau of Reclamation, as a part of a program for the geologic mapping and investigation of mineral resources in the Missouri River basin

---

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1956

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.25 cents (paper cover)

CONTENTS

ILLUSTRATIONS

[Plates 45–47 in pocket]

TABLES

A CONTRIBUTION TO ECONOMIC GEOLOGY

GEOLOGY OF THE STANFORD-HOBSON AREA, CENTRAL MONTANA

By James D. Vine

ABSTRACT

The Stanford-Hobson area comprises an area of about 1,300 square miles on the northern flank of the Little Belt Mountains and in the southern part of the Judith Basin, in Judith Basin and Fergus Counties, Mont. As a part of the program of the Department of the Interior for the development of the Missouri River basin, studies were made of the lithology, thickness, and distribution of 12 formations of Paleozoic and Mesozoic age cropping out in the area. The structure and stratigraphic relationships of these formations were studied in sufficient detail to permit an evaluation of the mineral resources, with particular reference to the oil and gas possibilities and the coal resources of the area.

The bedrock formations range in age from the Madison limestone of Mississippian age to the Judith River formation of Cretaceous age. Much of the area of the younger rocks, outside of the mountain area, is covered by extensive terrace deposits and alluvium of Quaternary age. These deposits form the most valuable agricultural land of the region.

Stratigraphically the lowest formation mapped was the Madison limestone of Mississippian age. It consists of gray, dense limestone that forms massive cliffs and hogbacks along the front of the Little Belt Mountains. It is overlain unconformably by the formations of the Big Snowy group: the Kibbey sandstone (190 feet thick), the Otter formation (545 feet thick), and the Heath shale (435 feet thick). Overlying the Big Snowy group is the Amsden formation of Mississippian and Pennsylvanian(?) age. The Amsden consists of 575 feet of sandstone and shale overlain by about 135 feet of gray dense limestone containing red shale partings near the top.

The Ellis group, of Middle and Late Jurassic age, which unconformably overlies the Amsden formation and older beds, is comprised of the Piper formation at the base, overlain successively by the Rierdon and Swift formations. The Ellis group is nearly 500 feet thick in a well in the basin part of the area, but in the outcrops the group is represented by only 60 feet of sandstone assigned to the Swift formation.

The Morrison formation, overlying the Swift formation, is composed of from 150 to 300 feet of varicolored shale and siltstone interbedded with gray limestone and gray to green shale. A bed of coal is near the top.

Unconformably overlying the Morrison is the Kootenai formation of Early Cretaceous age, 550 feet thick, consisting of a basal sandstone and overlying interbedded red shale and brown sandstone. Conformably above the Kootenai and constituting the lower part of the Colorado shale is 720 feet of dark-gray to black shale containing thin beds of sandstone and bentonite that is considered equivalent to the Thermopolis shale of the Bighorn Basin. This is overlain by 135 feet of bentonite, shale, and sandstone, equivalent to the Mowry shale.

Overlying the Mowry shale equivalent is shale of Late Cretaceous age, 100 feet thick, which contains lenses and dikes of sandstone and thin bentonite beds and is considered the equivalent of the Belle Fourche shale. Above this is a section consisting chiefly of shale and including 85 feet of strata equivalent to the Greenhorn limestone, 310 feet of strata equivalent to the Carlile shale and 410 feet of strata equivalent to the Niobrara formation, which is the uppermost unit of the Colorado shale. The Telegraph Creek formation of the Montana group, 160 feet thick, was mapped with the underlying Colorado shale, because it was not possible to separate beds of these groups in the field. The uppermost beds of Mesozoic age consist of 250 feet of the Eagle sandstone and unmeasured thicknesses of the Claggett shale and the Judith River formation of the Montana group.

Four sequences of terraces and alluvium of the flood plains were mapped. Landslides, consisting chiefly of shale and angular slump blocks, were also mapped separately.

Several domes and anticlines are present and may have possibilities for production of oil and gas, because seven formations that produce oil in surrounding areas are presumed to underlie this area also. Other materials of possible economic importance that occur in the area include coal in the Morrison formation, gypsum in the Piper formation and in all three formations of the Big Snowy group, bentonite in the Mowry shale, and gravel deposits on Quaternary terraces and alluvial plains.

INTRODUCTION

LOCATION

The Stanford-Hobson area is located in Judith Basin and Fergus Counties, Mont., and includes approximately 1,300 square miles in the southern part of the Judith Basin (fig. 52). The mapped area is nearly triangular, being bounded on the east by the meridianal line 109°40′, on the north by the north line of township 18 (approximately

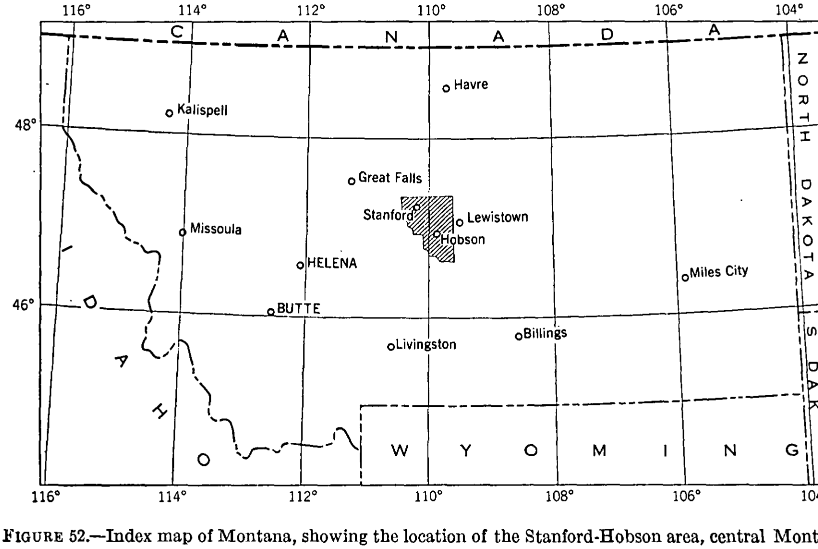


FIGURE 52.—Index map of Montana, showing the location of the Stanford-Hobson area, central Montana.

parallel 47°11′), on the west by the meridianal line 110°30′, and on the south by an irregular line trending generally northwest near the northern base of the Little Belt Mountains. It is 40 miles long on the north side and 46 miles long on the east side and about 45 miles long on the southwest side.

PURPOSE AND SCOPE OF REPORT

The Stanford-Hobson area project was undertaken by the United States Geological Survey, in cooperation with the United States Bureau of Reclamation, as part of a program for the geologic mapping and investigation of mineral resources in the Missouri River basin. The field work that is the basis of the ensuing report consisted of mapping the geology and determining stratigraphic relationships in sufficient detail to evaluate the mineral resources, especially the oil and gas possibilities in the area.

PREVIOUS INVESTIGATIONS

The principal geologic features of central Montana are well known, as the result of a number of previous geologic investigations, several of which are truly classical studies. The first comprehensive description of the geology and economic resources of a part of this area appeared in the Little Belt Mountains and Fort Benton folios of the U. S. Geological Survey (Weed, 1899a and 1899b) and in a description of the geology of the Little Belt Mountains (Weed, 1900). This was followed by more detailed geologic mapping and detailed descriptions of the coal resources in the areas adjacent to the Little Belt and Big Snowy Mountains by Calvert (1909) and by Fisher (1909). Still later, Reeves' geologic mapping of the plains adjacent to the Highwood Mountains (Reeves, 1929) and of the Big Snowy Mountains (Reeves, 1930) added to our knowledge of areas to the north and to the east of the Stanford-Hobson area. A study of the physiography and glacial geology of eastern Montana by Alden (1932) includes a discussion of the three chief terrace levels in this area. Meanwhile, continuing investigations by paleontologists and stratigraphers contributed greatly to our knowledge and understanding of the sedimentary rocks. Of particular significance to the geology of this area are the studies of the Mississippian and Pennsylvanian rocks by Scott (1935 and 1942), and by Perry (1943); the studies of the Jurassic rocks by Cobban (1945), by Brown (1946), by Imlay (1945), and by Imlay and others (1948); and the studies of the Cretaceous rocks by Cobban (1951), and by Cobban and Reeside (1951). These studies have defined and described the sedimentary formations as they are mapped in the Stanford-Hobson area.

FIELD WORK AND ACKNOWLEDGMENTS

Field investigation of the Stanford-Hobson area was undertaken by the U. S. Geological Survey during the summers of 1948 and 1949. A map and short report of the findings of the first summer's field work (Vine and Hail, 1950) and a similar map and report of the second summer's work were published in advance of this report (Vine and Johnson, 1954.) The areal geologic mapping was done on aerial photographs at a scale of approximately 1:20,000 and transferred to the base by means of a vertical sketchmaster. Horizontal and vertical control for the mapping was established by plane table triangulation and adjusted wherever possible to U. S. G. S. benchmarks and triangulation stations.

The writer is indebted to William J. Hail, Jr., who assisted with the geological mapping during the summer of 1948 and William D. Johnson, Jr., who assisted during the summer of 1949. Both helped in the compilation of maps in the office. Robert H. Dott, Jr., served as a field assistant during the summer of 1948. William A. Cobban visited the party during the summer of 1949 and aided in selecting the formation boundaries within the Colorado shale.

The writer also wishes to express his sincere thanks to the many residents in the area for the kindnesses and courtesies that facilitated the work in the field.

GEOGRAPHY

TOPOGRAPHIC AND PHYSIOGRAPHIC FEATURES

The Stanford-Hobson area of central Montana (pl. 45) is located in the southern part of the Judith Basin, a topographic depression in an unglaciated part of the northern Great Plains that is partly enclosed by several isolated mountain ranges. A sketch map, fig. 53, shows the principal physiographic features in the area. Five mountain ranges, the Highwood, Little Belt, Big Snowy, Judith, and Moccasin Mountains nearly enclose the Judith Basin, except on the north. The two principal streams, Judith River and Arrow Creek, have sources in these mountains, drain the Judith Basin, and flow northward along generally parallel courses to join the Missouri River as it flows eastward across central Montana.

Rolling plains from 3,500 to 4,500 feet above sea level make up the greater part of the area. The five mountain ranges that nearly enclose Judith Basin rise abruptly from the plains to elevations of 6,000 to 9,000 feet above sea level. The plains consist chiefly of gently sloping, gravel-covered terraces that are dissected by steep-sided stream valleys that range in depth from a few feet near the heads of small coulees to several hundred feet along the major stream

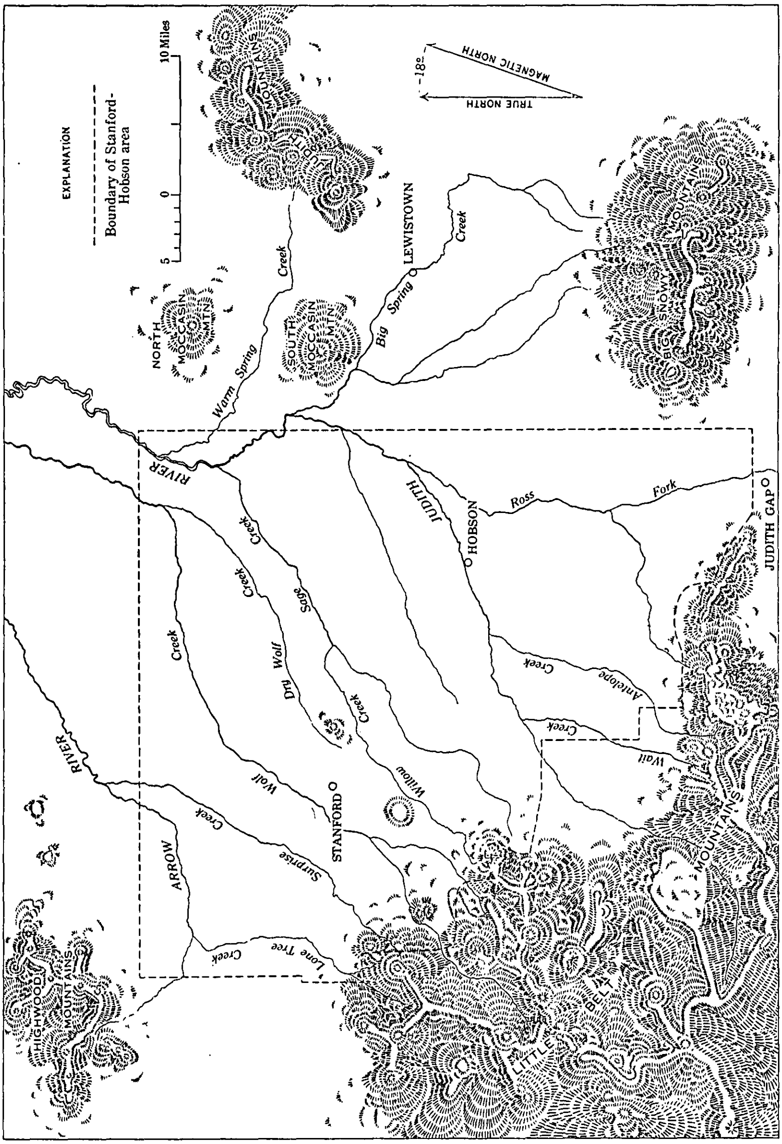


FIGURE 53.—Sketch map of the Stanford-Hobson area, central Montana.

354332—56——2

courses. However, an observer standing on one of these terraces sees an apparently uninterrupted and featureless plain extending to the foothills of the mountains. Deep dissection along Arrow Creek and its tributaries has resulted in areas of badlands unsuited for cultivation and very inadequate for grazing. A belt of foothills in which gently dipping bedrock crops out generally separates the terraced plains from the main flanks of the mountains. Locally, terraces that resemble remnants of pediments extend to the steep slopes of the mountains and lie on steeply tilted and truncated strata.

The Highwood Mountains, northwest of the area, are a highly dissected mass of volcanic rocks and laccoliths. They are separated from the Little Belt Mountains on the south by about 12 miles of rugged uplands that form the western drainage divide of Arrow Creek. The Little Belt Mountains are structurally complex, with sedimentary rocks uplifted along a northwest-trending axis. On the northern flank of the range these rocks are disturbed by a series of stocks, other igneous intrusions that arch the sedimentary rocks, small domelike uplifts, faults, and minor folds. This range forms the southwestern limit of the area mapped. The Little Belt Mountains are separated from the Big Snowy Mountains to the east by a structural and topographic saddle or divide known as Judith Gap. The Big Snowy Mountains are composed of sedimentary rocks uplifted along a northwest trending axis that is slightly offset from the axis of the Little Belt Mountains. The Judith and Moccasin Mountains lie to the north of the Big Snowy Mountains and are separated from them by a lobe of the Judith Basin. The Judith and Moccasin Mountains consist of igneous intrusions that are probably stocks or laccoliths over which the sedimentary strata are domed.

Two prominent topographic features interrupt the continuity of the terraced plains in the vicinity of Stanford. About 2½ miles west of the town, a group of gravel-capped remnants of a high terrace surface consititute Stanford Buttes. About 5½ miles southwest of Stanford, Skull Butte towers nearly 1,000 feet above the adjacent plains and is the topographic expression of a structural dome. Other named landmarks in the area lie near the mountains. Wolf Butte is a prominent mountain peak that stands out somewhat in front of the main flank of the Little Belt Mountains about 10 miles south of Geyser. Square Butte and Round Butte are prominent buttes at the east end of the Highwood Mountains and are about 8 miles north of the area mapped. West of Antelope Creek the north flank of the Little Belt Mountains is characterized by a prominent hogback to which no general name has been applied.

TRANSPORTATION FACILITIES AND ACCESSIBILITY

Nearly all the towns are located on one or the other of the two railroads that cross the area. A branch of the Great Northern Railway with a terminus in Great Falls enters the area at Geyser and passes south through Judith Gap, with a branch line extending east to Lewistown. The Chicago, Milwaukee, St. Paul and Pacific Railroad has its route along the north side of the Highwood Mountains and enters the Stanford-Hobson area near the town of Arrow Creek. A branch line of the latter railroad passes south through Judith Gap to Harlowton.

Two paved highways provide easy access to most of the area: U. S. Highway No. 87 between Lewistown and Great Falls crosses the center of the area from northwest to southeast; near Hobson it is joined by Montana State Route No. 19, which comes north from Harlowton through Judith Gap. A secondary highway across the northern part of the area through the towns of Denton and Coffee Creek has been graded and partly graveled. Many other secondary roads have been graded and graveled and, hence, are passable in nearly all kinds of weather. A close network of secondary roads and trails permits access by car in good weather to within one or two miles of any part of the area.

The nearest commercial air fields are those in Lewistown and Great Falls, but 3 small private fields at Moore, Stanford and Denton provide facilities for light airplanes. An emergency landing field, maintained by the Civil Aeronautics Administration, is located about 2 miles east of Geyser. Small airplanes are flown by several ranchers and land on cleared areas on their ranches.

CLIMATE AND VEGETATION

The plains in the Stanford-Hobson area, under semiarid climate, supported a thick growth of grass before the modern period of excessive grazing and cultivation, and grass still covers areas left uncultivated. Conifers are abundant on the slopes of the mountains and the thickest stands are found on the northwest-facing slopes. On the plains, trees grow only locally. Thus conifers grow along the outcrop of sandstone beds, such as the basal part of the Kootenai formation and the Eagle sandstone. Other evergreens also grow along some of the sheltered coulees and steep-sided gulches that are tributary to Arrow Creek. Deciduous trees, such as cottonwoods and aspens, are found in some sheltered valleys where more moisture is available than on the open plains.

Heavy rains occur in June and during that month many secondary roads are impassable. Afternoon thunder showers are common

TABLE 1.—*Temperature and precipitation data for the Stanford-Hobson area*

Station	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average temperatures														
Denton	17	20.0	25.4	30.6	43.7	51.6	60.7	67.0	66.1	56.4	45.2	34.6	23.9	43.8
Geyser	4	15.0	23.6	29.0	40.7	47.6	56.4	64.2	63.4	55.0	42.3	37.0	22.9	41.4
Lewistown	46	21.6	23.3	31.2	42.2	50.9	58.6	65.8	63.7	54.2	45.2	32.8	25.2	42.9
Stanford	18	22.2	23.0	30.3	41.8	51.3	57.8	67.0	64.6	55.4	46.0	34.2	27.5	43.4
Average maximum temperature														
Denton	17	31.0	33.4	41.4	55.7	64.3	73.1	81.0	80.6	69.5	56.7	45.8	34.0	55.5
Geyser	4	24.4	31.0	41.3	52.5	58.1	67.5	77.1	77.8	68.8	52.7	47.1	31.4	52.5
Lewistown	32	32.6	36.1	44.1	55.9	64.1	73.2	81.7	80.5	69.1	58.8	45.3	36.3	56.5
Average minimum temperature														
Denton	17	9.1	17.5	19.7	31.7	39.0	48.3	53.1	51.6	43.4	33.7	23.4	13.8	32.0
Geyser	4	5.7	16.1	16.6	28.9	37.1	45.4	51.3	49.1	41.3	31.9	27.0	14.4	30.4
Lewistown	32	9.6	11.1	18.9	28.2	36.1	43.6	48.6	46.5	37.9	30.2	19.3	12.6	28.6
Highest temperature														
Denton	17	63	67	80	86	96	100	102	106	99	88	75	63	106
Geyser	4	59	62	67	80	85	85	95	91	95	79	70	55	95
Lewistown	32	60	66	88	86	93	105	105	101	98	92	81	71	105

Lowest temperature														
Denton	17	−46	−30	−19	5	19	32	37	28	22	−2	−22	−42	−46
Geyser	4	−38	−31	−14	12	17	28	33	26	22	4	−5	−14	−38
Lewistown	32	−46	−36	−28	−12	11	25	32	27	6	−8	−25	−40	−46
Average precipitation (inches)														
Denton	31	0.58	0.43	0.63	0.92	1.90	3.79	1.64	1.14	1.68	0.88	0.48	0.46	14.53
Dry Wolf Camp	4	1.57	1.01	0.72	1.36	3.50	4.28	2.15	2.18	2.99	1.70	0.85	1.22	23.71
Geyser	5	0.27	0.25	0.25	0.87	2.80	3.98	2.00	0.43	1.12	0.75	0.19	0.21	13.12
Hobson	8	0.46	0.43	0.74	1.14	2.21	3.81	1.97	1.28	1.28	0.81	0.70	0.62	15.45
Lewistown	45	0.73	0.77	1.03	1.27	2.72	3.79	2.07	1.38	1.53	0.36	0.21	0.20	16.06
Stanford	18	0.47	0.50	0.73	0.98	2.24	3.24	1.63	1.58	1.33	0.97	0.60	0.51	14.78
Average number of days with 0.01 inch or more of precipitation														
Denton	17	6	4	6	6	8	11	7	6	7	6	4	5	76
Hobson	8	4	4	6	8	9	13	9	8	6	6	4	4	81
Lewistown	31	8	6	8	7	10	12	8	7	7	7	6	7	93

during July and August. Light snow or frost may occur during any month of the year but only rarely during the summer months. In September there is usually an increase in precipitation, but during October and November the weather is generally dry and mild.

Temperatures are moderate in the summer and there are rarely a few days of uncomfortably warm weather. The table (table 1) was compiled from temperature and precipitation data for the Stanford-Hobson area as recorded in the U. S. Weather Bureau Office, Helena, Montana.

Moderately strong, cool winds blow almost continuously, and the nights are usually cool, even in midsummer. The winters are severe.

UTILIZATION OF THE LAND

Wheat, cattle, and sheep are the chief economic products of the farms and ranches in the area. The gravel-covered terraces are usually mantled by two or three feet of fine, loamy soil, and a large part of these uplands is cultivated and planted in wheat. In addition, parts of the more gently sloping valley lands and of the rolling foothills region surrounding the mountains are also cultivated and planted in wheat. Some of the highest yields of wheat are obtained along the foothills of the mountains where the soils are derived from decomposed sandstone and red shale and in the valley lowlands where the soils are derived from sandy black shale. Nearly all the remaining area, which is not cultivated, is used as grazing land for cattle and sheep or is reserved for hay meadows and winter pasture. The largest cattle and sheep ranches are found along the foothills of the mountains or along the broad alluvial river plains, which are too moist for the cultivation of wheat.

Coal mining was for a time an industry of secondary importance in the area. The abandoned town of Lehigh, about 3½ miles southwest of Windham, was once a thriving coal mining camp. The coal was used by the Great Northern Railroad, but about 1921 most of the mines were closed and have never reopened.

STRATIGRAPHY

Sedimentary strata ranging in age from Mississippian to Recent are present in the Stanford-Hobson area (pl. 45). Older Paleozoic formations present in the Little Belt and Big Snowy Mountains include about 850 to 1,300 feet of Cambrian rocks and 130 to 165 feet of Devonian rocks that have been described by Weed (1899a, 1899b) but were not investigated for this report. The younger Paleozoic formations and the Mesozoic formations to the Judith River formation, totaling as much as 6,500 feet of strata, are described herein. The rocks from the Madison limestone of Mississippian age to the Eagle sandstone of Late Cretaceous age are represented graphically on plate 46, which is a composite of surface sections measured in the area. A comparison with the sample log of the Pacific Western Oil Co. Todd no. 1 well, table 2, from the northern part of the area indicates variations in the stratigraphic sequence within the area that will be discussed in detail. The only rocks overlying the Mesozoic strata are Pleistocene and Recent terrace gravels and alluvium.

TABLE 2.—*Sample log of the Pacific Western Oil Co. Todd No. 1 well*

Location: SW¼NW¼ sec. 32, T. 17 N., R. 14 E.
Drilling commenced: September 15, 1948
Drilling completed: October 29, 1948
Total depth: 3356 feet
Surface formation: Colorado shale
Microscopic study of well samples made by William J. Hail, Jr.

Lithologic description	Thickness (feet)	Depth (feet)
Colorado shale (as penetrated):		
No samples	40	40
Siltstone, gray, with some gypsum	75	115
Limestone, light-gray	15	130
Shale, gray and dark-gray; bentonitic in lower part	70	200
Shale and siltstone, gray; bentonite from 230 to 240 ft	110	310
Shale, gray, and white bentonite; high concentration of bentonite between 340 and 360 ft	70	380
Siltstone and shale, gray; in part sandy	70	450
Shale, gray to dark-gray; in part silty and sandy	220	670
Siltstone, gray; sandy in upper 20 ft	75	745
Sandstone, light-gray, very fine grained, friable; in part silty	45	790
Shale, gray	10	800
Sandstone, gray, very fine grained	30	830
Shale, gray; sandy from 870 ft to 940 ft	160	990
Sandstone, gray, friable, very fine grained to fine grained; interbedded with some gray shale	80	1070
Kootenai and Morrison formations, undifferentiated:		
Shale, red, grayish-red, and gray; in part silty	50	1120
Sandstone, grayish-yellow-green, medium-grained to silty	75	1195
Limestone, pale-yellowish-brown, varicolored	20	1215
Shale, red, gray, varicolored; in part sandy	35	1250
Limestone, grayish-orange-pink and light brown, dense	25	1275
Siltstone, gray, sandy; interbedded with gray shale	20	1295
Limestone, pale-yellowish-brown	15	1310
Siltstone, gray, sandy; interbedded with varicolored shale	85	1395
Limestone, yellowish-gray; siltstone at base	25	1420
Siltstone, light-gray; interbedded with gray shale; sandy at the base	30	1450
Shale, dark-gray and red; loose sand grains	125	1575
Sandstone, light-gray, very fine grained to silty	25	1600
Shale, dark-gray, red, and varicolored; carbonaceous near the top; in part sandy	115	1715
Limestone, light-olive-gray; interbedded with gray shale	30	1745
Shale, dark-gray, red, and varicolored; interbedded with siltstone and sandstone	50	1795

TABLE 2.—*Sample log of the Pacific Western Oil Co. Todd No. 1 well*—Continued

Lithologic description	Thickness (feet)	Depth (feet)
Ellis group:		
Sandstone, light-gray, glauconitic; shaly toward the base	50	1845
Shale, gray and grayish-red	20	1865
Shale and sandstone, interbedded, gray and grayish-red, glauconitic	50	1915
Limestone, light-gray, silty; some siltstone and shale	30	1945
Siltstone, light-gray; interbedded with red shale	30	1975
Shale, gray and dark-gray; some limestone near top	60	2035
Shale, red and gray, and calcareous siltstone	35	2070
Shale, gray, and anhydrite; interbedded	45	2115
Shale, siltstone, and limestone, interbedded, gray and varicolored	50	2165
Siltstone and shale; interbedded, varicolored; some anhydrite	90	2255
Limestone, pale-yellow-brown, dense	10	2265
Shale, gray and dark-gray to red, varicolored	25	2290
Heath shale:		
Shale, gray to grayish-black	15	2305
Shale and limestone interbedded	30	2335
Shale, grayish-black	20	2355
Shale and siltstone, gray and varicolored	35	2390
Shale, grayish-black	10	2400
Shale, dark-gray, interbedded with gray siltstone	20	2420
Shale, dark-gray; siderite pellets with magnetite centers	5	2425
Sandstone, pale-brown, medium-grained	15	2440
Shale and siltstone, dark-gray and varicolored	120	2560
Otter formation:		
Shale, green, gray, and varicolored, silty; thin limestone beds at 2600 and 2630	110	2670
Limestone, gray, silty	30	2700
Shale, gray, greenish-gray and red	30	2730
Limestone, light gray, dense	20	2750
Shale, gray, green, and varicolored	10	2760
Limestone, gray, shaly	10	2770
Shale, gray, grayish-red, greenish-gray, and grayish-black	40	2810
Limestone, light gray, silty, and shaly	10	2820
Shale, gray, grayish-black and varicolored	15	2835
Limestone, gray to light-gray, shaly	10	2845
Shale, light-gray to dark-gray, and varicolored	60	2905
Kibbey sandstone:		
Siltstone, light-gray, shaly	25	2930
Shale, light-gray to dark-gray	25	2955
Sandstone, white, fine- to medium-grained	15	2970
Shale, light- to dark-gray, and varicolored, sandy	45	3015
Sandstone, pale brown, very fine-grained and silty	30	3045
Shale and anhydrite, interbedded	10	3055
Shale gray, dark-gray, and varicolored, silty	40	3095
Sandstone, siltstone and shale; interbedded, pale-yellow-brown to pale-red	90	3185
Madison limestone (as penetrated):		
Dolomite, light-gray	5	3190
Limestone, light- to dark-gray, oolitic	30	3220
Limestone, anhydrite and shale, interbedded	75	3295
Siltstone and anhydrite, sandy and shaly	10	3305
Shale, gray to dark-gray	15	3320
Limestone, light-olive-gray, to pale-yellowish-brown; interbedded with some gray shale	36	3356
(Bottom of well)		

MADISON LIMESTONE

The Madison limestone is the most conspicuous, resistant formation exposed in the area. It is about 1,000 feet thick (Weed, 1899b, p. 2) and forms steep hogbacks on the tree-covered flanks of the Little Belt and Big Snowy Mountains (see figs. 54 and 55). It also caps many

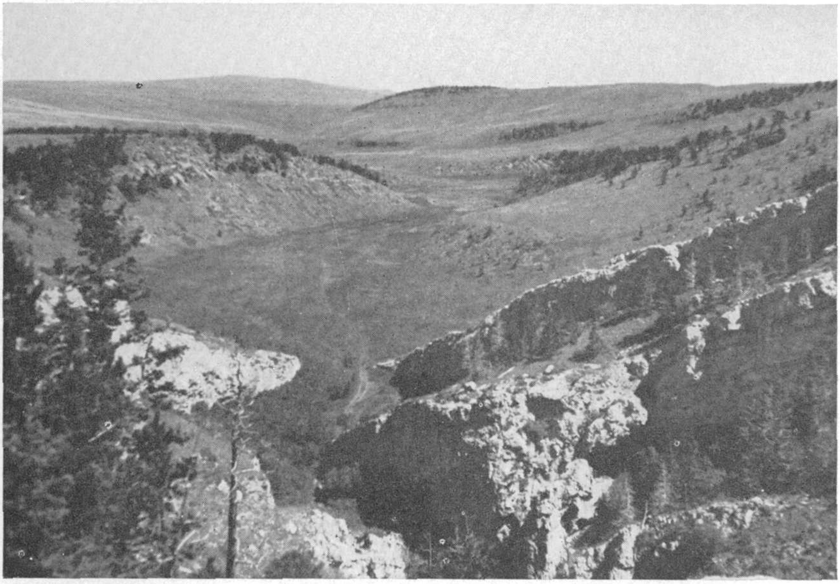


FIGURE 54.—The Madison limestone, in foreground, which forms the steeply dipping hogback along the north flank of the Little Belt Mountains. View north along Antelope Creek.

high peaks in the mountains. The top of the Madison limestone was the oldest contact mapped, and the formation was not studied in the same detail as the overlying formations. The upper part of the Madison limestone, where mapped, consists of gray, dense limestone, weathering light gray. Locally, the upper part of the formation is fractured and brecciated.

BIG SNOWY GROUP

The term Big Snowy group was first applied to strata above the Madison limestone and below the Amsden formation by H. W. Scott (1935, p. 1023). Three formations—from oldest to youngest, the Kibbey sandstone, the Otter formation, and the Heath shale—comprise the group.

Before the introduction of the term Big Snowy group, all the strata in central Montana above the Madison limestone and below the Ellis group were assigned to the Quadrant formation by Weed (1899b, p. 2) and others. Strata thus included in the Quadrant formation in the

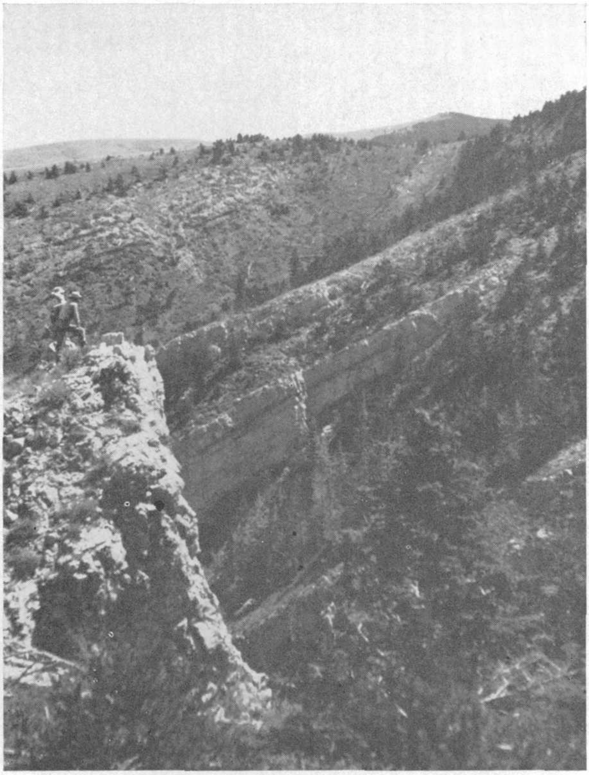
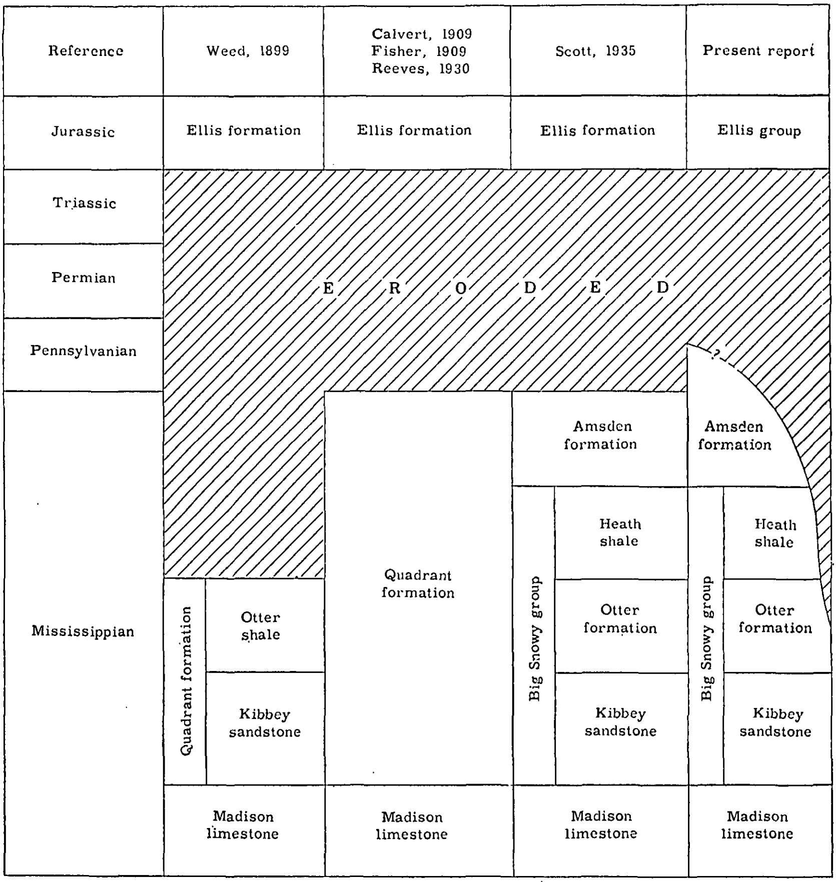


FIGURE 55.—The Madison limestone and the Kibbey sandstone in the canyon of Antelope Creek where the creek breaches the hogback of the Madison limestone. The contact of the formations is at the top of the ledge on which the men stand. View east across the canyon.

type area at Quadrant Mountain in northwestern Yellowstone Park are of middle Pennsylvanian age. However, the term Quadrant formation as formerly used in central Montana was applied chiefly to rocks of Mississippian age, although rocks of Pennsylvanian and Permian ages may possibly have been included. Scott (1935, p. 1022) also extended the use of the term Amsden formation by applying it to strata in central Montana that lie beneath the Ellis group and above the Big Snowy group. In contrast to earlier usage of the term Quadrant formation, the term Quadrant quartzite is restricted at the present time to beds in southwestern Montana that overlie the Amsden formation and are approximately equivalent to the Tensleep sandstone. In that area there are probably no strata present that are equivalent in age to the Big Snowy group of central Montana. A comparison of these terms as used by various authors in central Montana is shown in the chart on the following page.



Comparison of names used for upper Paleozoic formations in central Montana

(Dates refer to entries in bibliography)

According to Scott (1935, p. 1031) the Big Snowy group is not older than Warsaw nor younger than upper Chester series and probably ranges in age from middle Valmeyer to middle Chester. An erosional unconformity separates the Big Snowy group from the underlying Madison limestone. The following descriptions of stratigraphic sections (1 and 2) of the Big Snowy group and of the Amsden formation indicate the characteristics of these strata in the southwestern part of the Stanford-Hobson area.

Stratigraphic section 1.—The Big Snowy group north of Woodhurst Mountain, sec. 2, T. 14 N., R. 11 E.

	Feet
Amsden formation.	
Big Snowy group:	
Heath shale:	
Shale, black; mostly covered	175
Igneous rock in sill, mafic alkalic, deeply weathered	40
Shale, black; mostly covered; loose fragments of aragonite on covered slope	134
Igneous rock in sill, mafic alkalic, deeply weathered	60
Shale, black; mostly covered	127
Total, Heath shale	536
Otter formation:	
Limestone, gray, dense; shale partings	9.5
Covered slope	86
Shale, light greenish-gray; interbedded with beds of thin gray limestone	90
Limestone, gray, dense	4
Shale, light-gray, light purplish-gray, light greenish-gray	47
Limestone, dark-gray, dense, bedded	14.5
Shale, gray; partly covered	38
Covered slope	120
Covered slope with limestone fragments in the soil	137
Total, Otter formation	546
Kibbey sandstone:	
Sandstone, partly covered, yellow and yellowish-gray, fine-grained sandstone fragments exposed on soil covered slope	125
Siltstone, red; mostly covered	65
Total, Kibbey sandstone	190
Total, Big Snowy group	1,272
Unconformity.	
Madison limestone.	

Stratigraphic section 2.—Big Snowy group and Amsden formation on the southeast side of the Blacktail Hills, secs. 19 and 30, T. 15 N., R. 11 E.

Ellis group.	
Unconformity.	
Amsden formation:	
Limestone, gray to light-brown, dense; in beds as much as 3 ft thick	80
Covered slope	330
Sandstone, light-brown, friable, thin-bedded to massive	90
Covered slope	80
Sandstone, light-brown, friable, massive	120
Total, Amsden formation	700

Stratigraphic section 2.—Continued

	Feet
Big Snowy group:	
Heath shale:	
Shale, black; mostly covered, but exposures are occasionally found in animal diggings; fragments of aragonite veins are scattered on the ground	470
Total, Heath shale	470
Otter formation:	
Shale, pale-green and moderate-green; with limestone beds 2 to 6 in. thick at intervals of 5 to 10 ft	220
Shale, light-gray and pale-green; with limestone beds as much as 3 ft thick; 3-ft limestone bed at the top; grayish-yellow limestone beds interbedded with dark-gray shale and grading downward into the light-yellow sandstone beds of the Kibbey sandstone at the base	200
Total, Otter formation	420
Kibbey sandstone: Sandstone, light-yellow, fine-grained; mostly covered, the basal 25 to 50 ft is a red siltstone	250
Total, Kibbey sandstone	250
Total, Big Snowy group	1, 140
Unconformity.	
Madison limestone.	

KIBBEY SANDSTONE

The Kibbey sandstone consists of red siltstone, sandstone, and shale in the lower part of the formation and of yellow to white sandstone or siltstone in the upper part and ranges from 150 to nearly 300 feet in thickness. A fine- to medium-grained quartz sandstone in some exposures of the upper part of the Kibbey is friable and porous and is a potential reservoir rock for oil or gas. A bed of gypsum 20 feet thick, about 25 feet below the top of the Kibbey, is exposed in a prospect pit north of Wolf Butte (sec. 21, T. 16 N., R. 10 E.). The extent of the deposit is unknown. Elsewhere, thin lenses of gypsum were found in the Kibbey. The red sandstone, siltstone, and shale in the lower part of the Kibbey may represent the residual products formed by the erosion of the Madison limestone.

The Kibbey sandstone is formed from the first sediments to be deposited on the Madison limestone in this area after an interval of erosion, and variations in thickness of the Kibbey sandstone may be due in part to the irregular surface of the Madison limestone. The actual contact of the Madison and Kibbey is seldom visible, owing to the dense growth of conifers on the outcrops of these formations, so the physical evidence for an unconformity is rarely seen.

Completely exposed sections of Kibbey were not found in the area, and the formation has been widely mapped on the evidence of red or yellow sandstone fragments on the soil-covered slopes. The contact of the Kibbey and Otter formations, where visible, is gradational through a vertical interval of 10 to 15 feet. Thus, thin-bedded yellow sandstone grades upward into gray and black shale, interbedded with thin layers of impure yellow limestone. Where poorly exposed, the contact of the Kibbey and Otter formations was established by the highest occurrence of yellow sandstone fragments in the soil at approximately the correct distance above the Madison limestone.

OTTER FORMATION

The Otter formation consists of 400 to nearly 500 feet of shale and limestone. Grayish-green to moderate-green shale is very characteristic of the Otter formation. The formation also includes some light-gray to purplish shale and many thin beds of gray limestone, which are generally less than 3 feet thick. The limestone beds, some oölitic, commonly occur in the lower half of the formation. Prominent beds of green shale, described by some geologists as "vivid green shale," usually occur in the upper 200 to 300 feet. Similar green shale does not occur in any of the younger formations in this area, and therefore the top of this interval is an important horizon marker. A bed of black shale about 8 feet thick is present in the upper part of the Otter formation in the East Buffalo Creek section, (stratigraphic section 9, p. 428) and suggests interfingering of the typical Heath shale with beds typical of the Otter formation. Between Running Wolf Creek and Lone Tree Creek in the western part of the area the contact of the Otter and Heath is marked by a thin, gray, silty limestone that forms a minor ledge on soil-covered slopes.

Few good exposures of the Otter formation can be found, because it is composed of a nonresistant sequence of strata and the outcrops are usually mantled with soil. The Otter formation and the Heath shale form valleys and gentle slopes between more prominent outcrops of the Madison limestone and the Amsden formation. East of the Judith River most of the outcrops of the Otter formation occur in zones of faulting or deformation, and most of the measurements of sections of these strata are not reliable (fig. 56).

HEATH SHALE

Heath shale is the term applied to the youngest division of the Big Snowy group. At its type locality in the Big Snowy Mountains (Scott, 1935, p. 1028) the formation consists of black petroliferous shale and has several sandstone beds in the upper part. The formation in the area mapped includes, in addition to these strata, dense,

FIGURE 56.—The Otter and Swift formations exposed along a fault. The Otter formation forms the light-colored slopes on the right and is apparently overlain by a ledge formed by the Swift formation above the fault. View looking across Antelope Creek in sec. 16, T. 12 N., R. 13 E.

black and gray limestone beds, granular, brown sandy limestone beds; north of Wolf Butte it contains gypsum. Typically a soft, slope-forming formation, the Heath is generally covered with soil and is commonly partly concealed by talus and landslide material from the Amsden formation above it. The thickness of the Heath shale where measured along the north flank of the Little Belt Mountains west of the Judith River ranges from 536 to 470 feet (stratigraphic sections 1 and 2). The only exposure of Heath north of this outcrop belt is in the Skull Butte dome, where it is 466 feet thick as shown in stratigraphic section 3.

Stratigraphic section 3—Heath shale and Amsden formation at Skull Butte dome, sec. 6, T. 15 N., R. 12 E.

Swift formation.

Unconformity.

	Feet
Amsden formation:	
Limestone, gray, dense, bedded	51.5
Covered slope; red soil and red shale in the soil	220
Sandstone, red, arkosic; contains coarse grains of quartz, shell fragments, chert pebbles and limestone pebbles	15.5
Covered slope	67
Sandstone, brown, ferruginous, somewhat friable	5
Total Amsden formation	359

Stratigraphic section 3.—Continued

	Feet
Heath shale (Big Snowy group):	
Covered slope	57
Shale, black, fissile; lower part mostly covered	26
Sandstone, yellow to white, fine-grained, friable	16
Shale, black; partly covered	98
Sandstone, dark-brown, medium-grained; forms minor ledge	5
Shale, black, partly covered	34
Limestone, gray	1
Shale, black; partly covered	75
Igneous rock in sill, deeply weathered, mafic alkalic rock	27
Shale, black; interbedded with thin beds of gray chert; partly covered	32
Igneous rock in sill, deeply weathered, mafic alkalic rock	1
Shale, black; with several thin beds of gray chert; partly covered	38.5
Limestone, dark-gray	0.5
Shale, black; partly covered	55
Total, Heath shale	466
Otter formation.	

Near the intrusive igneous rocks of the Little Belt Mountains, the Heath shale contains at least two sills of igneous rock. The sills, where not too deeply weathered, form ledges on the soft-shale slopes and from a distance resemble sandstone beds. They may be traced along the outcrop for many miles. Although not included in the columnar section (pl. 46), the sills are mentioned in the descriptions of the stratigraphic sections.

Layers of aragonite, as much as 2 inches thick, that display columnar crystal structure were commonly observed in the Heath shale. The fact that unweathered fragments of these layers were found with brachiopods and other fossils attached to the upper surfaces, suggests that the layers are a primary depositional feature. The presence of such aragonite fragments on soil-covered slopes provides a good criterion for the identification of the Heath shale.

A relatively thin unit of Heath shale, only 270 feet thick, is overlain directly by an unusually thick unit of strata of the Ellis group where these formations were penetrated by the drill in sec. 32, T. 17 N., R. 14 E. This is interpreted as being due to pre-Ellis erosion which removed not only the Amsden formation, but also part of the Heath shale (fig. 57).

AMSDEN FORMATION

The type section of the Amsden formation, named by N. H. Darton (1906, p. 31–33), is in the Bighorn Mountains of Wyoming, where rocks of Mississippian(?) and Pennsylvanian ages are exposed, resting on the Madison limestone and overlain by the Tensleep sandstone. The term has since been applied by Scott (1934, p. 1020–1023) to rocks in a somewhat similar stratigraphic position in central Montana. Many geologists believe that the Amsden in the Stanford-Hobson

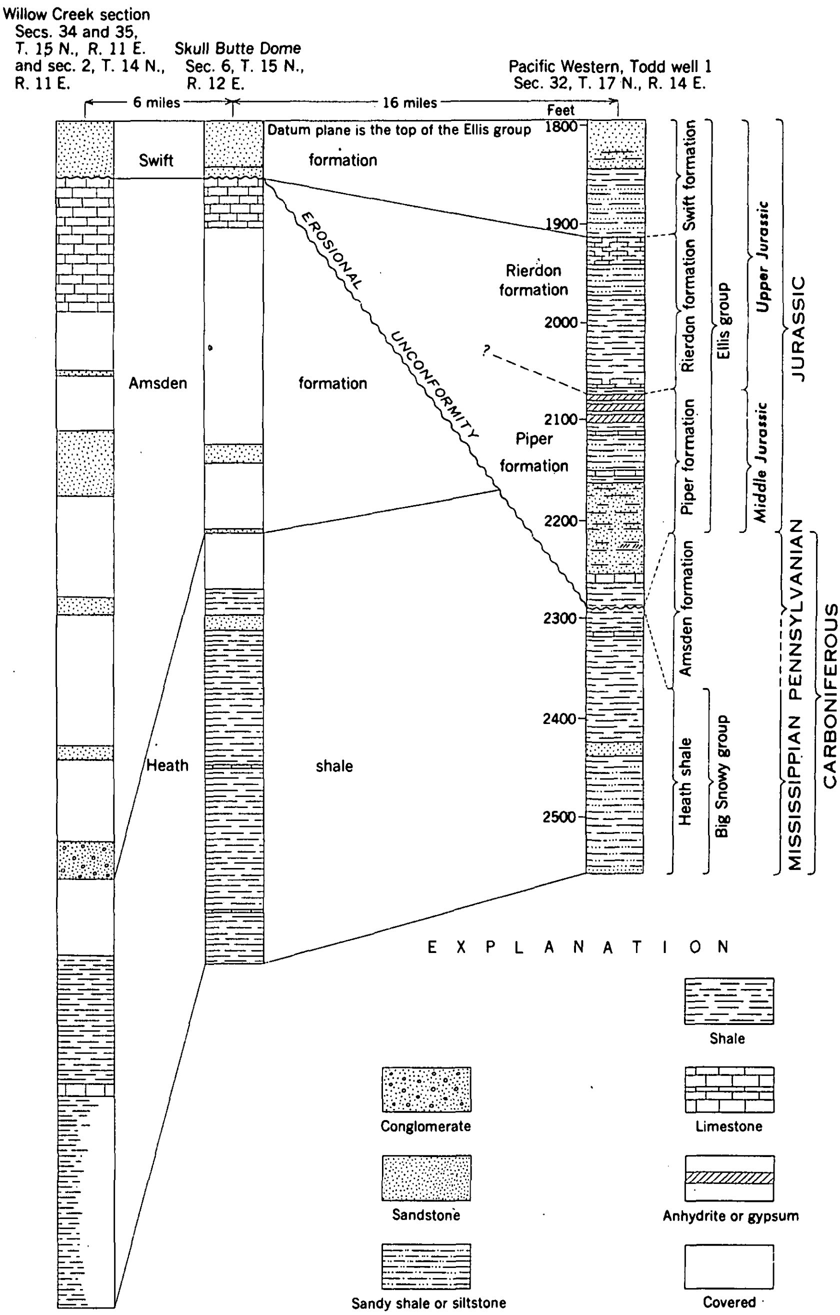


FIGURE 57.—Graphic diagram showing relationship of Heath shale, Amsden formation and Ellis group.

area is of Mississippian age, but the writer does not have sufficient evidence to prove or disprove this age assignment.

The Amsden formation in the Stanford-Hobson area is a mappable unit not defined by time boundaries and includes all the strata above the Big Snowy group and below the Ellis group. This definition is rather broad and includes strata of widely differing types and thicknesses. Stratigraphic sections of the Amsden formation measured in the Stanford-Hobson area range in thickness from 159 feet to 917 feet. Stratigraphic sections (4–10 and pl. 47) show the changes in thickness and lithologic character of the formation.

Stratigraphic section 4.—Upper part of Heath shale and Amsden formation east of Lone Tree Creek, sec. 3, T. 16 N., R. 10 E.

	Feet
Swift formation.	
Unconformity.	
Amsden formation:	
Covered slope; reddish-orange soil containing limestone fragments	88
Limestone, gray, dense; massive near the base	27
Covered slope; soil contains pale-yellow, dense, thin-bedded limestone fragments	28
Covered; red soil with red shale in the soil	77
Sandstone, red, ferruginous; partly covered	38
Sandstone, white, red, and yellow, crossbedded, friable; forms ledge	60
Total, Amsden formation	*318*
Heath shale (Big Snowy group):	
Shale, black; mostly covered	171
Gypsum, gray; forms ledge	22
(The lower part of the Heath shale was not measured)	
Total, incomplete section, Heath shale	193

Stratigraphic section 5.—Upper part of the Heath shale, the Amsden formation and lower part of the Ellis group, northwest of Surprise Creek, sec. 12, T. 16 N., R. 10 E.

	Feet
Ellis group:	
Sandstone, brown; contains chert pebbles and oyster shells (Not measured)	
Shale, brown; mostly covered	11
Limestone, brown, dense	2
Total, incomplete section, Ellis group	13
Unconformity.	
Amsden formation:	
Covered	26
Shale, red	16
Limestone, gray to white, dense	3
Covered	5
Limestone, very light-gray to pale-yellow, fine-grained crystalline	16
Covered; limestone fragments on the ground	40
Sandstone, red, coarse-grained, crossbedded; forms ledge	62
Total, Amsden formation	168

Stratigraphic section 5.—Continued

Heath shale (Big Snowy group):	Feet
Covered; sandstone talus from Amsden above	16
Shale, black; mostly covered	44
Limestone, brown, impure; weathers like sandstone	1
Shale, black, fissile	31
Limestone, brown, impure; contains silt and sand grains	1
Shale, black, fissile; covered at the base	77
(The lower part of the Heath shale was not measured.)	
Total, incomplete section Heath shale	170

Stratgraphic section 6.—Amsden formation south of Surprise Creek, sec. 18, T. 16 N., R. 11 E.

Ellis group.

Unconformity.

Amsden formation:	Feet
Covered slope	72
Limestone, gray, dense; forms a ledge	5
Covered slope	11
Limestone, crystalline; weathers brown	1.5
Shale, red; with some yellow and brown siltstone; mostly covered	32.5
Conglomeratic sandstone, brown, thin-bedded	1
Sandstone, red, locally mottled with white; ferruginous, crossbedded; somewhat friable	36
Total, the Amsden formation	159

Stratigraphic section 7.—Upper part of the Amsden formation along Dry Wolf Creek, sec. 5 T. 15 N., R. 11 E.

Ellis group.

Unconformity.

Amsden formation:	Feet
Limestone, gray, dense	22
Shale, red	28
Limestone, gray, dense	1
Shale, red	56
Sandstone, red	3
Sandstone, yellow, thin-bedded, ripple-marked; some red shale partings	22
Covered	50
Sandstone, yellow to white, medium-grained, massive to crossbedded, somewhat friable; forms ledge	22
Sandstone, brown; in beds 0.5 to 3 ft thick with black shale partings up to 4 in thick	54
Sandstone, brown to white, massive to crossbedded, fine-grained, somewhat friable	34
Total, incomplete section, Amsden formation, base not exposed	292

Stratigraphic section 8.—Upper part of the Heath shale and the Amsden formation, northwest side of Willow Creek, secs. 34 and 35, T. 15 N., R. 11 E.

Ellis group.

Unconformity.

Amsden formation:	
Limestone, gray, dense; in beds from 5 to 10 ft thick, with thin partings of red shale	135

Stratigraphic section 8.—Continued

	Feet
Amsden formation—Continued	
Covered; red soil with red shale in the soil	60.5
Sandstone, white to orange, friable	5
Covered	56
Sandstone, white, orange and red, medium-grained, bedded; color varies rapidly both horizontally and vertically	64
Covered	102
Sandstone, gray, in part massive, friable	18
Covered	133
Sandstone, brown, medium- to coarse-grained; weathers into large rough-surfaced blocks	15
Covered slope	82
Sandstone, red, coarse-grained, locally conglomeratic, hematitic; breaks into angular fragments	38.5
Total, Amsden formation	709
Heath shale:	
Covered slope; talus from the sandstone beds of the Amsden formation above	77
Shale, black, fissile; partly covered	131
Limestone, black, dense	10
(The lower part of the Heath shale is covered.) Total, incomplete section Heath shale	218

Stratigraphic section 9.—Ellis group, Amsden formation, and Otter formation (Big Snowy group), on East Buffalo Creek, secs. 11 and 14, T. 12 N., R. 16 E.

	Feet
Morrison formation.	
Ellis group:	
Swift formation:	
Sandstone, brown, fine-grained, glauconitic	75
Siltstone, grayish-yellow	5
Total, Ellis group	80
Unconformity.	
Amsden formation:	
Limestone, light-gray to pale grayish-orange, coarsely crystalline, fossiliferous	152
Covered slope	55
Limestone, light-gray, dense to fine-grained, granular	10
Covered slope	90
Limestone, light-gray, dense to fine-grained, granular; contains brachiopods	25
Covered slope	160
Sandstone, yellowish-orange, fine-grained, thin-bedded	9
Siltstone, red, and red, coarse-grained, arkosic and conglomeratic sandstone; contains fossil tree trunk	50
Limestone, light-gray, dense; forms ledge	4
Shale, red; with thin beds of red hematitic sandstone	50
Sandstone, grayish-orange, very fine grained	6
Shale, red, and red siltstone	106

Stratigraphic section 9.—Continued

	Feet
Amsden formation—Continued	
Sandstone, grayish-orange, very fine grained	22
Covered	105
Shale, red, and red silt; mostly covered	70
Sandstone, grayish-orange, quartzose, scattered limonite stains	3
Total, Amsden formation	917
Otter formation (Big Snowy group):	
Covered slope	90
Shale, light-green; interbedded with thin limestone beds	132
Shale, black, fissile; contains pyrite nodules weathering to limonite	8
Limestone, gray; in part oölitic, in part fragmental	2. 5
Shale, moderate-green; lower part mostly covered	47. 5
Limestone, light yellowish-gray, massive, dense	10
Covered slope	20
Limestone, light-gray, oölitic	5
Covered slope	25
Limestone, light yellowish-gray, somewhat mottled	8
Total, incomplete section, Otter formation	348
(The lower part of the Otter formation is absent, owing to faulting.)	

Stratigraphic section 10.—Upper part of the Otter formation and the Amsden formation, exposed on Antelope Creek, secs. 9 and 16, T. 12 N., R., 13 E.

Ellis group.

Unconformity.

	Feet
Amsden formation:	
Covered slope	100
Limestone, light-gray, dense; in beds 3 to 6 ft thick with red shale partings; partly covered	310
Sandstone, brown and yellow, medium-grained, friable, crossbedded; partly covered	70
Sandstone and conglomerate, red; partly covered	110
Limestone, gray, dense, cherty	30
Total, Amsden formation	620
Otter formation (Big Snowy group):	
Shale, green, olive-green, and brown, interbedded	5
Shale, green, purple, red, and gray, interbedded; and one thin bed of green limestone	15
Covered slope	95
Shale, moderate-green; interbedded near the top with thin beds of purplish limestone that contain pyrite crystals	185
Limestone, light-gray to purplish-gray, ripple-marked; in part a breccia, contains fossil fragments	3
Shale, moderate-green	27
Total (incomplete thickness), Otter formation	330
(Lower part of the Otter formation is not exposed, owing to faulting.)	

Two distinct lithologic units are recognizable in most stratigraphic sections of the Amsden formation that were measured in the Stanford-Hobson area. A lower, clastic unit contains red shale and siltstone, and red, brown, or white sandstone and conglomerate, and an upper unit contains thick beds of dense, gray limestone with some gray and red shale partings. Two additional units are present along Antelope and Wait Creeks, in T. 12 N., R. 13 E. At the base of the Antelope Creek section (section 10) a marine limestone underlies the lower, clastic unit, and at the top of the Wait Creek section (section 11) another clastic unit containing white sandstone and red shale is present. Locally, only one unit is present. In the area just west of Dry Wolf Creek, the upper unit (the top unit in stratigraphic section 7) thins westward and locally is completely missing. Where the hogback of the Amsden formation is crossed by Surprise Creek the lower, clastic unit consists of a red sandstone bed 62 feet thick (lowest unit in stratigraphic section 5). About half a mile south of Surprise Creek this red sandstone unit thins to 36 feet (lowest unit in stratigraphic section 6) and about 1 mile south of Surprise Creek the upper limestone unit is separated from the Heath shale by only a thin, covered interval. This thinning or disappearance of the lower, red sandstone may be evidence of an unconformity within the Amsden, or it may be due to nondeposition.

An unconformity that marks an important hiatus separates the Amsden formation from the overlying Ellis group. Over a large area this unconformity is characterized by progressive overlap of Jurassic rocks over older rocks of the Amsden formation, Big Snowy group, and Madison limestone. The unconformity does not show as an angular discordance at any exposure in the Stanford-Hobson area but was recognized by the differences in the lithology and fauna of the Amsden formation and the Ellis group. Pre-Ellis erosion has removed the Amsden formation from most of the area north of a line drawn just north of the towns of Geyser, Stanford, Moccasin, and Moore, as shown on figure 58. The Ellis group rests on the Heath shale in exposures along South Moccasin Mountain and also in the Pacific Western, Todd no. 1 well, sec. 32, T. 17 N., R. 14 E. (see table 2, p. 416). Data from the drillers' logs of other wells in the area are of questionable reliability, but it is estimated that from 180 to 210 feet of Amsden strata were found in the Nesson Rock Creek wells in sec. 36, T. 14 N., R. 16 E. A thickness map of the Amsden formation (fig. 58), based on the limited data now available, shows the distribution and thickness of the Amsden formation in the area mapped.

The Amsden formation is a resistant unit that holds up the outer hogback along the northeast flank of the Little Belt Mountains. At the eastern end of the Little Belt Mountains, at the western end of

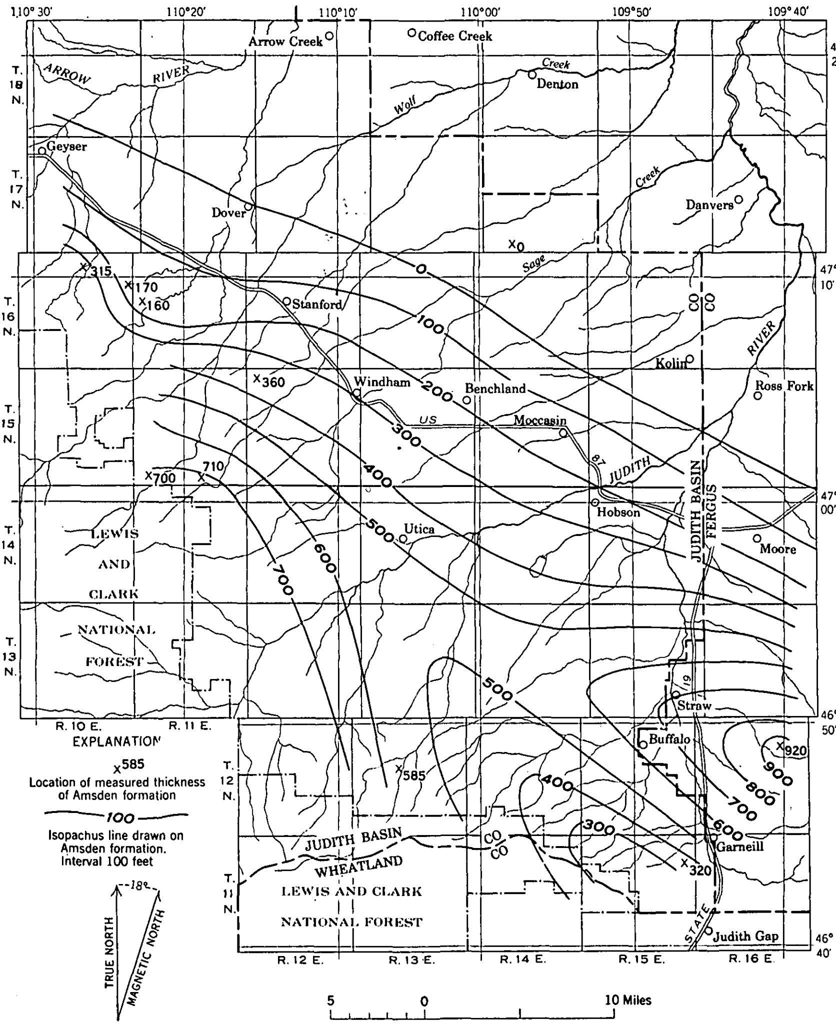


FIGURE 58.—Thickness map of the Amsden formation.

the Big Snowy Mountains, and along the Little Belt Mountains west of Antelope Creek the limestone beds of the upper unit of the Amsden formation generally form the highest ridges stratigraphically above the Madison limestone (fig. 59).

It is sometimes difficult to determine accurately the boundary of the Big Snowy group and the Amsden formation, because the units do not have constant lithologic characteristics. The contact of the Heath shale and the Amsden was generally chosen so as to place all thick units of black shale in the Heath. In the stratigraphic section exposed at Skull Butte (section 3, p. 423) a sandstone bed 16 feet thick and similar to sandstone beds in the Amsden formation is

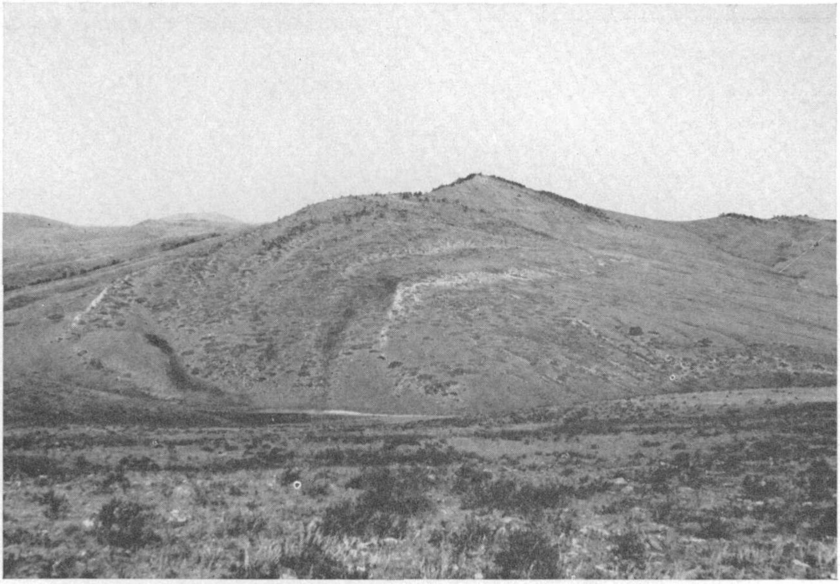


FIGURE 59.—Hogback formed by the Amsden formation. In the center of the picture the light-colored limestone beds in the upper part of the Amsden formation dip steeply to the right (north). View is west across Willow Creek in sec. 10, T. 18 N., R. 16 E.

overlain by a partly covered, but apparently thick, unit of black shale. It was decided to place both the sandstone and the black shale in the Heath shale, in order to preserve the lithologic definition of the Heath shale.

In some exposures the contact between the Heath shale and Amsden formation is not readily apparent. This suggests that the two formations may be transitional or interfingering. Walton (1946, p. 1304), following a different line of reasoning, considers that the absence of the Heath shale in localities near Judith Gap is a result of erosion after gentle folding and before the deposition of the Amsden. He thus places an erosional unconformity between the Heath and Amsden. Within the area studied, no physical evidence other than the local thinning and disappearance of Heath black shale below typical Amsden was found to confirm Walton's interpretation. Other structural and sedimentary explanations for the local thinning and disappearance of the black shale may be postulated. At East Buffalo Creek (stratigraphic section 9, p. 427), though no black shale is exposed, the lower Amsden is unusually thick, and it may be that part of the lower Amsden is equivalent to the Heath. There may even be units of black shale represented by the covered intervals in the Amsden section at this locality. Thinning and local absence of black shale at the east end of the Little Belt Mountains and in the Antelope Creek sections (stratigraphic section 10, p. 429) may be due to intense structural deformation that caused the nonresistant black shales to be either squeezed out or faulted out.

Though the contact of the Amsden formation and the Ellis group is usually easy to distinguish, in an area west of Antelope Creek and on both sides of the Judith River the contact is problematical. Stratigraphic section 11 (below) was measured along a branch of Wait Creek and illustrates this difficulty. In this section the upper part of the Amsden formation consists of limestone and sandstone beds that are overlain by 5 feet of conglomerate and by 43 feet of dark-red shale that contains 2 thin beds of limestone. This in turn is overlain by 5 feet of fossil-fragmental limestone and 15 feet of brown shale that contain Jurassic fossils. It is not certain that the conglomerate and the dark-red shale are correctly assigned to the Amsden. Imlay (Imlay and others, 1948, locality 20) recognized similar beds in the Piper formation along the Judith River, 3½ miles southwest of Utica, but he collected no fossils. This interval of redbeds has been tentatively included in the Amsden formation in the present report and is differentiated as Amsden(?) formation in stratigraphic section 11.

Another interpretation of this section is that the white friable sandstone at the top of the known Amsden formation is equivalent to the Tensleep sandstone, and the dark-red shale above this sandstone represents the Chugwater formation. These formations extend into southern Montana from Wyoming, but are not known to be present in the Judith Basin.

Throughout most of central Montana pre-Ellis erosion removed the Tensleep and the Chugwater, but it is quite possible that there are some remnants. This interpretation was applied by Gardner and others (1946, p. 50, 52) to similar strata exposed on the south flank of the Big Snowy Mountains.

Stratigraphic section 11.—Ellis group and the upper part of the Amsden formation on a branch of Wait Creek, sec. 1, T. 13 N., R. 12 E.

	Feet
Morrison formation.	
Ellis group:	
Swift formation:	
Sandstone, brown, medium-grained, unfossiliferous	15
Sandstone, gray, medium- to coarse-grained, crossbedded, glauconitic; contains chert pebbles and oyster shells	20
Sandstone, brown, fine- to medium-grained, thin-bedded, glauconitic	23
Conglomerate, brown; with chert pebbles, oyster shells and belemnites in a matrix of sand	7
Rierdon formation: Shale, brown, fossiliferous	15
Piper formation: Limestone, brown, granular, consisting of broken fossil fragments	5
Total, Ellis group	85
Unconformity.	

Stratigraphic section 11.—Continued

	Feet
Amsden(?) formation:	
Shale, dark red	13
Limestone, gray, dense	0. 5
Shale, dark-red	5
Limestone, gray, dense	0. 5
Shale, dark-red	24
Conglomerate, brown, angular chert and quartz pebbles in a matrix of sand	5
Total, beds of Amsden(?) age	48
Amsden formation:	
Sandstone, white, fine-grained, friable	3
Limestone, pale yellowish-gray to white, dense	1
Sandstone, white, fine-grained, friable, bedded	18
Limestone, pale yellowish-gray to white, dense	30
Sandstone, white, fine-grained, friable, only the top exposed.	
(The lower part of the Amsden formation was not measured.)	

ELLIS GROUP

Use of the term Ellis for rocks of Jurassic age dates back to some of the earliest geologic mapping in western Montana (Peale, 1893, 1896, Iddings and Weed, 1894). The name is taken from old Fort Ellis, near Bozeman, Montana, which is now considered to be the type locality. It is applied to marine Jurassic strata in Montana and adjacent areas of Wyoming. Cobban (1945) raised the Ellis formation of north-central Montana to group status and divided it into the Sawtooth, Rierdon, and Swift formations. Imlay and others (1948) applied the name Piper formation to strata in central Montana and showed that the Piper is correlative with Cobban's Sawtooth formation but of a different facies.

Stratigraphic section 12.—Swift and Morrison formations on the east side of Skull Butte dome, Sec. 5 T. 15 N., R. 12 E.

	Feet
Kootenai formation.	
Unconformity.	
Morrison formation:	
Coal	3
Covered, gray shale in the soil	80
Siltstone, brown, ferruginous, interbedded with gray shale	5
Covered, gray shale in the soil	13
Limestone, brownish-gray, impure	1
Covered, gray shale in the soil	11
Sandstone, brown, fine-grained	3
Shale, greenish	5
Covered, red shale in the soil	22
Limestone, gray, dense, interbedded with gray shale	3
Shale, varicolored, mostly covered	26
Total, Morrison formation	172

Stratigraphic section 12.—Continued

	Feet
Swift formation:	
Sandstone, brown, fine- to medium-grained, speckled with limonite	49
Sandstone, gray to brown, coarse-grained, speckled with dark minerals, including, probably, glauconite	10
Total, Swift formation	59
Unconformity.	
Amsden formation.	

Stratigraphic sections of the Ellis group where it was measured north of the Little Belt Mountains indicate that the sequence consists chiefly of medium- to coarse-grained brown glauconitic sandstone belonging to the Swift formation. Locally the sandstone contains chert pebbles as much as one inch in diameter and, in some exposures, an abundance of fragmental shells of oysters and other pelecypods. In exposures on a branch of Wait Creek (Stratigraphic section 11) and on Judith River, from 15 to 20 feet of brown fossiliferous shale and brown fragmental limestone that lie below the Swift formation probably represent the Rierdon and Piper formations. In exposures along the north flank of the Little Belt Mountains, the Ellis group is commonly about 60 feet thick and is rarely more than 100 feet thick. About 250 feet of Ellis was found in the Nesson Rock Creek wells, sec. 36, T. 14 N., R. 16 E.; 440 feet is exposed on the north side of South Moccasin Mountain (Calvert, 1909, p. 21); and 495 feet was found in the Pacific Western, Todd No. 1 well, sec. 32, T. 17 N., R. 14 E. (table 2, p. 416). These changes in thickness of the Ellis group are explained by the fact that the Ellis was deposited on an irregular surface that resulted from a long interval of erosion. The oldest Ellis strata were deposited on the low parts of the old erosion surface in the northern part of the area, and only the younger beds in the Ellis group covered higher parts of the surface, near the site of the present Little Belt and Big Snowy Mountains.

To the north the Ellis group rests on successively older beds of the Amsden formation and the Big Snowy group. For several miles north of the Little Belt Mountains the combined thickness of the Amsden formation and the Ellis group probably remains nearly constant, because the Ellis group thickens toward the north, whereas the Amsden formation thins northward and disappears. At some localities north and northwest of the area mapped the Ellis group rests directly on the Madison limestone. Although the occurrence of a hiatus is unquestioned, no angular unconformity was observed at the base of the Ellis and the only local criteria that indicates the position of the uncomformable contact are the marked faunal change between the Ellis and underlying beds and a conglomeratic sandstone at the base of the Swift formation where it rests on pre-Jurassic rock.

MORRISON FORMATION

The Morrison formation, an Upper Jurassic continental deposit, is recognizable over large areas in the Rocky Mountain Region. The name is derived from the town of Morrison, near Denver, Colorado, where the type section is exposed. The name was first used in central Montana in 1909 by Calvert (1909, p. 22–24) and Fisher (1909, p. 28–30), though in a more restricted sense than it is today. The top of the Morrison as then mapped was from 60 to 90 feet below the coal bed that is now included in the Morrison (Cobban, 1945, p. 1269; R. W. Brown, 1946). A comparison of the terms used by other geologists in mapping the strata above the Ellis and below the Colorado shale is shown in table 3.

TABLE 3.—*Comparison of names used for Upper Jurassic and Lower Cretaceous formations in central Montana*

Weed, 1899	Calvert, 1909 and Fisher, 1909	Reeves, 1930	Cobban, 1945, and present report
Colorado formation	Colorado shale	Colorado shale	Colorado shale
Dakota formation	Kootenai formation	Kootenai and Morrison formations undifferentiated	Kootenai formation
			Basal sandstone of Kootenai formation
--coal bed---	-coal bed---	-coal bed---	-coal bed---
Cascade formation	Morrison formation		Morrison formation
Ellis formation	Ellis formation	Ellis formation	Ellis group

In the Judith Basin area the Morrison formation consists of 150 to 300 feet of variegated shale and siltstone, thin nodular limestone, white and brown sandstone, black shale, and, near the top, coal or carbonaceous shale. Owing to the lenticular nature of the freshwater deposits in the Morrison, only such a general description of the lithologic character of the formation can be made.

Dinosaur bones, gastroliths, and fossils of fresh water clams are common in the Morrison formation. Stratigraphic sections 12 and 13 show the thickness and lithologic character of the formation at two localities in the area.

Stratigraphic section 13.—Morrison formation on the southeast side of Dry Wolf Creek, secs. 8 and 9, T. 15 N. R. 11 E.

	Feet
Kootenai formation.	
Unconformity.	
Morrison formation:	
Covered slope; sandstone talus from the basal Kootenai above	16
Shale, gray; partly covered	19
Sandstone, brown, silty	2
Shale, gray; partly covered	12
Limestone, gray, impure	1
Shale, gray	42
Sandstone, reddish-brown, silty	3
Shale, reddish and greenish	6
Siltstone; brownish-orange and thin gray limestone	5
Limestone, gray; somewhat chalky	4
Shale, reddish and greenish; partly covered	2
Sandstone, brown, well-cemented, medium-grained	1
Shale and siltstone, interbedded; mostly covered	47
Total, Morrison formation	160
Swift formation.	

The coal bed in the upper part of the Morrison has an average aggregate thickness of from 3 to 6 feet of coal, but locally is absent. A detailed description of the coal beds and of the mining districts once active in this area, is presented in the reports by Calvert (1909, p. 56–78) and Fisher (1909, p. 50–81). In these reports the coal bed was included in the Kootenai formation. In the area south and west of Skull Butte, a sandstone below the coal bed in the Morrison cannot be distinguished in mapping from the overlying basal sandstone of the Kootenai.

The Morrison formation generally forms gentle slopes and valleys between the ridges formed by the underlying Swift formation and the overlying basal sandstone of the Kootenai. For this reason, it is rarely well exposed. Where these bounding sandstone beds are steeply dipping, as along the mountain front, the Morrison is usually thin, probably because of squeezing that accompanied the structural deformation.

An erosional unconformity separates the Upper Jurassic Morrison formation from the Lower Cretaceous Kootenai formation. The relief on the surface of the unconformity is not great, but it is sufficient to cause the stratigraphic interval between the coal bed and the Kootenai formation to vary in thickness as much as 15 feet. Locally the coal bed is missing, owing to erosion.

KOOTENAI FORMATION

The use of the term "Kootenai" was extended into Montana from Canada, where it had long been applied to the basal lower Cretaceous strata. In central Montana the Kootenai formation is a continental deposit and includes all strata above the Morrison formation and below the marine Colorado shale. The Kootenai formation as mapped by Calvert (1909, p. 24–28) and Fisher (1909, p. 30–36) included the coal bed that in this report is placed in the Morrison and also from 60 to 90 feet of strata below the coal. Reeves (1930, p. 139), on the other hand, recognized the term Kootenai, but mapped the Morrison and the Kootenai formations as one undifferentiated unit.

The Kootenai formation consists of a sequence of red shale, siltstone, thin nodular freshwater limestone, and yellow and brown sandstone of continental origin that extends from the base of a prominent sandstone bed, about 100 feet thick which overlies the coal bed in the Morrison to the base of the thin-bedded brown sandstone and black, sandy shale that characterize the lower part of the Colorado shale. In some areas limestone pebble and siltstone pebble conglomerate beds are abundant in the Kootenai. The observed thickness ranges from 350 to 550 feet. Stratigraphic section 14 shows the detailed character of the formation. Dip readings at the base of the section measured 22 degrees, whereas at the top of the section they measured 16 degrees. The thickness of the section was calculated on the assumption that the dip gradually changed from the maximum to the minimum angle.

Stratigraphic section 14.—Kootenai formation exposed on east side of Skull Butte dome, sec. 5, T. 15 N., R. 12 E.

Colorado shale.	
Kootenai formation:	*Feet*
Shale, red; mostly covered; red soil with red shale in soil	185
Shale, brown, calcareous; interbedded with limestone, impure gray	10. 5
Covered; red, sandy soil	52
Sandstone, light brown; speckled with limonite; partly covered	10
Covered slope; red soil	31
Sandstone, brown, fine- to medium-grained; containing siltstone and limestone pebbles; partly covered	5
Covered slope; red soil	19
Sandstone, brown	0. 5
Covered slope; red soil	41
Sandstone, brown, medium- to coarse-grained; containing pebbles of limestone and siltstone	5
Covered slope	33
Sandstone, brown, fine-grained, thin-bedded	4. 5
Red shale; mostly covered; red soil	15
Limestone; gray; with limestone-pebble conglomerate at top	3
Siltstone, gray, calcareous, thin-bedded; weathers brown	2. 5
Covered	13
Sandstone, gray, "salt and pepper" appearance, medium- to coarse-grained, crossbedded; weathers into large blocks	122
Total, Kootenai formation	552
Unconformity.	
Morrison formation.	

The most prominent bed persistent enough to be useful in mapping the Morrison and Kootenai part of the stratigraphic column is a sandstone bed averaging 100 feet in thickness that is found at the base of the Kootenai. For convenience in mapping and in order to obtain the control that is necessary to determine geologic structure this basal sandstone bed was mapped as a separate unit. It consists of a medium- to coarse-grained, impure, dark-brown to gray, crossbedded sandstone and chert-pebble conglomerate, which weathers into large angular blocks. It is continental in origin and somewhat lenticular in nature, but is persistent enough in the area of outcrop to be readily identified. A similar sandstone of approximately the same age, in the Cat Creek oilfield is known by drillers as the Third Cat Creek sand, and another in the Cut Bank oilfield is called the Cut Bank sand. Sandstone was not reported at this zone in the drill cuttings from the Pacific Western, Todd no. 1 well, sec. 32, T. 17 N., R. 14 E., (table 2) but this may be due to poor samples, because the electric log of this, well shows a deflection characteristic of a sandstone at this horizon.

Many of the early oil test wells in this area were drilled only deep enough to test the Kootenai, because the sandstone beds in the Kootenai were known to produce oil in the Cat Creek area and the red shale of the Kootenai made a good horizon marker that was readily recognized by the drillers.

COLORADO SHALE

The Colorado shale and the Telegraph Creek formation underlie most of the Stanford-Hobson area. The soft shale strata that charac terize these formations are easily weathered, and as large parts of the outcrop area are blanketed by deposits of terrace gravel, there are few good exposures of the bedrock. In other areas, where well exposed, the Colorado shale can be subdivided into smaller units of formational rank (Cobban, 1951). However, in the Stanford-Hobson area the unit is poorly or not at all exposed in the uplands, and it was not feasible to map individual formations.

The Colorado shale includes strata of both Early and Late Cretaceous age. Cobban and Reeside (1951) have demonstrated the existence of an Early Cretaceous fauna in the Mowry shale and equivalent rocks in Colorado, Wyoming and Montana. This places the Early–Late Cretaceous boundary between the rocks probably equivalent to the Mowry shale and the rocks probably equivalent to the Belle Fourche shale; the boundary is about 850 feet above the base of the Colorado shale in the Stanford-Hobson area.

ROCKS EQUIVALENT TO THERMOPOLIS SHALE

The lowest 720 feet of strata in the Colorado shale consist of dark-gray to black fissile shale, sandy shale, and thin beds of brown sandstone that are generally not very fossiliferous and are similar in lithology and probably equivalent in age and stratigraphic position to the Thermopolis shale in the Bighorn Basin of northwestern Wyoming. The contact of the Colorado shale and Kootenai formation is marked in the Stanford-Hobson area by a thin-bedded sandstone at the base of the strata equivalent to the Thermopolis shale. This sandstone is very fine-grained, with thin yellow- and brown-colored laminae and prominent fucoidal markings. It is generally underlain by red shale and overlain by black shale. Where well exposed, this sandstone forms a minor ledge, but it was frequently necessary to search for fragments of this sandstone in the soil in order to locate the Kootenai and Colorado shale contact.

The following stratigraphic sections (15 and 16) of strata equivalent to the Thermopolis shale are composite sections made up of several incomplete sections measured west and northwest of Geyser.

Stratigraphic section 15.—The part of the Colorado shale probably equivalent to the Thermopolis shale and the lower part of the Mowry shale, secs. 26, 34, and 35, T. 18 N., R. 9 E.

Colorado shale:	
Rocks probably equivalent to the lower part of the Mowry shale:	*Feet*
Tuff, bentonitic, white to light gray, massive	8
Covered slope; soft, gray clay soil	24
Bentonite, pale-olive-yellow	8
Total, incomplete thickness, rocks probably equivalent to part of the Mowry shale	40
Rocks probably equivalent to the Thermopolis shale:	
Shale, black, partly covered	11
Shale, silver-gray; contains fish scales; resembles the Mowry shale	2
Covered slope	11
Igneous rock in sill; deeply weathered mafic alkalic	2
Shale, black; mostly covered	66
Shale, light-gray, bentonitic	4. 5
Shale, dark-gray	6. 5
Sandstone, gray, mottled; medium-grained; forms ledge	3
Shale, dark gray; interbedded with thin sandstone beds, mostly covered	80
Sandstone, brown, medium-grained, impure; forms ledge	2. 5
Shale, gray, sandy	8
Sandstone, brown, medium-grained, impure; forms ledge	6. 5
Covered slope; talus from overlying sandstone beds	207
Shale, black, fissile	58
Igneous rock in sill; deeply weathered mafic alkalic	3
Shale, dark-gray; interbedded with thin sandstone beds; partly covered	12
Sandstone, thin hard	1
Covered slope; probably dark-gray shale	15. 5
Sandstone, gray and brown mottled, fine-grained	0. 5

Stratigraphic section 15.—Continued

	Feet
Colorado shale—Continued	
Covered; probably dark gray shale	21
Igneous rock in sill; fine-grained, hard	3
Shale, dark-gray; interbedded with thin sandstone beds; partly covered	30. 5
Sandstone, gray and brown mottled; contains *Inoceramus*	1
Shale, black, interbedded with thin sandstone beds; partly covered	104
Igneous rock in sill; deeply weathered mafic alkalic	3
Shale, black, sandy; interbedded with thin beds of laminated brown and yellow sandstone; mostly covered	52
Sandstone, brown and yellow laminae, thin-bedded, fine-grained, fucoidal markings	2. 5
Shale, dark-gray, fissile	8. 5
Sandstone and sand, gray, massive, friable	5. 5
Total,[1] rocks probably equivalent to the Thermopolis shale	720
Kootenai formation.	

[1] Does not include thickness of sills of igneous rock.

Stratigraphic 16.—The part of the Colorado shale probably equivalent to the lower part of the Mowry shale and the upper part of the Thermopolis shale, secs. 30 and 31, T. 18 N., R. 10 E.

	Feet
Colorado shale:	
Rocks probably equivalent to the lower part of the Mowry shale:	
Tuff, bentonitic; weathers white	7. 5
Bentonite, gray	15. 5
Shale, gray, bentonitic	4
Bentonite, gray; weathers white	9
Total incomplete thickness, rocks probable equivalent to part of Mowry shale	36
Rocks probably equivalent to the upper part of the Thermopolis shale:	
Covered slope	46
Sandstone, medium-grained, crossbedded	2
Shale, dark gray, partly covered	18. 5
Bentonite, gray	15. 5
Covered interval; overlies a sandstone bed believed to be equivalent to the 2.5-foot thick ledge forming sandstone about 186 feet below the top of the Thermopolis shale equivalent in Stratigraphic section 15	118
Total, incomplete thickness, rocks probably equivalent to upper part of the Thermopolis shale	200

ROCKS EQUIVALENT TO MOWRY SHALE, BELLE FOURCHE SHALE, AND GREENHORN LIMESTONE

Rocks probably equivalent to the Mowry shale, the Belle Fourche shale, and the Greenhorn limestone overlie the Thermopolis-shale equivalent in the Stanford-Hobson area. The Mowry shale at its type locality in Wyoming consists of silicious shale that weathers silver gray and contains numerous fish scales and some thin beds of bentonite. Exposures of the Mowry equivalent in the north bank of Arrow Creek northeast of Geyser, however, consist of approximately 40 feet of bentonite, tuffaceous shale and porcelanite in the lower part, overlain by about 95 feet of gray and brown soft interbedded shale, sandstone and bentonite in the upper part. The predominantly bentonitic lower part weathers to a distinctive white or light-gray outcrop what was mapped locally for structural control. W. A. Cobban measured a section (stratigraphic section 17) of Mowry shale equivalent in 1949 on the north side of Arrow Creek, about 5 miles northeast of Geyser, Montana. In 134 feet 5 inches of section only 3 beds in the upper part correspond in lithology to the Mowry shale of the type locality.

Stratigraphic section 17.—Part of the Colorado shale measured on the north side of Arrow Creek, five miles northeast of Geyser, Montana, secs. 13 and 24, T. 18 N., R. 10 E.

(Measured by W. A. Cobban)

	Feet	*Inches*
Colorado shale:		
Rocks probably equivalent to lower part of Carlile shale (Blue Hill shale member):		
Shale, dark gray, noncalcareous, poorly exposed (not measured).		
Rocks probably equivalent to Greenhorn limestone and basal Carlile shale (Fairport chalky shale member):		
Shale, dark gray, weathering orange brown, soft; forming slope; contains several thin beds of creamy-gray bentonite and a few thin shaly lenses of limestone weathering orange brown; limestone contains fish scales, and a small smooth oyster was found	14	6
Shale, gray, weathering orange-tan, highly calcareous; some chalky layers; contains thin lenses of gray limestone; forms a prominent cliff; unit contains fish scales, shark teeth, a small smooth oyster, and fragments of *Inoceramus labiatus* (Schlotheim)	10	0
Shale, dark-gray, calcareous	17	0
Shale, dark-gray, calcareous; grading upward into bluish-black, fissile, less calcareous shale	25	6
Bentonite, light-olive; passing upward into medium-gray bentonite; inconspicuous	3	6
Shale, calcareous, dark-gray, weathering medium-gray	13	6
Limestone concretions, medium-gray; weathering to lighter gray; closely spaced; highly septarian with thick veins of brown and pale-yellow calcite	1	3
Total, rocks probably equivalent to Greenhorn limestone and basal Carlile	85	3

Stratigraphic section 17.—Continued

Colorado shale—Continued	*Feet*	*Inches*
Rocks probably equivalent to the Belle Fourche shale and lower part of Greenhorn formation:		
Shale, dark bluish-gray; lower part fissile; upper part sandy and massive containing hard, tan-weathering lenses of fine- to very fine-grained sandstone as much as 3 inches in thickness. Near top was found one fragment of *Metoicoceras* sp	30	0
Shale and mudstone, dark-gray to bluish-gray, more or less sandy, firm; cut by thin sandstone dikes	26	0
Bentonite, creamy	1	0
Shale, dark bluish-gray, base and top sandy	8	9
Bentonite, creamy; micaceous at base	----	6
Sandstone and shale, gray to dark-gray, very interbedded	6	6
Bentonite, yellow cream	1	0
Sandstone and shale, weathers, bluish; much interbedded; resistant, forming ledge	3	0
Shale, dark bluish-gray; contains thin lenses of hard, very fine-grained sandstone	12	9
Bentonite, creamy	----	6
Shale, dark bluish-gray; contains thin lenses of hard, very fine-grained sandstone	7	9
Shale, brown, bentonitic; locally, creamy bentonite	1	0
Total, rocks probably equivalent to the Belle Fourche shale and lower part of Greenhorn formation	98	9
Rocks probably equivalent to Mowry shale:		
Shale, dark-gray, weathering light bluish gray, hard, finely sandy; forms ledge	2	6
Bentonite, creamy gray	2	9
Shale, dark-gray, hard	0	8
Bentonite, creamy	0	7
Sandstone, gray, weathering to prominent brown ledge, very fine-grained and hard, shaly, ripple-marked; contains abundant fish bones and teeth	1	6
Shale, dark-gray, hard, finely sandy; weathers light gray, contains some fish scales and 2 thin layers of bentonite	10	6
Sandstone, salt and pepper, coarse-grained, massive, hard; contains abundant fish bones; dip 3° 15′ N	0	3
Bentonite, creamy-gray	1	0
Sandstone, gray; weathering to brownish ledge, fine- to very fine-grained; in thin ripple-marked layers separated by films of dark shale	2	6
Sandstone, gray, fine- to very fine-grained, soft, thin-bedded	6	0
Bentonite, creamy-gray	1	0
Sandstone, gray, fine- to very fine-grained, soft, thin-bedded	18	0
Sandstone and shale, gray to brownish, soft; much interbedded; contains minute carbonaceous flakes	27	0

	Feet	Inches
Colorado shale—Continued		
Rocks probably equivalent to Mowry shale—Continued		
Bentonite, creamy	0	4
Shale, brownish to gray, soft, finely sandy; much interbedded shaly very fine-grained sandstone and 2 thin layers of bentonite	16	3
Shale, dark-gray, weathering light gray; very finely sandy, hard; forming ledge; contains a few fish scales	2	9
Shale, dark-gray, firm, very finely sandy	2	7
Bentonite, creamy gray to medium gray	6	3
Bentonite, tuff, and porcellainite, creamy, massive; forms prominent white outcrop; contains very few fish scales	25	0
Bentonite, olive grading up into yellow and cream; forms prominent light-gray barren gumbo	9	0
Total, rocks probably equivalent to the Mowry shale	134	5
Rocks probably equivalent to the Thermopolis shale:		
Shale, dark bluish-gray, hard, very finely sandy	11	0
Sandstone, gray to brownish, fine- to very coarse-grained; some parts containing black chert pebbles as much as three-fourths of an inch in diameter; friable, porous, crossbedded; in lenses as much as 1.5 feet thick separated by dark-gray shale; forms a ledge	2	9
Shale, dark bluish-gray, hard, very finely sandy	12	6
Sandstone, gray, weathering brown, fine-grained; with very fine to coarse streaks; thin-bedded, ripple-marked, crossbedded, hard; forms ledge; contains some fish bones	1	3
Shale, dark bluish-gray, hard, very finely sandy; contains many lenses of very fine-grained sandstone (not measured).		

Overlying the Mowry shale equivalent is a unit consisting of 98 feet and 9 inches of dark-gray or dark bluish-gray fissile shale containing several thin bentonite beds and, near the top, thin mudstone beds that are cut by fine-grained sandstone dikes. This unit is considered by Cobban (oral communication) probably to be equivalent to the Belle Fourche shale and basal part of the Greenhorn formation in the Black Hills.

Rocks equivalent to the Greenhorn limestone and basal Carlile shale (Fairport chalky shale member) are included by Cobban in one unit 85 feet 3 inches thick. The upper 24½ feet of this unit consists of gray calcareous shales and thin lenses of gray limestone which weather into conspicuous orange-colored outcrops that are locally mappable. The lower part of the unit consists chiefly of dark-gray calcareous shale with a minor amount of bentonite and concretionary limestone. Cobban (1951, p. 2190) reports that shale similar to the upper 14½ feet (stratigraphic section 17) of this unit yields fossils of Fairport age near Mosby, Montana.

ROCKS EQUIVALENT TO THE CARLILE SHALE AND NIOBRARA FORMATIONS

Rocks probably equivalent to the rest of the Carlile shale and to the Niobrara formations were not measured in the Stanford-Hobson area, because the low dips, wide outcrop bands, and lack of continuous exposures make detailed measurements impractical. Sections measured by W. A. Cobban indicate that 310 feet of Carlile shale and 402 feet of Niobrara formation are present near Mosby, Montana, and from 157 to 180 feet of Carlile shale and as much as 635 feet of Niobrara formation are present in northwestern Montana (Cobban, 1951, p. 2190–2193). Though the Mosby section is nearly 90 miles east of the Stanford-Hobson area, measurements from wells of the latter area indicate that similar thicknesses of Carlile and Niobrara equivalents are present here. The Carlile-shale equivalent consists chiefly of dark bluish-gray to black fissile shale. From 30 to 45 feet above the base of the section of equivalent strata there is a zone of red ironstone concretions. Still higher in the section, there is a zone of light-yellow limestone concretions, and near the top, a zone of gray limestone concretions occurs. The formation is sparsely fossiliferous. The Niobrara formation equivalent consists chiefly of dark-gray fissile shale that is calcareous in the upper part, contains many thin beds of bentonite, and yields *Baculities codyensis* Reeside and fragments of a large *Inoceramus* commonly having attached clusters of *Ostrea congesta* Conrad.

TELEGRAPH CREEK FORMATION

The name Telegraph Creek formation is applied to transitional beds between the underlying Colorado shale and the overlying Eagle sandstone. The formation is 160 feet thick in the northeastern part of the Stanford-Hobson area and consists of yellow-weathering dark-gray to dark-brown shale and sandy shale. Because the base of the Telegraph Creek is seldom exposed, the formation was not separated from the Colorado shale in mapping. Faunal studies, however, indicate that the Telegraph Creek is more closely allied to the overlying Eagle sandstone than to the Colorado shale and it is therefore assigned to the Montana group.

Stratigraphic section 18.—Telegraph Creek formation on the west side of the Judith River, sec. 5, T. 18 N., R. 16 E.

	Feet
Eagle sandstone.	
Telegraph Creek formation:	
Shale, dark brown, slightly sandy; a 4-inch bed of aragonite with cone-in-cone structure at the base	50
Shale, grayish brown, soft; interbedded with several thin beds of hard, brown siltstone	33
Siltstone, brown, hard	5. 5
Shale, dark gray	30. 5

Stratigraphic section 18.—Continued

	Feet
Telegraph Creek formation—Continued	
Sandstone, white, medium-grained, thinly laminated, forms ledge	1
Sand, soft interbedded with shale, brown	40
Total, Telegraph Creek formation	160
Colorado shale.	

EAGLE SANDSTONE

The Eagle sandstone, which was first named by Weed (1899a) for exposures along the Missouri River near the mouth of Eagle Creek, is well exposed in the northeastern part of the Stanford-Hobson area (fig. 60). The measured section (section 19) that is given is exposed

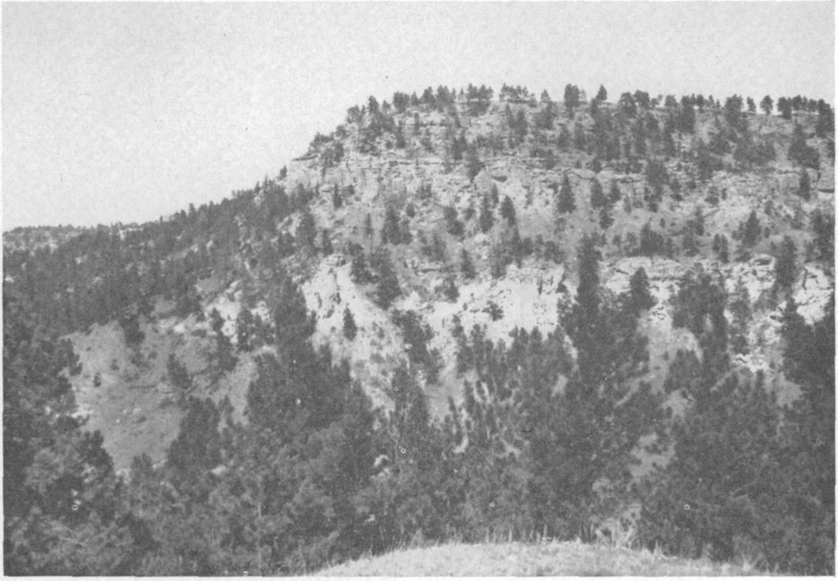


FIGURE 60.—Three units in the Eagle sandstone. The top unit is a massive ledge-forming sandstone; the middle unit is a slope-forming shale; and the basal unit is a second ledge-forming sandstone, which here overlies the slope formed by the Telegraph Creek formation. View is north in sec. 10, T. 18 N., R. 16 E.

in cliffs along the west side of the Judith River. There, the Eagle consists of a lower, white and brown, concretionary, cliff-forming sandstone, 72.5 feet thick; a middle, slope-forming unit of gray shale, sandy shale, and thin lignite seams, 66 feet thick; and an upper, brown and white, cliff-forming sandstone 110.5 feet thick, making a total of 249 feet. The sandstone beds are medium- to coarse-grained, soft, and friable and weather readily into grotesque monuments and pinnacles. The following section shows the detailed character of the formation.

Stratigraphic section 19.—Eagle sandstone on the west side of the Judith River, sec. 6, T. 18 N., R. 16 E.

Claggett shale.	
Eagle sandstone:	*Feet*
Sandstone, brown and white, massive, friable	55
Coal	0.5
Sandstone, brown and white; the upper part forms a massive white cliff	55
Shale, gray; interbedded with sand; partly covered	22
Shale, gray; interbedded with coal seams; partly covered	14
Covered; forms a slope	30
Sandstone, brown and white, fine- to medium-grained, friable; contains a few black chert grains in addition to quartz; forms a prominent cliff	72.5
Total, Eagle sandstone	249
Telegraph Creek formation.	

CLAGGETT SHALE

The Claggett shale is present in the vicinity of Judith Gap, and there is one small exposure in the northeastern part of the area. However, the exposures are inadequate for accurate measurement of the thickness or for a detailed study of the lithology. The Claggett consists of a dark gray or brown marine shale that forms valleys and weathers into gentle slopes. Near Mosby the formation was measured by Cobban (oral communication), and its thickness was determined to be 430 feet. Bowen states (1915, p. 98–99) that the Claggett is about 500 feet thick along the Missouri River.

JUDITH RIVER FORMATION

The lower part of the Judith River formation is present in Judith Gap, but the exposures are so poor and scattered that mapping it is rather indefinite, and measurement of the section is impossible. Where visible, it consists of beds of soft, friable, gray sandstone similar to those in the Eagle sandstone. To the east, where Cobban (oral communication) measured this formation near Mosby, he found it to be 273 feet thick. To the north, along the Missouri River, Bowen (1915, p. 100–101) reports a thickness of about 620 feet.

TERRACE GRAVELS AND ALLUVIUM

GENERAL DESCRIPTION

Gravel deposits that represent a succession of several terrace surfaces are present in the interstream areas of the Judith River and Arrow Creek drainage basins. A comparison of the terrace designations for gravel deposits that mantle the succession of terrace surfaces as applied in this report and by Alden (1932) is shown in table 4.

Gravel deposits that are small isolated remnants of the highest and oldest surface, the number 1 terrace, are present at scattered localities in the area. These remnants consist of coarse, consolidated gravel beds and at a former time may have been part of an extensive terrace surface that covered a large portion of the area. The second oldest deposit of gravel, the number 2 terrace, is the most extensive of those preserved in the area and, at one time, must have blanketed nearly all the lowlands of Judith Basin. Local variations of the main terrace surface, some which can be seen to merge with the main surface, are designated by a plus (+) or a minus (−) sign following the terrace number, according to whether they are higher or lower than the main surface. The number 2 terrace is so well preserved that many places show no signs of erosion. Younger deposits that occur on lower terrace surfaces, the number 3 and 4 terraces, are locally preserved

TABLE 4.—*Comparison of terrace designations as used in this report with those used by W. C. Alden in 1932*

Present report	Alden (1932)
Number 1 terrace (Gravel deposits on the highest and oldest terrace surface. Map symbol: Qt_1.)	Number 1 bench (Remnants of first or high main bench of stream terraces and alluvial fans. Map symbol: Tt^1.)
Number 2+ terrace (Gravel deposits slightly higher than the main second highest or most extensive terrace surface. Map symbol: Qt_{2+}.)	
Number 2 terrace (Gravel deposits on the main second highest or most extensive terrace surface. Map symbol: Qt_2.)	Number 2 bench (Remnants of second or medial bench of stream terraces and alluvial fans. Map symbol: QT^2.)
Number 2− terrace (Gravel deposits slightly lower than the main second highest or most extensive terrace surface. Map symbol: Qt_{2-}.)	
Number 3 terrace (Gravel deposits on the third highest terrace surface. Map symbol: Qt_3.)	Number 3 bench (Remnants of third or lowest bench of stream terraces and alluvial fans. Map symbol: Qt^3.)
Number 4 terrace (Gravel deposits on the main fourth or lowest terrace surface. Map symbol: Qt_4.)	
Number 4− terrace (Gravel deposits slightly lower than the main fourth or lowest terrace surface. Map symbol: Qt_{4-}.)	
Alluvium (Gravel deposits in the flood plains of the modern streams. Map symbol: Qal.)	Alluvium (Modern stream gravels and alluvial fans. Map symbol: Qal.)

along the main streams, such as Judith River, Ross Fork, Wolf Creek and Arrow Creek. These terraces were never much more extensive than at the present. The youngest and lowest deposit of gravel found in the flood plains of the modern streams is mapped as alluvium. Along parts of the valley of the Judith River, the two or three minor terrace surfaces too small to be mapped separately are included with the alluvium.

The lithologic composition and texture of the gravels of the terraces are functions of their proximity to the mountains and of the lithologic types exposed in the adjacent parts of the mountains. Opposite the higher parts of the Little Belt Mountains where intrusive igneous rocks are exposed, the gravels contain as much as 60 percent of igneous rocks. Parts of the Little Belt Mountains where no igneous rock is exposed yield gravels containing as much as 100 percent of limestone boulders. Sandstone boulders make up less than 25 percent of most gravel samples. North of Arrow Creek and opposite the Highwood Mountains dark-colored weathered igneous rocks make up nearly 100 percent of the gravels. The size of the gravel boulders varies locally but, in general, increases toward the mountains and decreases from them. Except near the mountains and along some stream channels, the gravels generally have less than 10 percent of the material larger than 6 inches in diameter.

Long narrow gravel ridges, occurring in some localities, are from 3 to 5 feet above the general level of the number 2 terrace surface and from 30 to 50 feet wide. These features were first observed on the aerial photographs, where they appear as straight lines trending northeast-southwest and parallel to the trend of igneous dikes that occur in the same general area. On photographs the similarity in appearance of these gravel ridges to igneous dikes led to an investigation that failed to demonstrate any definite relationship between the two features. The origin and significance of the gravel ridges is not clear.

AGE OF THE TERRACE SURFACES

Evidence in this area for the exact age determination of the various terrace surfaces is scanty. Alden (1932 p. 13) correlates the highest terrace surface with the surface on the Flaxville gravel in northeastern Montana, which he considers to be late Tertiary in age. There is no paleontological evidence in the Stanford-Hobson area for the age of this or for any of the lower surfaces. Because of the difficulty of correlating the high terrace in this area with anything so far away as the Flaxville gravel, no attempt has been made to distinguish Tertiary from Quaternary terrace surfaces. All surfaces have been assigned to the Quaternary.

Physical evidences that at least the number 2 terrace is pre-Wisconsin in age are shown by involutions. Involutions are a type of surficial deformation in which the stratified material to a depth of 5 or 10 feet below the surface of the ground is distorted into irregular structures, some of which resemble anticlines and synclines. Examples of these structures are shown in figure 61. In roadcuts along State

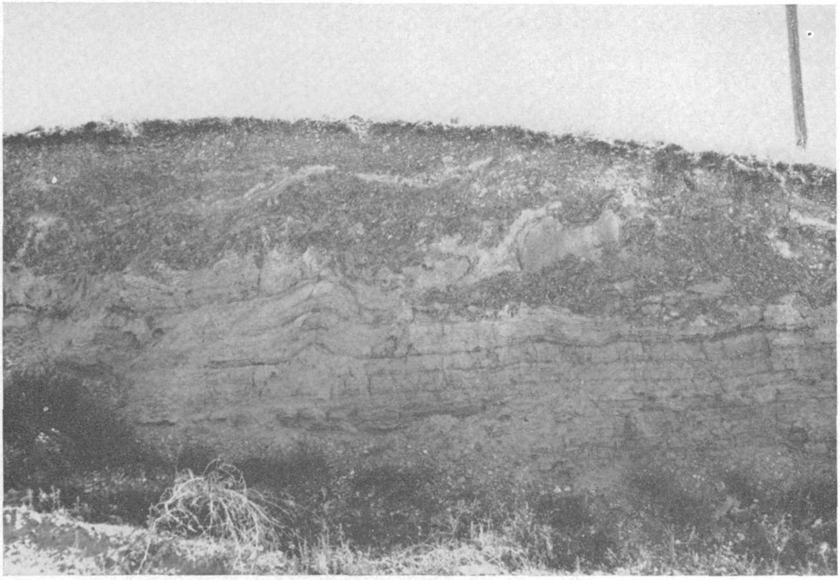


FIGURE 61.—Involution, a type of surficial deformation that is due to frost action. Deformation has affected both the terrace gravel and the underlying Eagle sandstone, as seen in 10-foot deep roadcut, about 3 miles northeast of Denton, in sec. 7, T. 18 N., R. 15 E.

Route 19 west of Moore the soil and gravel on the number 2 terrace have been deformed to a depth of 6 or 8 feet. In roadcuts about 3 to 4 miles northeast of Denton the soil, gravel, and the underlying Eagle sandstone were observed to be deformed to a depth of about 8 feet. The areas in which these structural features were observed have not been subjected to continental glaciation, recent tectonic deformation, landslide movements, or to swelling of beds of bentonite or gypsum: causes that might account for the observed structures. It is believed that these involutions were caused by intense frost action during the stages of ice advance in Pleistocene time. Similar structural features are not being formed in the modern soils and gravels at this elevation in Montana. However, it is believed that deformation could take place under the influence of the colder climate that existed during the periods of ice advance in the region peripheral to the continental glacier. In such a periglacial region a layer of perennially frozen ground is likely to be formed which would inhibit the drainage of ground water and facilitate the freezing and expansion of surface water causing the deformation of the surficial strata.

Involutions in this and adjacent areas have been described by J. P. Schafer (1949, p. 164) who cites evidence that they were probably formed during the younger, or Wisconsin, ice advance. If the deformation of the gravels took place during the Wisconsin stage of glaciation, the gravel itself is most likely pre-Wisconsin in age. Because the number 2 terrace is the youngest surface on which these structures were observed, it is reasonable to tentatively correlate this surface with the pre-Wisconsin, or Sangamon, interglacial stage.

The number 1 terrace is older than the number 2 terrace and is represented only by widely separated remnants. If this surface ever was as extensive as the number 2 terrace, it was extensively eroded before the gravel of the number 2 terrace was deposited. If this is true, the number 1 terrace is early Pleistocene in age or, perhaps, even Pliocene. The number 3 terrace is younger and lower than the number 2 terrace and is only developed locally along the major streams. Its surface probably formed immediately after the Wisconsin stage of glaciation. The lower terraces and the alluvium are undoubtedly local post-Pleistocene surfaces that may be due to changes in climate or to successive lowerings of the base level by the Missouri River.

ORIGIN OF THE GRAVELS

The cobbles and boulders that make up the terrace gravels are comprised of limestone, igneous rock, and quartzite similar to those which crop out in the adjacent mountain areas. This fact and the areal distribution of the terraces and modern streams converging toward Arrow Creek and Judith River from the surrounding mountains provide good evidence that the terrace gravels were deposited by former local streams converging on Judith Basin from the mountains in a manner similar to the pattern of the modern streams. The former streams probably differed from the modern streams in some respects: at times they must have carried a greater volume of water, capable of transporting a larger amount of coarse material from a readily available source. Their base level was more distant or considerably higher. These conditions can be explained by the glacial climate that prevailed during the Pleistocene epoch. Small glacial cirques in the high peaks of the Little Belt Mountains are evidence that a rigorous climate accompanied the glacial stages and caused an increase in the rate of erosion in the mountains and a seasonal swelling of the streams that enabled them to transport a larger volume of material. The number 2 terrace is only about 200 feet above the present streams near the Little Belt Mountains but is about 600 feet above the present streams near the junction of Surprise and Arrow

Creeks. Thus it is evident that the streams at the time the alluvium of the number 2 terrace was deposited had a lower gradient than the present streams; therefore base level must have been higher or more distant.

The following hypothetical set of conditions is proposed to explain the origin of the extensive number 2 terrace.

1. At the end of an early stage of Pleistocene ice advance the physiographic setting for the Judith Basin was similar to that at the present. However, there were remnants of only one major terrace above the flood plains of the streams, and the streams were all descending from the mountains onto a plains country of much less topographic relief than exists today, for none of the streams were deeply incised.

2. The climate, although quite rigorous in the winter, was warm enough during the short summer to melt nearly all the snow which accumulated during the long winter, and the resulting meltwater reached the plains through swollen streams as floods which spread out onto coalescing alluvial plains.

3. Annual and daily cycles of freezing and thawing in the mountains caused a rapid disintegration of the rocks and supplied a large volume of boulders, which the streams in flood stage carried out onto the flood plains, depositing a mantle of cobbles as the stream velocity decreased farther from the mountains.

4. The process of transportation and deposition of the cobbles continued for a sufficiently long period of time to permit gravel deposits from the Highwood, Little Belt, Big Snowy, Judith and Moccasin Mountains to coalesce in the center of the Judith Basin to form a nearly continuous deposit, interrupted only by isolated hills of bed rock, such as Skull Butte and the gravel-capped hills that are remnants of the number 1 terrace deposit.

5. The resulting surface was not absolutely smooth or flat, for it was interrupted by meander scars of the many stream channels that crossed the area, and there was a gentle slope from the mountains toward the center of the basin and from the center of the basin toward the north where the streams eventually joined the ancestral Missouri River, probably near the bend of the present Missouri River at Virgille.

ECONOMIC IMPORTANCE

The terraces underlain with gravel and overlain by a thin veneer of soil are important as agricultural and grazing land. The deposits are an important source of road building and construction material. The highly permeable nature of most of the gravel makes it a good reservoir for water and provides a means of drainage. The fine loamy soil overlying the gravel on most of the terraces is ideal for agriculture. The terraces have very little relief and can be irrigated, and the gravel provides the good underground drainage that is necessary for continued irrigation. All the terraces are used for agriculture, but only the number 2 and lower terraces are commonly irrigated.

The gravels of the terraces are used throughout the area as local sources of road-building material, and it is rarely necessary to transport gravel more than short distances. There is an adequate source of gravel for all road construction and any other type of large scale construction in which gravels are needed.

The gravels form a permeable layer that is commonly water bearing. Most of the small towns and farms located on terrace gravels obtain water from wells dug to the base of the gravel deposit. Irrigation projects on the terrace gravels are generally more successful than those on bed rock, because the gravels provide a means of drainage for the water, thereby preventing the accumulation of saline minerals at the surface of the ground through evaporation.

IGNEOUS ROCKS

STRUCTURAL RELATIONS OF THE IGNEOUS ROCKS

Intrusive igneous rocks are found at several places in the Stanford-Hobson area. They occur in five principal types of igneous rock structures: dikes, sills, stocks, concordant intrusions or laccoliths, and combinations of these. Weed (1900, p. 317–343) describes in detail the petrology and structural relations of the igneous rocks within the Little Belt Mountains adjacent to the Stanford-Hobson area. Igneous dikes are common features, especially in the plains areas. The most striking examples are dikes of dark-colored igneous rock found in the Colorado shale where differential erosion has preserved parts of the dikes as ridges of igneous rock that stand out above the soft shale. Nearly all the dikes that occur in the plains area (with the exception of those near the Highwood Mountains) have a northeast-southwest trend. Sills composed of dark-colored igneous rock along the north flank of the Little Belt Mountains and in Skull Butte dome occur chiefly in the Heath shale. Both sills and enclosing sedimentary rocks are deformed. Sills and dikes of dark-colored igneous rocks also occur in the Colorado shale south of the Highwood Mountains. Two major stocks composed of light-colored igneous rocks, are present along the north flank of the Little Belt Mountains: one occurs on the east side of Running Wolf Creek, about 12 miles southwest of Stanford, and the other forms the peak of Wolf Butte, 12 miles south of Geyser. Windham dome, about 5 miles north of Windham, contains a concordant intrusion composed of light-colored igneous rocks. The igneous intrusion has arched the Colorado shale, and erosion has removed enough of the sedimentary strata to expose the igneous core. Because no base for the igneous rock is exposed, the structure is considered to be an intrusion in which the igneous rock is concordant with the arched sedimentary strata, rather than to specify that it is a laccolith. Structural features similar to the Windham dome occur along the north flank of the Little Belt Mountains, but are complicated by faulting or by containing partly discordant, light-colored igneous intrusive bodies. The dome-shaped structure in which Woodhurst Mountain is the highest peak is probably of this type.

Other structural features in which only sedimentary strata are exposed may be the result of igneous intrusions. Skull Butte dome, Blacktail Hills dome, and the small round dome in the Lone Tree dome are examples that probably have concealed igneous cores.

PETROGRAPHIC RELATIONS OF THE IGNEOUS ROCKS

The igneous rock types that occur in the Stanford-Hobson area have not been studied in as great detail as the sedimentary rocks. Specimens of representative igneous rocks were collected from a number of localities in the area, and from these, 10 were selected for more detailed examination by thin-section methods. Localities in which the 10 selected specimens were collected are marked on the map by the designations I–1 through I–10. The thin-sections were examined by W. T. Pecora who made the following report:

IGNEOUS ROCKS IN THE STANFORD-HOBSON AREA

By W. T. Pecora

For purpose of mapping, and in the absence of other criteria, the 10 rocks may be classed into 2 petrographic groups:

1. Quartz monzonite porphyry group (light-colored, quartz-bearing, fine-grained porphyritic intrusive rocks)

2. Mafic alkalic intrusive rocks (dark-colored, quartz-free, fine-grained to coarse-grained intrusive rocks with abundant potash feldspar and ferromagnesian minerals)

Group 1 includes specimens from I–1 to I–6.

Group 2 includes specimens from I–7 to I–10.

GROUP 1

Phenocrysts.—By volume the phenocrysts make up from 5 to 30 percent of the group and attain a maximum size of 2 centimeters. Plagioclase (ranging in composition from calcic oligoclase to calcic andesine) is the principal mineral, and quartz and sanidine are subordinate. Resorbed quartz phenocrysts are common only in specimen I–5.

Groundmass.—The groundmass is fine grained in all the rocks of Group 1, and is composed of quartz, potash feldspar, and plagioclase (calcic albite to calcic oligoclase). Specimen I–5 is richest in quartz (40 percent of groundmass).

Ferromagnesian minerals.—Biotite is the principal dark mineral and makes up less than 5 percent of the rocks.

Alteration.—Calcite, chloritized biotite, and sericitized feldspar are the principal alteration minerals.

Nomenclature and Comments.—Rocks in Group 1 range in composition from dioritic monzonite (I–6) to calcgranite (I–5). The assignment of "quartz monzonite" as a field name for mapping purposes and group description is, however, justifiable. Specimen I–5 is characterized by drusy vugs that are probably miarolitic in origin and by dark quartz grains that probably are the remnants of resorbed hexagonal intratelluric crystals. The group is similar to rocks known in several mountain uplifts in north-central Montana.

GROUP 2

The four rocks of this group (I–7 to I–10) show some fundamental differences, but all are characterized by an abundance of ferromagnesian minerals (augite, biotite, olivine) and a high proportion of potash feldspar. Specimens I–10 and I–9 are fine-grained shonkinite; I–8 is a plagioclase shonkinite; and I–7 is a mafic alkalic monzonite. These rocks are common in the central Montana petrographic province.

The plagioclase in I–8 is labradorite and makes up only a small amount of the rock. In I–7 the plagioclase is andesine, and the proportion of sanidine to andesine in the rock is about 2:1.

The ferromagnesian minerals make up from 30 to 50 percent of the rocks. Augite is the principal dark mineral, and resorbed olivine and biotite are subordinate. Alteration of I–10 has resulted in bleached biotite and calcite.

If definite rock names are required for *each* of the specimens, those of the following list can suffice:

Quartz monzonite porphyry: I–1, I–2, I–3, I–4
Calcgranite: I–5
Quartz calcmonzonite: I–6
Shonkinite: I–9, I–10
Plagioclase shonkinite: I–8
Mafic alkalic monzonite: I–7

Inasmuch as remarks on field relations were not submitted with the specimens, the chronological position of these rocks in the Montana province cannot be given. They are, however, characteristic rocks of the province.

STRUCTURE

STRUCTURAL SETTING

The Stanford-Hobson area is situated to the southeast of the Sweetgrass arch, a major structural element in Montana from the vicinity of Great Falls north to the Canadian border. The regional dip in the area is toward the northeast, and the strike is a continuation of the northwest-southeast trend which forms the eastern flank of the Sweetgrass arch. This gentle dip of the sedimentary rocks to the northeast is modified by uplifted strata on the flanks of several mountain ranges. Thus, the beds dip steeply on the flanks of the Little Belt, Big Snowy, Judith, and Moccasin Mountains, although in the Highwood Mountains there has been little structural arching. The resulting structure is a basin, enclosed along the southwest by the Little Belt Mountains, on the southeast by the Big Snowy Mountains, on the east by the Judith and Moccasin Mountains, but open on the north and northwest. Judith Gap is a structural (and topographic) saddle between the Little Belt and Big Snowy Mountains. The configuration of this structural basin is shown on the geologic map (pl. 45) by structure contours that are drawn at 100 foot intervals on the surface that is formed by the contact of the Kootenai formation and the Colorado shale.

The lack of data for strata below the pre-Ellis unconformity makes it impossible to determine accurately the elevation of the Paleozoic rocks. This limiting factor was the chief reason for making the structure contour map of the top of the Kootenai formation rather than of some older surface such as the top of the Madison limestone.

The regional structural features are greatly modified locally by small faults and domes. In fact, the northern flank of the Little Belt Mountains is so modified by many small structural features (Weed, 1900 p. 384–400) that the major structural trend of the mountains is obscured. It is, however, these small structural features that are of primary interest in the search for oil and gas, because they may serve as structural traps in which oil and gas may accumulate. Each of these possible structural traps is described below with respect to the type of structure, the history of exploratory drilling, and the future possibility of finding oil and gas.

INDIVIDUAL ANTICLINAL STRUCTURES

Garneill nose.—Garneill nose is a structural feature located on the west side of Judith Gap, the structural saddle between the Little Belt and the Big Snowy Mountains. It is a dome-shaped structure slightly more than a mile in diameter and forms the end of the nose protruding from the northern flank of the Little Belt Mountains. Several oil and gas test wells were drilled on this dome in the early 1920's, and the driller's log shows indications of oil and gas in the Otter formation. This fact, plus statements from local residents that oil flowed from the well for several years after it was drilled, interested D. C. Shay of the Chief Exploration Co., Billings, Mont., sufficiently to make a study of this dome in 1950. In February of that year he drilled 4 shallow exploratory holes to ascertain the amount of structural closure on this dome. An examination of the drill cuttings from these 4 test holes indicated at least 110 feet of structural closure. In August 1950 an oil and gas test well, the T. W. Doswell, Dolgan No. 1, was drilled to the rocks of Cambrian age without obtaining commercial production.

Buffalo dome.—A dome on the north flank of the Little Belt Mountains, is about ten miles northwest of Garneill nose. In plan it is a semioval structure and is flattened on the south side by the north flank of the Little Belt Mountains. It is asymmetrical, the gentle side dipping 4 to 5 degrees southward to the mountains, and the steep side dipping 15 to 17 degrees northward to the basin. The dome is dissected on the north side by two branches of Buffalo Creek; the western one has uncovered the top of the Ellis group. Outcropping strata on the south flank, where data are needed to determine the amount of structural closure, are obscured by a cover of soil and grass. The dome probably has less than 100 feet of closure, but the south flank is complicated by faulting that may make the effective closure greater. A test well was drilled on Buffalo dome in 1925 to a depth of 1,110 feet. The driller's log of this well shows a number of indications of oil and gas. Though the closure on this dome is not great, more thorough testing in a well located higher on the structure may be worthwhile.

Antelope Creek dome and smaller domes.—A small anticline that is exposed in the valley of Antelope Creek about 4 to 5 miles northwest of Buffalo dome is called the Antelope Creek dome. It is a small feature, being slightly more than a mile long and less than a mile wide. From the exposures on three sides, it is estimated to have at least 100 feet of closure. About 2 miles west of Antelope Creek dome are several other small flexures. These folds are in an area of complicated structure, the major structural trends being determined by a fault that terminates as an eastward pitching anticline south of Antelope Creek dome. An extension to the south and west of the area of complicated structure was not mapped. Until this adjacent area has been investigated, the structural relations cannot be fully understood. No test wells have been drilled in this area to date. Although the anticlines are small, a test well on Antelope Creek dome will have to be drilled only to a depth of about 1,500 feet to enter all the strata above the Madison limestone.

Skull Butte dome.—Skull Butte dome is about 4 or 5 miles southwest of Stanford and north of the main flank of the Little Belt Mountains; it is a circular dome about 2 miles in diameter in which differential erosion has formed a central topographic basin about 1 mile in diameter. Within this central basin, which locally is called Cayuse Basin, erosion has exposed the top of the Otter formation. Limestone beds of the upper part of the Amsden formation encircle the basin and form a hogback that is breached by a stream at the northeast side. The steep-sided, circular plan of this dome, closely resembling those of Windham dome and the dome-shaped structures along the north flank of the Little Belt Mountains, suggest the possibility of an intrusive core. It is difficult to prove or disprove the presence of such a core, however, until a test is drilled. In 1929 a well was drilled to a depth of 500 feet in the SW¼ sec. 6, T. 15 N., R. 12 E. and produced a flow of water. As no other information is available, the sequence of rocks penetrated is unknown. Although the exact position and elevation of the well is unknown, it is likely that it entered the Kibbey sandstone and the top of the Madison limestone. Skull Butte dome has several hundred feet of closure, and if there is no igneous core or if the igneous core is quite deep, it may have served as a structural trap for oil and gas. However, part of the Otter formation, the Heath shale, and the Amsden formation, are exposed so the only possible oil-producing formations that it would be feasible to test are the Madison limestone and the Kibbey sandstone. Further testing of this dome may be unsuccessful because of the likelihood of finding an igneous rock core. Such cores are not known to be productive of oil or gas.

Blacktail Hills dome.—This dome, a circular uplift about 2½ to 3 miles in diameter, is similar structurally to Skull Butte dome, but the upper surface of the Madison limestone forms a domelike hill surrounded by a ring-shaped valley eroded from the less-resistant strata of the Big Snowy group. The hill is dissected on the northwest side by Dry Wolf Creek. The circular form of this uplift, so similar to that of Skull Butte dome and the proximity of a large igneous mass less than one mile to the west are evidence for the belief that the core of the dome is a mass of igneous rock. Because all the possible oil-bearing strata younger than Madison limestone have been stripped from this dome, and because of the possibility of an igneous core, a test of this structure seems inadvisable.

Lone Tree dome.—North of Wolf Butte an uplifted area more than 5 miles in diameter is called the Lone Tree dome. On the dome is a smaller circular dome, 1 to 1½ miles in diameter and having about 350 feet of closure. In diameter the smaller dome is about one-half that of Blacktail Hills dome, but resembles it in structure and topography. The reasons that make it unadvisable to test the Blacktail Hills dome for oil and gas apply with equal logic to this small dome.

The anticlinal fold that is located about 1 mile west of the locality where Surprise Creek breaches the Amsden hogback is an eastward plunging fold with little or no closure. It is bounded on the north and east by the main hogback of the Amsden formation and on the south by a plunging syncline in which isolated blocks of the Amsden formation and the Ellis group are much lower than can be explained by the folded structure. It is apparent that these blocks have been lowered, but neither the strata above nor below the blocks show evidence of being displaced; therefore the blocks were mapped as landslide material. A third anticline that resembles a structural nose or terrace occurs within the Lone Tree dome in the broad area in which the Otter formation crops out. This area is so broad that there may be one or more gentle flexures not recognizable, owing to the lack of mappable horizons within the Otter formation. In 1929 a dry hole was drilled to a depth of 1,140 feet from a position near the topographic high point on the Otter outcrop band. Although the stratigraphic position of the top of the well within the Otter formation is unknown, it is probable that in drilling to a depth of 1,140 feet the well penetrated several hundred feet into the Madison limestone. One dry hole does not condemn the entire area within the Lone Tree dome; however, the prospects of finding oil within the area are limited to a relatively few stratigraphic horizons, namely the Madison limestone, and the Kibbey sandstone.

Windham dome.—An isolated circular dome rising abruptly above the gently dipping Cretaceous strata about five miles north of Windham is called in this report the Windham dome. This structural feature differs from most of those previously described, because it is more than 10 miles from the mountain front, yet erosion has exposed a core of igneous intrusive rock. Cretaceous strata probably equivalent to the Mowry shale are exposed on the flanks of the dome, dipping 10 to 15 degrees from the center of the dome, and erosional remnants of the same strata are exposed on the crest of the dome. The presence of an igneous core in this dome is added evidence for the hypothesis that several of the other circular domes in the area have igneous cores at depth.

Hidden structural features.—These domes and anticlines do not represent the only possible oil and gas producing structures in the area. As a large part of the area mapped is covered by gravel that obscures the structure of the underlying rocks, it is possible that additional anticlines or domes are present which can be discovered only by geophysical or other methods. At least five of the test wells in parts of the area that have no clearly defined anticlinal structures had indications of oil and gas. (See table 6.) These indications may or may not be evidence for the presence of hidden structural features; however, they definitely show that the Stanford-Hobson area is in a petroliferous province where oil or gas is likely to be present if favorable structural and stratigraphic conditions exist.

FAULTS

Faulting and thinning of the beds accompany the intense deformation along the north flank of the Little Belt Mountains west of Garneill nose. Locally the strata are overturned and the Madison limestone is faulted against the Amsden formation. The displacement may be due to a high angle reverse fault.

Strata on the south side of Garneill nose are dislocated by one large and several small faults. These appear to be tears with nearly vertical fault surfaces, but nearly all displacement is horizontal. As such, they are not likely to form oil or gas traps.

Several minor faults and one major fault are present in the area south and west of Antelope Creek dome. The east-west fault about 1½ miles south of Antelope Creek dome is a major fault that has its greatest displacement just west of the area mapped and that passes into a plunging anticline and syncline to the east. Because the western end was not mapped, the importance of this structure in localizing the accumulation of oil and gas is not known. The other faults in this area are small and probably have little or no significance as oil or gas traps.

About 2½ miles northwest of Utica a large fault trends northeast-southwest. Although the fault trace is largely concealed by the cover of gravel, the influence of the fault on the continuity of the outcrop bands is readily seen on the map. This fault may be somewhat similar to the one south of Antelope Creek, but because it is so poorly exposed, the detailed relationships cannot be given. For the same reason, it is not possible to say how important it may be in localizing the accumulation of oil and gas.

Along the northern border of the area, southeast of the Highwood Mountains, there are two grabens in which the Eagle sandstone is in contact with Colorado shale. Owing both to the difficulty in recognizing faults in the dark Colorado shale and to the extent of the gravel cover, it is certain only that the areas mapped as Eagle sandstone must be within the down-faulted block of the grabens. Indications of oil and gas have been reported in rocks adjacent to similar faulted structures several miles north of the area mapped.

SECONDARY STRUCTURAL TREND

Superimposed upon the major northwest-southeast regional strike is a secondary northeast-southwest structural trend prominent throughout the area of the Judith Basin. This trend is reflected by the large fault northwest of Utica; by a minor fault or flexure in the

Colorado shale in sec. 21, T. 15 N., R. 13 E.; by the northeast strike of many dikes in the area; and by the stream pattern of most of the streams in the area. The geologic map shows a conspicuous northeast-trending pattern of lines, including both drainage features and geology.

This structural trend might be significant if oil were discovered in the Judith Basin, for it is possible that any structural traps in the area would be complicated by secondary features in this general direction, and even a stratigraphic trap might be limited by a fault or dike parallel to this direction. This structural trend is subordinate to and probably later than the major structural features of the mountains, but it is nevertheless significant in the search for oil.

FORMATION THICKNESSES USED IN COMPUTING STRUCTURE CONTOURS

Structure contours were computed and drawn at 100-foot intervals on the top of the Kootenai formation. The formation thicknesses used in computing the structure contours for the formations above the Kootenai formation remained constant throughout the area. Owing to the many changes in thickness of the formations below the Colorado shale, it was necessary to calculate changes in thickness for use in different parts of the area. The following list and table 5 show the intervals used for purposes of calculating the structure contours in the area.

Unit	*Thickness of intervals from base of Colorado shale to tops of various formations mapped*
Claggett shale	2600
Eagle sandstone	2180
Telegraph Creek formation	1920
Colorado shale	1760
Greenhorn-formation equivalent	1040
Mowry-shale equivalent (bentonite zone)	760
Kootenai formation	0

TABLE 5.—*Variations in thickness of Kootenai and pre-Kootenai intervals*

Unit	Depths from base of Colorado shale to top of basal sandstone of Kootenai and to tops of underlying formations in indicated localities						
	Lone Tree Creek	Surprise Creek	Dry Wolf Creek and Running Wolf Creek	Willow Creek	Skull Butte	Antelope Creek and Wait Creek	Ross Fork
Basal sandstone of the Kootenai fm	350	350	350	350	450	250	275
Morrison formation	450	450	450	450	550	350	375
Ellis group	700	700	700	700	715	700	650
Amsden formation	775	775	775	775	775	800	710
Heath shale	1,095	945	1,475	1,485	1,134	--------	--------
Otter formation	1,420	1,270	1,945	1,920	1,570	1,400	1,400
Kibbey sandstone	1,920	1,770	2,365	2,465	--------	1,800	1,800
Madison limestone	2,070	1,920	2,615	2,655	--------	2,100	2,100

MINERAL RESOURCES

OIL AND GAS

From 1921 to 1950 sporadic well-drilling activity has resulted in the completion of at least 21 test wells in or near the Stanford-Hobson area. (See table 6.) Of these, 9 had indications of oil or gas, and the rest were dry holes or were completed as water wells. Most of these wells were located and drilled by small local companies. The log of a sample study of the Pacific Western Oil Company, Todd no. 1 well is given in table 2.

The Judith Basin area has not received as much attention from the petroleum industry in the past several years as have the nearby areas east of the Big Snowy Mountains, which are characterized by well-defined anticlinal structures. The known anticlinal structures in the Stanford-Hobson area are much smaller than those to the east, and some of them probably possess an igneous core. Though some of these anticlinal structures may eventually become a source of oil or gas, it is unlikely that they will become important fields. Probably the best possibility of finding an important oil or gas field in the Judith Basin is to discover either a stratigraphic trap or a large structural feature that, if present, is concealed by terrace gravel. Geophysical methods of exploration will probably have to be employed in either instance. Several possibilities for stratigraphic traps exist in this area. The Ellis group thins from nearly 500 feet in the Pacific Western, Todd no. 1 well north of Benchland, to about 60 feet along the front of the Little Belt Mountains. Because the Ellis group thins updip against the unconformably underlying Amsden formation, ideal conditions for a stratigraphic trap exist if any oil or gas is locally present in the lower part of the Ellis group—as is true at Bowes dome north of the Bearpaw Mountains. Other possibilities for stratigraphic traps are lenticular sand bodies, which are present in the Kibbey sandstone, the Heath shale and the Amsden formation. The discovery of an oil pool in these sand bodies, however, will be fortuitous, until considerably more subsurface geologic data is available than at the present time.

COAL

During the first quarter of the present century, coal mining was an industry of secondary importance in the Stanford-Hobson area. A number of small mines were operated along the north flank of the Little Belt Mountains, and there was one mining camp, Lehigh, about 3 miles southwest of Windham. Much of the coal was used by the Great Northern Railway and the rest was sold and used locally. Most of the mines were closed about 1921, and many of them were

TABLE 6.—*Records of wells drilled for oil and gas in the Stanford-Hobson area*

(Deepest formation—source of information: a, driller's log; b, sample log; c, driller's note)

Name	Location (section, township, range)	Date drilled	Surface formation	Deepest formation	Depth to top of deepest formation	Indications of oil or gas	Depth of well
T. W. Doswell, Dolgan no. 1	NE¼NW¼SE¼ 12, 11 N., 15 E.	1950	Kootenai	Cambrian [b]	4404		4822
Minnesota-Montana Petroleum Co. no. 1.	SW¼SE¼ 12, 11 N., 15 E.	1922	do				1200
Minnesota-Montana Petroleum Co. no. 2.	NW¼SE¼ 12, 11 N., 15 E.	1922	do	Otter [a]	835	Gas and oil shows	1220
E. E. Chard and L. H. Harvey no. 1	NE¼NW¼ 9, 12 N., 14 E.	1925	Colorado shale				550
E. E. Chard and L. H. Harvey no. 2	NE¼SW½ 9, 12 N., 14 E.	1925	do			Oil shows	1140
Buffalo Dome Oil Co. no. 1	NE¼NW¼SW¼ 21, 12 N., 14 E.	1922	Morrison	Madison [a]	954	Gas and oil shows	1100
Triple Dome Oil Co. Fulton no. 1	SW¼NW¼NE¼ 6, 13 N., 14 E.	1923	Colorado shale	Amsden [a]	(?) 1265	Oil shows	1761
F. E. Hunt, Oregon Mortgage Co. no. 2.	NE¼SW¼SE¼ 20, 14 N., 15 E.	1934	do	Kootenai [a]	996		1233
F. E. Hunt, Oldham no. 1	SE¼NW¼NW¼ 21, 14 N., 15 E.	1933	do	Kootenai	1065	Gas and oil shows	1243
F. E. Hunt, et al., Bone no. 3	NW¼SE¼NE¼ 30, 14 N., 15 E.	1935	do	Amsden (?) [c]		Oil shows	1870
Rock Creek Bench Oil Co., Nesson no. 1	NE¼NE¼NW¼ 36, 14 N., 16 E.	1947	do	Madison [b]	3185		3532
Rock Creek Bench Oil Co., Nesson no. 2, North line.	NE¼NW¼ 36, 14 N., 16 E.	1948	do	Otter(?) [b]			2305
John Carter	SW¼SW¼ 6, 15 N., 12 E.	1929	Heath	Otter(?)			500
Windham-South Dakota Oil Co.	SE¼NE¼ 24, 15 N., 12 E.	1921	Colorado shale	Madison(?) [a]	1977	Oil shows	2025
Goyt, Montana, no. 1	SW¼SW¼NW¼ 24, 15 N., 15 E.	1921	do	Kootenai [a]	1010	do	1185
Newton-Waddingham no. 1	SE¼NE¼SW¼ 15, 16 N., 10 E.	1930	Otter	Madison(?)			1140
Fisher-Peck no. 1	30, 16 N., 12 E.	1928	Colorado shale(?)				600
National Refining Co. no. 1	SW¼SW¼SW¼ 20, 16 N., 15 E.	1922	Colorado shale	Kootenai [a]	(?)1377		1800
Pacific Western Oil Corp., Todd no. 1	SW¼NW¼ 32, 17 N., 14 E.	1948	do	Madison [b]	3185		3356
Montana Drilling Equipment Co., Blackwood no. 1.	NE¼NE¼ 12, 18 N., 15 E.	1923	do	Ellis [c]	2285		2285
Montana Drilling Equipment Co., Blackwood no. 2.	SE¼NE¼ 12, 18 N., 15 E.	1925	do	Colorado shale(?)		Gas and oil shows	1700

never reopened. Since that time small amounts of coal have been mined intermittently by local operators.

The coal is mined from the bed of subbituminous to bituminous coal with an aggregate thickness of from 5 to 6 feet that occurs at or near the top of the Morrison formation in this area. Locally, the coal bed was eroded before the Morrison formation was covered by the sediments that formed the Kootenai formation. Impure coal or carbonaceous shale also occurs in the Eagle sandstone, but the coal bed in the Morrison formation is the only one in this area that has been mined commercially. The outcrop pattern of the coal bed in the Morrison formation closely parallels the Morrison-Kootenai boundary as shown on the geologic map (pl. 45). No attempt was made to obtain detailed information on the thickness and grade of the coal, as most of the mine openings are now caved and the workings flooded. The locations of coal mines and prospects, nearly all of which have been abandoned, are shown on the geologic map (pl. 45). Descriptions of the mines, coal sections, and coal analyses for the Sage Creek area are given by Fisher (1909, p. 71–80) and for the Buffalo Creek and Utica areas by Calvert (1909, p. 57–59 and 72–75).

GYPSUM

Gypsum and anhydrite, the mineral forms of calcium sulphate, occur at several stratigraphic zones in the Stanford-Hobson area. East of the Stanford-Hobson area, gypsum in the Piper formation of Middle Jurassic age is mined at Hanover, on the south side of the Moccasin Mountains, and also at Heath, several miles southeast of Lewistown. There are no outcrops of the Piper formation in the area mapped, but it was found in the Pacific Western, Todd No. 1 well (table 2), sec. 32, T. 17 N., R. 14 E., and thus is present at depth in the northern part of the area.

Gypsum in beds of Big Snowy age crops out in the southwestern part of the area. One such occurrence is from 100 to 150 feet above the base of the Otter formation where at least from 15 to 20 feet of white gypsum is exposed on the east end of a tree-covered ridge on the south side of the Blacktail Hills dome, sec. 25, T. 15 N., R. 10 E. The thickness and extent of the bed could not be determined. In the Lone Tree dome all three formations of the Big Snowy group contain gypsum. A 20-foot bed of impure gypsum occurs in the Heath shale from 170 to 190 feet below the Amsden formation in sections 3 and 4, T. 16 N., R. 10 E. It is more resistant than the shale and forms a gray ledge along the hogback. A 12-foot bed of gypsum that is interbedded with shale and limestone occurs from 100 to 112 feet above the base of the Otter formation in sec. 16, T. 16 N., R. 10 E. A 20-foot bed of white gypsum occurs from 25 to 45 feet below the top of the Kibbey sandstone and is exposed in a prospect pit at the boundary between section 20 and 21, T. 16 N., R. 10 E. The lateral extent of the bed is unknown.

GRAVEL DEPOSITS

The general distribution, age, mode of origin and economic significance of the gravel deposits in the area are discussed under the heading Terrace gravels and alluvium, on page 449. There is a supply of gravel in the area adequate for all foreseeable future uses.

BENTONITE

Bentonite deposits of possible commercial value occur in the Mowry shale equivalent. The bentonite zone is shown on the geologic map wherever it is exposed well enough to map. Probably the best exposures of this zone may be seen along the north bank of Arrow Creek, northeast of Geyser, and also along the east side ot Stanford-Buttes.

M. M. Knechtel (written communication) who made a brief examination of the bentonite outcrops about 3½ miles north of Geyser has supplied the following information:

"The following section of the bentonite beds and the enclosing bedrock was measured in NE¼ sec. 19, T. 18 N., R. 10 E. The upper of the two beds listed may be equivalent to the Clay Spur bentonite bed, in the upper part of the Mowry shale, which is mined extensively in the Black Hills district. The northward dip is gentle.

Bentonite beds near Geyser, Mont.

Bed	Description of material	Thickness Ft	Thickness In	Sample No.
	Shale, light-gray, siliceous and cherty, at top of Mowry.	1	6	--------
Clay Spur(?)	Bentonite	1	10	1
	Shale, light-gray, siliceous, with some chert.	21	0	--------
Bed, 7 feet, 11 inches thick.	Bentonite, yellowish-gray, weathers white.	2	5	2
	Bentonite, yellow-green; contains dark mineral particles.	5	6	3
	Shale, black, somewhat silicified; makes hard floor; grades downward to softer dark-gray shale.	----------		--------

The bentonite of these beds may be a possible source of clay for use in preparation of rotary oil-well drilling fluid. The suitability of the materials of the two beds for use by foundries as molding-sand bonding clay should also be tested."

LITERATURE CITED

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U. S. Geol. Survey Prof. Paper 174.

Bowen, C. F., 1915, The stratigraphy of the Montana group with special reference to the position and age of the Judith River formation in north-central Montana: U. S. Geol. Survey Prof. Paper 90–I, p. 95–153.

Brown, R. W., 1946, Fossil plants and Jurassic-Cretaceous boundary in Montana and Alberta: Amer. Assoc. Petroleum Geologists Bull. v. 30, no. 2, p. 238–248.

Calvert, W. R., 1909, Geology of the Lewistown coal field, Montana: U. S. Geol. Survey Bull. 390.

Cobban, W. A., 1951, Colorado shale of central and northwestern Montana and equivalent rocks of Black Hills: Amer. Assoc. Petroleum Geologists Bull. v. 35, no. 10, p. 2170–2198.

Cobban, W. A., 1945, Marine Jurassic formations of Sweetgrass arch, Montana: Amer. Assoc. Petroleum Geologists Bull. v 29, no. 9, p. 1262–1303.

Cobban, W. A., and Reeside, J. B., Jr., 1951; Lower Cretaceous ammonites in Colorado, Wyoming, and Montana: Amer. Assoc. Petroleum Geologists Bull., v. 35, no. 8, p. 1892–1893.

Darton, N. H., 1906, Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51.

Fisher, C. A., 1909, Geology of the Great Falls coal field, Montana: U. S. Geol. Survey Bull. 356.

Gardner, L. S., Hendricks, T. A., Hadley, H. D., and Rogers, C. P., Jr., 1945, Columnar sections of Mesozoic and Paleozoic rocks in the mountains of south-central Montana: U. S. Geol. Survey Oil and Gas Investigations Prelim. Chart 18.

——— 1946, Stratigraphic sections of Upper Paleozoic and Mesozoic rocks in south-central Montana: Montana Bureau of Mines and Geology, Mem. 24, 100 p.

Hadley, H. D., Gardner, L. S., and Rogers, C. P., Jr. 1945, Subsurface stratigraphy of Lower Mesozoic and Upper Paleozoic formations in the basin area of south-central Montana: U. S. Geol. Survey Oil and Gas Investigations Prelim. Chart 19, 1945.

Iddings, J. P., and Weed, W. H., 1894, Livingston, Montana: U. S. Geol. Survey Folio 1.

Imlay, R. W., 1945, Occurrence of Middle Jurassic rocks in the western interior of the United States: Amer. Assoc. Petroleum Geologists Bull. v. 29, p. 1019–1027.

Imlay, R. W., Gardner, L. S., Rogers, C. P., Jr., and Hadley, H. D., 1948, Marine Jurassic formations of Montana: U. S. Geol. Survey Oil and Gas Investigations Prelim. Chart 32.

Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U. S. Geol. Survey Bull. 110.

Peale, A. C., 1896, Three Forks, Montana: U. S. Geol. Survey Folio 24.

Perry, E. S., and Sloss, L. L., 1943, Big Snowy group: Lithology and correlation in the northern Great Plains: Amer. Assoc. Petroleum Geologists Bull. v. 27, p. 1287–1304.

Reeves, Frank, 1929, Thrust faulting and oil possibilities in the plains adjacent to the Highwood Mountains, Montana: U. S. Geol. Survey Bull. 806–E, p. 155–195.

Reeves, Frank, 1930, Geology of the Big Snowy Mountains, Montana: U. S. Geol. Survey Prof. Paper 165–D, p. 135–149.

Rogers, C. P., Jr., Gardner, L. S., and Hadley, H. D., 1945, Thickness and general distribution of Mesozoic and Paleozoic rocks in south-central Montana: U. S. Geol. Survey Oil and Gas Investigations Prelim. Map 43.

Schafer, J. P., 1949, Some periglacial features in central Montana: Jour. Geology v. 57, no. 2, p. 154–174.

Scott, H. W., 1935, Some Carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. Geology v. 43, no. 8, pt. 2, p. 1011–1032.

Scott, H. W., 1942, Ostracodes from the Upper Mississippian of Montana: Jour. Paleontology, v. 16, no. 2, p. 156–164.

Stebinger, Eugene, 1914, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90–G, p. 61–68.

Vine, J. D., and Hail, W. J., Jr., 1950, Geologic map of the Hobson area, central Montana: U. S. Geol. Survey Oil and Gas Investigations Prelim. Map 108.

Vine, J. D., and Johnson, W. D., Jr., 1954, Geology of the Stanford area, Judith Basin and Fergus Counties, Montana: U. S. Geological Survey Oil and Gas Investigations Map OM 139.

Walton, P. T., 1946, Ellis, Amsden, and Big Snowy group, Judith Basin, Montana: Amer. Assoc. Petroleum Geologists Bull. v. 30, no. 8, p. 1294–1304.

Weed, W. H., 1899a, Fort Benton Montana: U. S. Geol. Survey Folio 55.

Weed, W. H., 1899b, Little Belt Mountains, Montana: U. S. Geol. Survey Folio 56.

Weed, W. H., 1900, Geology of the Little Belt Mountains, Montana: U. S. Geol. Survey Ann. Rept. 20, pt. 3, p. 257–461.

INDEX

U. S. GOVERNMENT PRINTING OFFICE: 1956