UNIVERSITY OF MONTANA BULLETIN

BUREAU OF MINES AND METALLURGY SERIES NO. 4

GEOLOGY AND OIL AND GAS PROSPECTS OF CENTRAL AND EASTERN MONTANA

BY

C. H. CLAPP
ARTHUR BEVAN
G. S. LAMBERT

STATE SCHOOL OF MINES
BUTTE, MONTANA
June, 1921

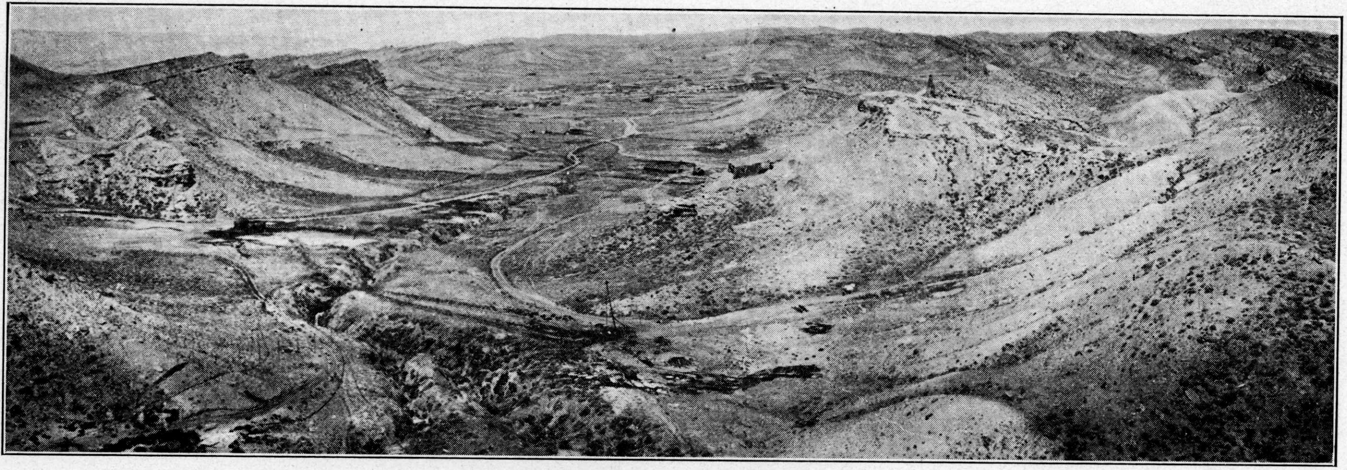

PLATE III.—ELK BASIN.

View from the south rim looking northward into Montana. The conspicuous escarpment has been produced by erosion along the crest of the anticline.

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STATE BUREAU OF MINES AND METALLURGY

CLAPP, CHARLES H. - - - - - - - Director and Geologist
PhD., Massachusetts Institute of Technology, 1919
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E. M. Montana State School of Mines, 1907
LAMBERT, GERALD S. - - - - - - - Assistant Geologist
B. S. School of Mines and Engineering, Univ. of Utah, 1919
BEVAN, ARTHUR C. - - - - - - - - Assistant Geologist
B. S. Ohio Wesleyan University, 1912.

PUBLICATIONS

No. 1. The Montana State Bureau of Mines and Metallurgy (an explanation of its purpose and operation).
No. 2. Directory of Montana Metal and Coal Mines.
No. 3. Mechanical Ore Sampling in Montana (by H. B. Pulsifer).
No. 4. Geology and Oil and Gas Prospects of Central and Eastern Montana (with a geologic map). (By C. H. Clapp, Arthur Bevan and G. S. Lambert.)

CONTENTS.

PART I. By C. H. CLAPP.

PART II.

Stratigraphy—

PART III. By G. S. LAMBERT.

ILLUSTRATIONS.

PART I

BY

C. H. CLAPP

INTRODUCTION

Region and Field Work.

On account of the discovery of oil in central Montana, and the consequent interest in the oil resources of the state, the State Bureau of Mines and Metallurgy undertook a geological survey of the oil and gas possibilities of Montana. Because of the greatly deformed and fractured character of the rocks in the western, mountainous region, it was believed that only in the central and eastern portions of the state are oil and gas possibilities of immediate prospective value. Hence, during the first season, only that porton of the state east of the main front range of mountains was surveyed. However, as that portion constitutes nearly two-hirds of the entire state, 98,000 square miles out of a total of 147,000 square miles, a task of considerable magnitude for a single season was undertaken.

A base map on a scale of four miles to an inch was compiled and on this was assembled all of the available geological information from reliable sources, chiefly the publications of the United States Geological Survey. In this way, several areas, approximating 50,000 square miles in extent, were mapped with varying degrees of accuracy, leaving several large unmapped areas. Thus there remained to be mapped during the season of 1920 about 48,000 square miles of territory, distributed throughout central and eastern Montana.

Two parties were organized, one consisting of G. S. Lambert and Arthur Bevan, and the other of C. H. Clapp and R. J. Wade. Mr. Bevan left for the field on June 14, accompanied by C. W. Vaupell, who assisted him until July 1, when G. S. Lambert joined the party. Lambert and Bevan finished their field work on September 22. C. H. Clapp left for the field on July 9 and returned on August 28. Since then a 3-day trip was made to the Cat Creek oil field by Clapp and Lambert during the last part of December. There were only 152 party days spent on actual field work, which necessitated an average of 315 square miles of mapping per party day.

The mapping, therefore, was obviously of a reconnaissance nature, but was checked by the work of several private surveys, as well as by the work of the United States Geological Survey in areas not yet published by them. No detailed work was, of course, possible. Nearly all the surveyed roads in the region were traversed in automobiles, locations being made from section corners and by measurement of distances with a speedometer. In unsurveyed townships, compass traverses were made of the roads, and distant contacts were located by a rough compass triangulation.

For publication the accompanying geologic map of central and eastern Montana, on a scale of 1:500,000, or about 8 miles to an inch, has been compiled by G. S. Lambert. The base map was compiled by the United States Geological Survey in 1913 and has been corrected and brought up to date by A. L. Longley with data from the United States Land Survey plats of 1913 to 1919.

Authorship and Acknowledgments.

The table of contents names the individual author of each portion of the report, but all portions were written after conference and discussion of all portions by all three authors. Much of the report must be considered as a compilation of reports already published, dealing with the geology and mineral resources of central and eastern Montana. Even for those areas, a geologic map of which has not been heretofore published, a large part of the information has been obtained from others.

It is not feasible, even if it were possible, to acknowledge by name all of those to whom credit is due for both general and specific information. The United States Geological Survey has furnished by far the major part of the data for both the report and map. Those papers prepared by the staff of the survey, which were actually used during the survey and preparation of the report are listed in the bibliography and specific mention is made to several of them throughout the report. In addition, a map of the central and eastern part of Montana was prepared by the United States Geological Survey showing several important geologic boundaries, especially in areas where no geologic maps have been published. These boundaries were not everywhere accepted, but were used where the writer's own work was too general or incomplete.

Acknowledgment to the Geological Department of the Anaconda Copper Mining Company should also be made. It was in this department that both the field and final maps were compiled and draughted. Although all members of the department contributed to the accuracy and value of the maps, specific acknowledgment is made to Mr. A. L. Longley in charge of the draughting, to Mr. P. R. Murphy, who compiled the geology for the field maps, and to Messrs. George Fowler and Paul Billingsly, who have been in charge of much of the areal geologic surveys and development for oil and gas carried on by the company.

Mr. Eugene Milburn of Miles City furnished the writer with many reports by various geologists obtained during his investigation of the oil and gas resources of the state. Areal information has also been obtained from Mr. Julius H. Warner, of the East Butte Copper Company. Detailed information and logs of wells have been freely given by most of the oil operators and geologists of the state. To many others the authors are indebted for the aid which has been given to them.

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The following list is not a complete bibliography of all the papers relative to the geology and mineral resources of central and eastern Montana. A complete bibliography dealing with the geology of the state is being compiled and will be published later. In the following list an attempt has been made to give only the more important and latest papers, for where a later publication supersedes an earlier one, the earlier one has not been given. All papers used during the work have, of course, been listed. The papers are first listed in the order of their publication and then indexed according to the counties to which they refer.

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County—	(Numbers refer to the foregoing bibliographic list)
Big Horn	(12) (38) (57) (60)
Blaine	(24) (33) (40) (48) (59)
Carbon	(13) (15) (20) (49) (60)
Carter	
Cascade	(5) (6) (7) (16) (21) (48) (50)
Chouteau	(6) (41) (48)
Custer	(18) (27) (28) (29) (36)
Dawson	(27) (30) (31)
Fallon	(27) (28) (29)
Fergus	(4) (6) (7) (16) (21) (22) (39) (48) (61)
Flathead	(8)
Gallatin	(3) (7) (34) (60)
Garfield	(59) (61)
Glacier	(45) (48) (51)
Hill	(24) (33) (48)
Lewis & Clark	(55)
Liberty	(45) (48)
McCone	(23) (59)
Madison	(60)
Meagher	(5) (7) (19) (56)
Musselshell	(39) (52) (54) (56)
Park	(3) (7) (34) (35) (60)
Phillips	(48) (53) (59)
Pondera	(45) (48) (51) (55)
Powder River	
Prairie	(27) (29) (36)
Richland	(23) (27) (31) (59)
Roosevelt	(23) (32) (59)
Rosebud	(36) (44) (61)
Sheridan	(32) (37) (59)
Stillwater	(3) (49) (54) (60)
Sweetgrass	(3) (7) (34) (54) (56) (60)
Teton	(48) (55)
Toole	(45) (48) (51)
Valley	(23) (53) (59)
Wheatland	(7) (19) (52)
Wibaux	(17) (27) (29) (30) (31)
Yellowstone	(38) (54) (57) (60)
General Stratigraphy	(1) (2) (9) (10) (11) (14) (25) (26) (58) (62) (63) (64)
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SURFACE FEATURES.

The eastern part of Montana is in the Great Plains region of North America, and the western part lies within the Rocky Mountain system of the mountainous Cordellera of the continent. Thus the state is divided into a western mountainous district and an eastern plains or prairie district, constituting almost two-thirds of the state. Although the boundary between the two districts is fairly well defined, crossing the state with a general N. 35° W. trend, the western part of the prairie district is characterized by several small ranges or groups of mountains, rising island-like above the general prairie level for over 200 miles east of the main mountain front. The prairie region itself may, therefore, be subdivided into a western and an eastern part, Central Montana and Eastern Montana. Thus the surface features of Montana divide the state into three distinct geographic districts, Western, Central and Eastern Montana. This report deals exclusively with Central and Eastern Montana.

In Central Montana the rocks are conspicuously folded with a general northwest trend, whereas in Eastern Montana, except in two or three places, the rocks are nearly flat lying or dip at angles of less than five degrees. Hence in Central Montana the more resistant rocks form the ranges and groups of mountains, which rise island-like above the general level of the prairies by 2000 to 6000 feet, whereas in Eastern Montana there are no distinct groups of mountains, although in places high cuestas, mesas, and buttes surmount the general prairie level by 1000 to 2000 feet.

Central and Eastern Montana are drained by prevailingly eastward and northeastward flowing, consequent streams, and owing to the semiarid climate by only relatively few tributaries of an insequent nature. In Central Montana, however, some of the tributary streams follow soft rock belts and hence are subsequent streams. With the exception of St. Mary River, which rises in the mountains a few miles south of the Canadian border and enters the Saskatchewan, all the rivers drain into the Missouri, which, rising in the mountains, flows generally eastward across the prairie. Its main tributary, the Yellowstone, rises in the mountains of northwestern Wyoming and flows northeast, joining the Missouri in North Dakota just east of the Montana line. These two rivers divide Central and Eastern Montana into three nearly equal portions extending east from the mountains to the North Dakota boundary.

North of the Missouri, following for some distance the pre-Glacial channel of the Missouri, is the Milk River. Between the Missouri and the Yellowstone is the Musselshell. South of the Yellowstone are several large streams, flowing into it, which, enumerated from west to east, are the Big Horn, Rosebud, Tongue, and Powder rivers, all except the Rosebud having their source in Wyoming. The extreme southeastern part of the state is crossed by Little Missouri River, which enters the Missouri in North Dakota.

The outlying ranges and groups of mountains of Central Montana consist from north to south of the Sweetgrass Hills, near the Canadian border; the Bearpaw and Little Rocky mountains, between the Milk and Missouri rivers; the Little Belt, Highwood, Moccasin, and Judith mountains south of the Missouri; the Castle and Big Snowy mountains, north of the Musselshell; the Crazy mountains between the Musselshell and Yellowstone rivers; and the Pryor and Bighorn mountains south of the Yellowstone. The Pryor mountains, lying wholly within Montana, are the northwestern portion of the Bighorn Mountains uplift, which was completely bisected by the Bighorn River.

Most of the mountains enumerated above are relatively low, in groups which are 10 to 40 miles across, each of which consists of a maturely eroded dome, exposing in most groups a central core of resistant igneous rocks. Only the higher peaks of the Little Belts, Big Snowy, Crazy, and Bighorn mountains have been glaciated into saw-tooth or serrated summits, whereas the other peaks, although usually steep and rugged, have more or less rounded or nearly level summits. The highest summits occur in the Crazy Mountains, which, although carved from nearly flat sediments intruded by resistant igneous rocks, are over 11,000 feet above sea level, or 6000 feet above the surrounding plains.

Eastern Montana consists of a broad, nearly level or gently sloping plain, above which remnants of former plains and slopes still remain to form mesas, buttes, and cuestas. Cut into the plain are the youthful to mature valleys of the present streams, which, in some places, have developed broad flood plains, and, in other places, still flow in narrow, although not very deep, gorges. In most places the insequent tributary streams of the larger rivers, throughout a zone varying in width from less than a mile to over 10 miles, have cut the prairie plain into breaks or bad lands.

The prairie plains slope in general toward the north and northeast, so that the elevation of the dominant rolling prairie plain ranges from 4000 feet above sea-level in Central Montana to 2300 feet in the extreme northeastern part of the state. Into this plain the larger rivers have cut their valleys to a depth of 100 to 500 feet. The lowest elevation in the state occurs where the Missouri and the Yellowstone cross the North Dakota boundary, each at an elevation of somewhat less than 1900 feet above sea-level.

Few of the buttes, mesas, or cuestas surmount the prairie level by more than 500 to 1000 feet. The principal mesas are the gravel covered plateaus along the Canadian border(1); Larb Hills between the

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(1) Described by A. J. Collier, Geology of northeastern Montana; U. S. Geol. Survey, Prof. Paper 120-B, page 19, 1918.

Milk and Missouri rivers; the Piney and Black buttes north of the Missouri; the Sheep and Little Sheep mountains north of the Yellowstone; Bull Mountains between the Musselshell and Yellowstone rivers; Pine Ridge between the Yellowstone and Bighorn rivers; and a number of conspicuous white buttes in the southeastern part of the state.

The Wolf and Rosebud mountains are the highest and most extensive of the mesas. Taken as a whole they form a broad synclinal plateau between Little Bighorn River and the deeply eroded northern part of the Black Hills uplift in the southeastern corner of the state. The western portion of the plateau, to which the name of Wolf Mountains is applied, forms a westward facing cuesta, whose steep front slope is from 1500 to 2000 feet high, the maximum elevation of the cuesta being 5663 feet above sea-level. The rocks, and hence the surface of the cuesta, dip gently eastward to elevations of less than 4000 feet. The eastern portion of the plateau, known as Piniele Ridge, forms a far less conspicuous eastward facing cuesta surmounting the lowland plain cut in the non-resistant rocks of the Black Hills uplift. The plateau is deeply cut by the Rosebud, Tongue, and Powder rivers, and near its northern edge is dissected into a number of small mesas and buttes surmountaing the prevailing lowland level, which merges toward the north and east into the rolling prairie characteristic of the greater part of Eastern Montana.

North of the Yellowstone in the vicinity of Forsyth, is a dome shaped uplift 40 by 30 miles, the limbs of which dip at angles up to 40 degrees. Where the more resistant rocks dip more steeply than 10 degrees, conspicuous ridges are formed. Similar ridges occur along the steeply dipping southwestern limb of the Cedar Creek anticline, extending from Glendive on the Yellowstone S. 30° E. into North Dakota. Less conspicuous and smaller ridges or cuestas surround the Black Hills uplift in the extreme southeastern portion of the state.

In a few placees, in and near the dome northwest of Forsyth and west of Jordan between the Piney and Black buttes, are resistant dikes of igneous rocks which form small ranges. Smoky Buttes, west of Jordan, is the most conspicuous, surmounting the prairie level by 400 feet.

GENERAL GEOLOGY.

The sedimentary rocks of Eastern Montana are almost everywhere flat lying or gently dipping. The older sedimentary rocks of Central Montana have, however, been deformed and intruded by igneous rocks, while the sedimentary rocks of Western Montana are still older and more deformed and have been intruded by larger and more frequent bodies of igneous rocks. The base of the main front range of the Rocky Mountain system roughly marks the boundary between the less deformed rocks of Eastern and Central Montana and the greatly deformed and igneous rocks of the western part of the state, and has been taken as the western boundary of the area mapped and described in this report.

Although the sedimentary and metamorphic rocks of Montana range in age from the most ancient, Archean, to the most modern, Quaternary and Recent, those of Central Montana are dominantly of middle age, late Paleozoic and Mesozoic, and those of Eastern Montana are dominantly early modern, late Mesozoic and presumably early Cenozoic. A large part of Central and Eastern Montana is covered by a mantle of loosely consolidated or unconsolidated drift, which north of the Missouri river consists chiefly of glacial detritus. Elsewhere the drift consists of gravels, sands, and muds deposited in the streams and lakes which have drained the mountains to the west, from the time of the mountainous uplift in the early Cenozoic. Of these mantle rocks, however, only the Recent alluvium deposits in the valleys of the larger rivers have been mapped.

The oldest rocks shown on the accompanying map, the Madison limestone, and rocks of the Quadrant formation, are of late Paleozoic, Mississippian and Pennsylvanian, ages. They are exposed only around the flanks of the mountain uplifts of Central Montana. Overlying them, and structurally speaking, virtually conformable with them, although angular unconformities do occur, are the rocks of Mesozoic and early Cenozoic(?) (Fort Union) ages, several thousand feet in thickness. In spite of their great thickness and the great length of time during which they were deposited, no significant angular unconformities, indicating widespread deformation and prolonged erosion occur. There are, however, certain horizontal unconformities or disconformities, indicating time intervals during which there was little or no deposition, but doubtless some local erosion.

However, resting upon the older rocks, with marked angular unconformity, and exposed only in the southeastern part of the state, are sedimentary rocks of early Cenozoic (Oligocene) age, known as the White River beds. Thus it appears as if the only marked period of deformation and igneous intrusion that has affected the Mesozoic and Fort Union rocks of Montana, occurred after the deposition of the Fort Union and previous to the deposition of the White River beds. The exact age of the Fort Union is doubtful. It has been generally considered to be of earliest Cenozoic, Eocene, age, and has been so considered in this report and on the accompanying map. But as discussed later it is perhaps better considered to be of latest Mesozoic, that is, latest Cretaceous age, in which case the period of deformation must have occurred during the Epi-Mesozoic (Mesozoic-Cenozoic) interval or during the Eocene epoch.

During the deformation the rocks of Central Montana were flexed into open folds with a general northwest trend, the actual bearing of the axes of the major folds varying from N. 15° W. to nearly due East and West. Although the limbs of some of the major folds were steeply tilted to angles of 25 to 50 degrees from the horizontal, in most of the folds east of the main front range the limbs were not more steeply tilted than 5 to 10 degrees.

In Eastern Montana the rocks were only slightly tilted toward the northeast, or were gently uplifted to form large, isolated anticlines. With one exception, a relatively narrow anticline in the extreme eastern part of the state, the anticlines are dome shaped uplifts 10 to 50 miles across, from which the component rocks dip away in all directions. The crest of the dome in the southeastern corner of the state occurs in Wyoming, so that in Montana the rocks dip only to the northeast, north, and northwest.

The major axis of folding in Central Montana extends along the crest of the Bighorn Mountains uplift, through a region characterized by several small folds, to the Little Belt Mountains uplift; and thence north along the crest of a broad, northward plunging, uplift, called the Sweetgrass arch, to the Canadion border. The general trend of the axis is N. 33° W. but in detail it varies from N. 15° to 75° W.

The Bighorn Mountains uplift in Montana consists of a northwesterly plunging anticline 30 miles across, striking N. 50° W. Although in places the limbs of the anticline dip at angles of more than 45°, in most places they dip at angles of less than 20°. Furthermore, the rocks flatten out rapidly away from the uplift and the limbs of the major fold, except as described below, are fairly regular and free from faults, although there are several places where the limbs flatten out to form noses or terraces, and along the flanks there are a few closed anticlines and domes.

Along Yellowstone River, in the vicinity of Billings, 25 miles north of the Pryor Mountains, the younger rocks have been affected by the Bighorn Mountains uplift and have been deformed into a number of minor folds broken by numerous faults.(2) The most remarkable feature of the structure is a long narrow belt of faulting 82 miles long, but not more than 6 miles wide, extending from Township 4 North, Range 17 East, to Township 1 North, Range 31 East. The belt trends N. 80° W. but the faults almost universally strike to the northeast, N. 50° E. being the average strike. Hancock(3) suggests torsional movements as a probable cause of the localized faulting along the narrow belt, the torsional stresses resulting from the Big Horn uplift to the south and the group of small uplifts and Little Belt Mountain uplift to the northwest.

North of the belt of faulting and southeast of the Little Belt Mountains uplift there are, as has already been mentioned, several relatively small folds whose axes, like the faults just described, have a general easterly or northeasterly trend. Of these the major folds are the Big Coulee-Hailstone dome, the Shawmut anticline, and the Elk

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(2) For detailed description of the structure see Hancock, E. T., Geology and Oil and Gas Prospects of the Huntley Field, Montana; U. S. Geol. Survey Bull. 711-G, pages 139-140, 1920; and Geology and Oil and Gas Prospects of the Lake Basin Field, Montana, U. S. Geol. Survey Bull. 691-D, pages 131-141, 1918.

(3) Idem.

uplift. The three major structures may themselves be divided into minor anticlines, domes, and terraces, forming on the east and northeast flanks of the Big Coulee-Hailstone dome, the Broadview dome and Belmont terrace, and on the southwest flank the Gibson dome; at the west end of the Shawmut anticline the West, Middle and East Domes; and in the Elk uplift, the Big Elk, Little Elk, Haymaker, and Daisy Dean domes.

The Little Belt Mountains uplift is a large anticline, 85 miles long, and 50 miles across, striking N. 75° W. It plunges in all directions except toward the west and southwest, in which directions it merges into the still larger anticline that forms the Big Belt Mountains, one of the front ranges of the Rocky Mountains. The limbs of the Little Belt Mountains anticline are flexed into several minor folds and are broken by faults. Most of the minor folds plunge away from the major uplift to form a series of radial crests. Some of them, however, are completely enclosed to form domes such as the Skull Butte and Stockett domes.

The Sweetgrass arch, north of the Little Belt Mountains uplift, is a broad, flat topped anticline, 130 miles long, and 80 miles wide. It strikes N. 15° W. and plunges to the northwest. The limbs of the folds dip at very low angles and are flexed into but few minor anticlines or terraces. There may be local anticlines and domes within the arch, but this can be determined only by detailed field work.

Between the major axis of anticlinal folding just described and the axis of much greater deformation along the main front range of the Rocky Mountain system, is a synclinal area 15 to 75 miles wide. It is, however, interrupted in its central portion by an anticline, which extends east from the Big Belt Mountains anticline through the Little Belt Mountains and Big Snowy Mountains anticlines into eastern Montana. Within the synclinal area are numerous, relatively small anticlines and domes. Those south of the Little Belt Mountains anticline are Potter Basin dome, McLeod dome, Dean anticline, Dry Creek dome, and, with only their northern parts within Montana, Elk Basin and Frannie domes. North of the Little Belt Mountains the synclinal area may be divided, as described by Stebinger(4), into two structural areas, an eastern area in which the beds are nearly horizontal or very gently folded, and a western area in which the beds have been greatly folded and broken by faulting. In the eastern area the rocks dip gently westward at an average angle of 20° to 30°, but there are several terraces and anticlines, of which the larger and better enclosed are the Willow Creek anticline, Dupuyer anticline, Scoffin Butte anticline, the anticlines on Birch Creek, the Blacktail Creek anticline, the Cut Bank Creek anticline and one 3 miles to the southwest,

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(4) Stebinger, Eugene, Geology and coal resources of northern Teton Conuty, Montana; U. S. Geol. Survey Bull. 621-K pp. 128-129, 1916; Anticlines in the Blackfeet Indian Reservation, Montana; U. S. Geol. Survey Bull. 641-J., pp. 292-294, 1917; and Oil and gas geology of the Birch Creek-Sun River Area, Northwestern Montana, U. S. Geol. Survey Bull. 691-E., pp. 168-182, 1919.

and an anticline on the North Fork of Milk River. In the western area the folds are all long and narrow and many are broken by strike faults, but there are several enclosed anticlines which are structurally favorable to the accumulation of oil and gas. These are noted and named on the accompanying geologic and structural maps.

The huge east-west anticline, which, as described above, interrupts the synclinal area east of the main front range, has a general N. 81° W. trend, although the western portion strikes more nearly east and west than the eastern portion. The anticline is characterized by several minor anticlines and domes, and hence is properly called an anticlinorium. East of the Little Belt Mountains anticline, which has already been described, there is a well defined anticline along the north and along the south edge of the anticlinorium, the two anticlines being separated by a broad, nearly flat, synclinal area. The outer limbs of the two anticlines dip steeply away from the major axis at angles ranging from 5° to 85°, averaging in the western portion 40° to 50° and in the eastern portion 5° to 10°, whereas the inner limbs dip gently toward the central synclinal area at angles averaging less than 5°.

Just east of the Little Belt Mountains the two anticlines consist of the Big Snowy Mountains uplift on the south and a number of much smaller uplifts forming the Judith and Moccasin mountains on the north. The latter are to a great extent laccolithic uplifts(5) and it is probable that the former is of the same nature, although, as yet, no extensive core of igneous rocks has been exposed by erosion in the Big Snowy Mountains. The asymetrical character of the southern anticline is well developed in the Big Snowy Mountains uplift, but not in the Judith and Moccasin Mountains uplifts. Furthermore, the central synclinal area between the two major uplifts is distinguished by several smaller domes which also appear to be laccolithic in origin(6).

Farther east the two anticlines are known as the Cat Creek anticline on the north and the Devil's Basin anticline on the south. The two anticlines pitch in general to the southeast away from the Judith and Big Snowy Mountains uplifts, but are characterized by several domes, forming completely enclosed structures. Along the Cat Creek anticline there are from west to east the Black Butte, Kootenai, Brush Creek, Oiltana, West Mosby, and East Mosby domes. Along the Devil's Basin anticline there are from west to east the Devil's Basin, Big Wall, Howard Coulee and Ragged Point domes.

Between the Cat Creek and Devil's Basin anticlines the synclinal area is warped into broad open folds, the largest of which consists of the Button Butte terrace and the Flat Willow anticline.

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(5) Weed, W. H., and Pirsson, L. V., Geology and mineral resources of the Judith Mountains of Montana; U. S. Geol. Survey, Eighteenth Ann. Rept. Part 3, pp. 487-616, 1898.

(6) Calvert, W. R., Geology of the Lewistown coal field, Montana; U. S. Geol. Survey Bull. 390, pp. 48-51, 1909.

East of Musselshell River the two anticlines are less well developed and both culminate and terminate in a single huge dome, 40 by 30 miles, called the Porcupine dome. The anticlines do continue, however, and the northern is represented by the McGinnis Creek dome in township 13 North, Range 34 East, and a terrace on the north flank of the Porcupine dome in townships 13 and 14 North, Ranges 37 and 38 East; and the southern is represented by the Sumatra anticline, Ingomar dome, and a terrace on the south flank of the Porcupine dome in Townships 6 and 7 North, Ranges 37 and 38 East. The only rocks younger than the definitely known Cretaceous (Colorado and Montana) in the entire anticlinorium form a synclinal area of Lance sandstones between the Sumatra anticline and the McGinnis Creek dome.

Between the Devil's Basin anticline and the Big Coulee-Hailstone dome and Shawmut anticline are two anticlines. The northeastern, which plunges to the southeast, is divided into two parts called the Devil's Pocket and Pole Creek anticlines, and the southern, which is completely enclosed with relatively steep dips on the northeast and southwest, is called the Woman's Pocket anticline.

North of the low east-west anticlinorium is another less well developed anticlinorium striking N. 60° W. Along its axis are three groups of dome shaped uplifts, presumably laccolithic in character. These form, from northwest to southeast, the Sweetgrass Hills and Bearpaw and Little Rocky mountains. All of them have a central core of igneous rocks, although those in the Bearpaw Mountains are largely of volcanic origin.

Between the Moccasin and Judith mountains on the south and the Bearpaw Mountains on the north and also to the north of the Bearpaw Mountains are several small anticlinal or monoclinal structures most of them faulted.(7) The better known of these are the structures in the vicinity of Winifred, south of the Bearpaw mountains, and the Havre, Brown's Coulee, Red Rock Coulee, Lodge Creek, Battle Creek, Coal Creek, and Signal Butte anticlines north of the Bearpaw Mountains.

With one exception the Cedar Creek anticline, the major uplifts of Eastern Montana are dome shaped. In the northern part of the state is the Bowdoin dome(8) over 60 miles in diameter but with very low dips, usually less than 1°. On the southeast flank of the Bowdoin dome, completely enclosed but virtually a terrace, is the Poplar dome, 20 miles in diameter. Between the two domes are at least two anclines. The one best developed extends through Wolf Point with a general N. 20° W. trend, with limbs which have a maximum dip of 4°. To the north of the Poplar dome are three low anticlinal areas

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(7) Stebinger, Eugene, Oil and gas in north-central Montana U. S. Geol. Survey Bull, 641-C, pp. 65-88, 1917.

(8) Collier, A. J., The Bowdoin dome, Montana;. U. S. Geol. Survey Bull. 661-E, pp. 205-207, 1917.

forming the Coal Creek dome, Scobey anticline, and Big Muddy Creek dome.

In the central part of Eastern Montana is the Porcupine dome already described and the long relatively narrow anticline, known either as the Cedar Creek or Glendive-Baker anticline, which extends from north of the Yellowstone River, west of Glendive, S. 30° E. into North Dakota. The west limb of the anticline is much steeper than the east limb, having an average dip of about 20° whereas, the average dip of the east limb is less than 5°. West of Baker the west limb is complicated by minor folds, the axes of which are parallel to the major fold.

In the southeastern corner of the state are two dome shaped uplifts with a broad terrace to the west. The uplifts represent the northern extension of the major Black Hills uplift into Montana. Between the two uplifts is a shallow synclinal area which is complicated by both minor parallel and cross folds. The southern and larger of the two uplifts is also complicated by both parallel and cross minor folding to form in places enclosed anticlines such as the Seven Mile and Five Mile domes.

PART II

CRETACEOUS AND TERTIARY CONTINENTAL FORMATIONS

BY

C. H. CLAPP

The rocks which overlie the definitely known Cretaceous rock of the Montana group have been mapped as belonging either to the Lance or to the Fort Union formations. In general they have been formed under very different conditions from the underlying rocks which are largely marine and are continuous and fairly uniform over large areas. The rocks of the Lance and Fort Union formation are almost entirely of fresh water or continental origin, and vary greatly in detail within relatively limited areas; although their general characteristics are persistent through the greater part of Central and Eastern Montana. The age of these two formations has been the subject of a great deal of controversy, which lately has broken out with renewed vigor. It is out of place to discuss the subject in detail in a report of this kind, especially as the authors have not given the matter detailed study.

The United States Geological Survey after a consideration of all available evidence, (9) most of which has been secured by its own investigators, considers the Lance formation to be of doubtful lowermost Tertiary age and the Fort Union to be definitely of Tertiary, Eocene age. Some of the Survey geologists, (10)for several reasons, such as the recently discovered occurrence of a marine member, the Cannonball, in the upper part of the Lance in southwestern North Dakota, which carries a fauna much more closely connected with the Cretaceous than with the Eocene, believe that the Lance is Cretaceous. Schuchert(11) has gone further and considers both the Lance and Fort Union as Cretaceous, basing his conclusion largely on the essential continuity of the Fox Hills, Lance, and Fort Union. With this premise the present author is in complete agreement. Even Knowlton(12) one of the strongest advocates of the theory that the

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(9) Cross, Whitman, Science, April 1, 1921, page 305.

(10) The latest paper is by Stanton, T. W., The Fauna of the Cannon-ball marine member o fthe Lance formation. U. S. Geol. Survey Prof. paper 128-A, 1920.

(11) Schuchert, Charles, Are the Lance and Fort Union formations of Mesozoic Time? Science, pp. 45-47, Jan. 14, 1921.

(12) Knowlton, F. H., Science, April 1, 1921, page 307.

Lance and Fort Union formations are of Tertiary age, states that, "If the Cannonball marine member of the Lance formation is Cretaceous, then both Lance and Fort Union are Cretaceous, for there is no stopping short of the top of the Fort Union." If diastrophism is to be the basis of periods or systems, certainly Schuchert's conclusion is sound, for, from the extensive reconnaissance carried on in Montana, there is no question that there is no essential break, sudden change, or marked deformation following the close of the deposition of the Bearpaw shale until after the deposition of the Fort Union formation.

The late Cretaceous sandstanes of Fox Hills age, variously mapped in Montana as Lennep, Colgate, and Horsethief sandstones so closely resemble the overlying true Lance, it was impossible by rapid reconnaissance to distinguish between them on lithologic or structural grounds. There is no important or widespread erosion interval, and in many places there is no essential lithologic difference between the sandstones which, at the top of the Bearpaw, are found interbedded with it in a transitional zone 30 to 60 feet thick, and the normal sandstones of the unquestioned Lance. Therefore, for the purpose of the reconnaissance mapping all the sandstones and clays largely of fresh water origin directly overlying the Bearpaw Shale were mapped as Lance, and have been considered as of Cretaceous age. The lower limit of the Lance has been placed at the base of the first thick and persistent sandstone overlying the Bearpaw shale.

The upper limit of the Lance has been determined partly by the difference in color between the Lance and overlying Fort Union; the Lance in general being dull and somber, whereas, the Fort Union shows bright, contrasting colors. The limit has been determined largely, however, by the occurrence, either of the Lebo shale, the basal member of the Fort Union, or of the lowest persistent coal or lignite seam. In this report, following the practice of the United States Geological Survey, the Fort Union has been considered as of Tertiary, Eocene, age.

Fort Union formation.—The Fort Union formation was named in 1862 by Meek and Hayden(13) from a former military post on the Missouri River in North Dakota, about 3 miles from the Montana boundary, where the formation is typically exposed. For several years the rocks of the Fort Union and Lance formations were referred to the Laramie, but since 1907, when detailed work in the lignite and coal areas of Montana and North Dakota was begun by the United States Geological Survey, the rocks have been definitely subdivided into the Lance and Fort Union formations.

The Fort Union directly underlies the greater part of Eastern

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(13) Meek, F. B., and Hayden, F. W., Description of new lower Silurian (Primordial), Jurassic, Cretaceous, and Teritary fossils collected in Nebraska by the exploring expedition nder the command of Capt. W. F. Reynolds, U. S. Topog. Eng., with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Phila. Proc., vol. 13, p. 433, 1862.

Montana and is continuously exposed over an area of nearly 25,000 square miles. It has been largely eroded along the principal rivers, and from the major uplifts, Bowdoin and Poplar domes, Cedar Creek anticline, and the northern extension of the Black Hills uplift in the southeastern part of the state. The only large area of Fort Union rocks in Central Montana, an area of over 1000 square miles in extent, is that of the Bull Mountain coal field, an elliptical synclinal basin, 50 by 30 miles. Smaller areas are also found underlying Pine Ridge, southeast of the Bull Mountain area; in the Red Lodge coal field, and in Crazy Mountains. The former area has been mapped as Lance by Rogers(14), but before the Lance and Fort Union beds were separated as definitely as they are today. Another small area of Fort Union rocks, less than 2 square miles in extent, has been mapped by Bowen(15), six miles east of Big Sandy in Chouteau county. Its presence in this locality, far removed from all other known areas of Fort Union rocks, is due to faulting, which has brought the beds down to the level of older rocks. It is, of course, possible that the coal bearing rocks of the St. Mary River formation and the overlying Willow Creek formation mapped by Stebinger(16) are in part the equivalent of the Fort Union, but the authors have preferred to map them as of Lance age.

The rocks of the Fort Union formation consist of coarse to fine grained, loosely to firmly cemented arkosic (feldspathic and micaceous) sandstones and sandy clays, and clay-shales in about equal amounts. Numerous lignite beds, which grade into sub-bituminous coal seams in Central Montana, occur throughout the formation. As a rule the sandstones are massive, fairly thick bedded, and of a light yellow color, and the clays are either dark or greenish gray, brownish, or nearly white, and where clinkered by the burning of underlying lignites are bright red. In general, therefore, the prevailing appearance of the Fert Union is in marked contrast to the more uniform, dull and somber appearing rocks of the Lance. In places, however, the lithologic distinction is not clear, the prevailing color of the Fort Union rocks being ash gray(17).

Concretions of spherical to cylindrical, log-like shapes are common, especially in the lower part of the formation. The concretions consist of more firmly cemented sandstone in the loosely cemented sandstones, and of calcareous and sideritic (iron carbonate) replacements in the shales. In a few places(18) in the sandstones are lenses of conglom-

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(14) Rogers, G. Sherbune, Geology and coal resources of area southwest of Custer, Montana: Bull. 541-H, pp. 30-31, 1914.

(15) Bowen, C. F., Big Sandy coal field, Montana: U. S. Geol. Survey, Bull. 541-H, pp. 74-75, 1914.

(16) Stebinger, Eugene, Geology and Coal Resources of northern Teton County, Montana: U. S. Geol. Survey, Bull. 621-K, pp. 124-128, 1916.

(17) Stebinger, Eugene, Sidney lignite field, Montana: U. S. Geol. Survey, Bull 471, p. 285, 1912.

(18) Woolsey, L. H., and others, Bull Mountain coal field, Montana; U. S. Geol. Survey, Bull. 647, pp. 27, 1917, and Rogers, G. S., Little Sheep Mountain Coal field, Montana: U. S. Geol. Survey, Bull. 531-F., p. 11, 1913.

erate, consisting of shale and sandstone pebbles in a sandstone matrix. Many of the sandstones are locally laminated and cross stratified as a result apparently of depositions both from water and from wind. In the shales, many of which are calcareous, there are in places, many flakes and small crystals of gypsum, so that the weathered surface resembles in places the outcrop of the Bearpaw shales. In the Bull Mountain area there are also thin layers, 1 to 3 feet thick, of buff limestone(19).

The Fort Union formation is in most places readily subdivided into a lower part consisting largely of clay-shale, sandy shale, and soft sandstone, which has been called the Lebo shale member(20) and an upper part consisting chiefly of sandstones more massive and resistant than any of those found in the Lebo shale member. Over a large area in Central and the western portion of Eastern Montana, the Lebo shale contains a considerable amount of tuffaceous andesitic material, and it is on the basis of this and of stratigraphic position also(21) that correlation is made with the "Lebo shale andesitic member of the Fort Union," at the type locality northeast of Crazy Mountains.

In the extreme eastern part of the state there is little distinction in the lithology of the lower and upper parts of the Fort Union. Coal and lignite seams are found in both the Lebo shale and overlying sandstones, but few of the seams in the Lebo shale proper are of the best quality and in many places are merely carbonaceous shales(22).

The Fort Union rocks, at least south of the area covered by glacial drift, are well exposed. Where flat lying or nearly so, the sandstones form buttes, mesas, and terraces, terminated by scarps, 50 to 100 feet high. In places the sandstones weather into smooth rounded faces, but more commonly into fantastic forms and pinnacles with honey-combed surfaces. The shales weather into gentler and smoother slopes and rounded buttes, and in favorable places into badland topography. Where more steeply dipping, the sandstones form ridges or cuestas, between valleys cut in the less resistant shale.

Although local unconformities occur in most places, the Lance formation and the Lebo shale appear to be generally conformable and to represent virtually continuous deposition. The same is true of the contact of the Lebo shale with the overlying and much thicker part of the Fort Union formation, and therefore, although erosion has removed hundreds of feet from the top of the Fort Union, no significant amount of erosion has occurred during its accumulation. The Lebo shale is estimated to be from 200 to 300 feet thick, but as mentioned, thins out to nothing in the eastern part of the state. The

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(19) Woolsey, L. H. and others, Bull Mountain coal field, Montana; U. S. Geol. Survey, Bull. 647, p. 28, 1917.

(20) Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation of Montana: Econ. Geology, vol. 5, p. 746, 1910.

(21) Rogers, G. S., Little Sheep Mountain coal field, Montana: U. S. Geol. Survey, Bull. 531-F., p. 15, 1913.

(22) Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Montana: U. S. Geol. Survey, Bull. 711-G, pp. 126-127, 1920.

Fort Union is variously estimated throughout Eastern Montana from 1000 to 1400 feet thick, but to the west it thickens. In the Bull Mountain area, where presumably the amount of erosion is greater than in Eastern Montana, the upper part of the formation alone is 1650 feet thick, and although the Lance and Fort Union formations do not appear to have been definitely separated in the Red Lodge and Crazy Mountains areas, yet the undoubted Fort Union rocks are at least 2800 feet in the former(23) and over 3000 feet in the latter area(24).

Detailed sections of the Fort Union are given in most of the United States Geological Survey publications dealing with Eastern Montana. One of the most instructive is the generalized section given by Calvert(25) of the Sidney lignite field.

The Fort Union contains a very large flora, approximately 500 species(26), generally acknowledged to be Eocene. It has a far less abundant fauna, consisting of fresh water shells, some vertebrates, and even small mammals, that is less generally believed to be Eocene. The plants and shells as well as the numerous coal seams indicate, however, that the Fort Union was deposited in fresh or nearly fresh water, presumably in inland streams and lakes, and possibly in estuaries.

Lance formation.—The name Lance formation, first used by Stanton(27) is an abbreviated form of the term "Lance Creek beds" used by Hatcher(28) to designate what had been previously called the "Ceratops beds" of the Laramie. Since Stanton's use of the term in 1910, all of the rocks underlying the Fort Union and overlying the Bearpaw shales or the Fox Hills sandstone have been called Lance, and none of the rocks of Central and Eastern Montana have any longer been referred to the Laramie.

The Lance formation outcrops so as to form a broad belt, 3 to 60 miles wide, averaging 25 miles wide, between the predominating Fort Union rocks of Eastern Montana and the predominating Mesozoic rocks of Central Montana. It is further exposed in Eastern Montana along the larger rivers and on the flanks of the larger uplifts, the Cedar Creek anticline and the northern extension of the Black Hills uplift, and at the crests of the smaller uplifts, like the Coal Creek dome, Scobey anticline, and Big Muddy Creek dome. In Central Montana, south of the Little Belt-Big Snowy anticlinorium, the formation

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(23) Woodruff, E. G., Red Lodge coal field, Montana: U. S. Geol. Survey, Bull. 341, p. 94, 1909.

(24) Stone, R. W., Coal near the Crazy Mountains, Montana: U. S. Geol. Survey, Bull. 341, p. 82, 1909.

(25) Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey, Bull. 471, p. 199, 1912.

(26) Knowlton, F. H., Science, April 1, 1921, p. 307.

(27) Stanton, T. W., Fox Hills sandstone and Lance formation in South Dakota, North Dakota, and eastern Wyoming: Am. Jour. Sci., 4th ser., vol. 30, p. 172, 1910.

(28) Hatcher, J.B., Relative age of the Lance Creek beds of Converse County, Wyo., the Judith River beds of Montana, and the Belly River beds of Canada; Ann. Geologist, vol. 31, p. 369, 1903.

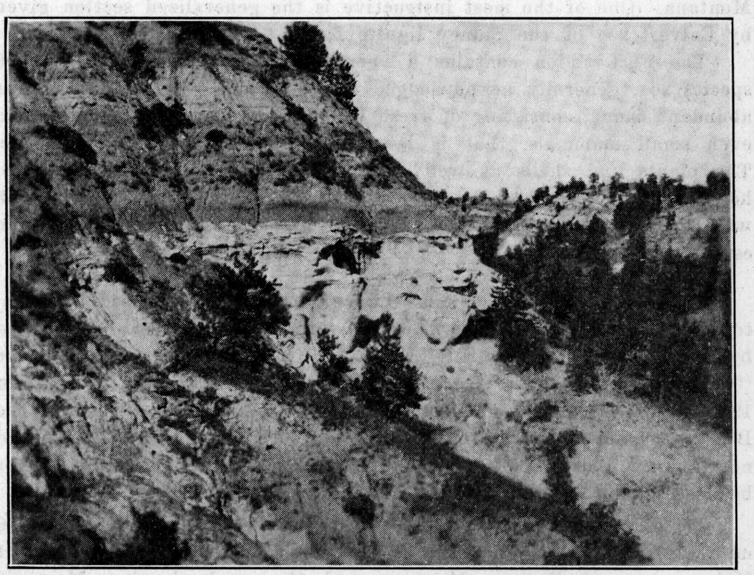

PLATE IV.—LANCE FORMATION.

A typical exposure of the Lance formation showing the white basal member, Colgate sandstone, and the overlying somber-colored shales and sands. Sec. 8. T. 19 N., R. 29 E.

is exposed around the flanks of the Bull Mountain syncline, and underlies the greater part of the synclinal area between the major anticlinal axis and the main front range of the Rocky Mountains. There are also a few small outliers between the two synclinal areas. North of the anticlinorium the Lance forms two synclinal areas, one south of the Little Rocky Mountains uplift and the other to the north, extending into Canada. Between the Sweetgrass arch and the main front range, the rocks of the St. Mary River and Willow Creek formations, referred by Stebinger(29) to the Tertiary(?) Eocene(?), and also the Horsethief formation of Cretaceous age, have been mapped by the authors as the equivalent of the Lance.

The Lance formation is composed of alternating beds of dull grayish to greenish yellow, soft to hard sandstones, greenish to gray sandy shale, drab, yellow, gray, and in a few places brown clays, and clay-shale. In most places the sandy rocks predominate and the prevailing dull neutral colors have given rise to the name "somber beds." West of the Sweetgrass arch, the St. Mary River formation is chiefly maroon to chocolate brown in color, so that the formation has a predominating brownish red appearance, due partly to the covering of red soil.

The sandstones are noticeably harder, coarser grained, even arkosic and conglomeratic in places, and more massive in the lower part of the formation. In the upper part there are numerous carbonaceous layers and a few relatively thin and non-persistent seams of impure lignite and high-ash coal. At least in the northeastern and northwestern parts of the Lance area in Montana there are a few relatively thin lentils of impure limestone(30). The sandstones, particularly the lower and more massive ones, are cross bedded and ripple marked, and contain numerous dark brown, iron stained concretions, some spherical and rounded, others cylindrical and log-like up to large sizes, 3 feet in diameter and 20 to 30 feet long.

Although the Lance formation in most places is readily divided into three subdivisions, a lower part consisting chiefly of massive sandstone, a middle part of alternating clays and soft sandstones, and an upper carbonaceous or lignitic part, yet it was not feasible to make the subdivision during rapid reconnaissance mapping. The lower massive sandstones contain in several places an undoubted Cretaceous marine fauna and are best considered as of Fox Hills age. Fox Hills beds have been definitely determined bordering the Cedar Creek antinicle just east of the Montana line in North and South Dakota(31), but the same beds have been included in the Colgate sandstone mem-

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(29) Stebinger, Eugene, Geology and coal resources of northern Teton County, Montana: U. S. Geol. Survey, Bull. 621-K, p. 124, 1916.

(30) Smith, C. D., The Fort Peck Indian Reservation lignite field, Montana: U. S. Geol. Survey, Bull. 381-A, p. 43, 1910, and Stebinger, Eugene, Op. Cit. p. 27.

(31) Winchester, D. E., et al., The lignite field of northweetern South Dakota: U. S. Geol. Survey, Bull. 627, pp. 17-18, 1916.

ber of the Lance formation in Montana(32). The sandstones and shales overlying the Bearpaw shales along the Missouri River north of Jordan, have also been referred to the Fox Hills sandstone by Leonard(33).

In the upper Musselshell Valley, an assemblance of andesitic sandstones and dark shale between the Bearpaw and Lance formations has been designated as the Lennep sandstone(34). The fossil shells found in the formation are about equally fresh, brackish water, and marine, and are more closely related to the Cretaceous than to the Tertiary. It occupies the stratigraphic portion of the Fox Hills and has been included in this report with the other basal members of the Lance.

In the northeastern part of Central Montana, the Horsethief sandstone overlies the Bearpaw shale and underlies the Tertiary(?) formations. It consists chiefly of a sandstone, which becomes shaly toward the base, and to the south near Augusta, contains some conglomerate with well rounded pebbles of fine grained igneous rock. In places the sandstone is exceedingly fossiliferous, some beds being almost entirely composed of oyster and other shells. The fauna is Cretaceous and of both brackish water and true marine, although near-shore types(35). This formation has also been included in this report with the other basal members of the Lance.

The upper lignitic portion of the Lance is doubtless best correlated with the Ludlow lignitic member of the Dakotas(36). However, in reconnaissance mapping, as already mentioned, the contact between the Lance and Fort Union, where not marked by the Lebo shale was placed at the contact of the beds of dull and bright colors, or at the lowest persistent coal seam, both of which vary considerably in position. As a result, most of the beds in Montana of the same horizon as the Ludlow lignitic member have been placed in the Fort Union.

Like the Fort Union rocks, those of the Lance formation are well exposed south of the area covered by glacial drift. Furthermore, where flat lying, the sandstones form buttes, mesas, or series of scarps, 50 to 100 feet high, whereas, the shales weather into smooth, gentle slopes and rounded buttes, and in favorable places into bad land topography. Where more steeply dipping, the sandstones form cuestas and hogbacks, separated by narrow valleys cut in the soft shales.

The basal sandstone of the Lance formation is thickest near the mountains and thins slightly to the east. In the northwestern

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(32) Calvert, W. R., Geology of certain lignite fields in eastern Montana: U. S. Geol. Survey, Bull. 471, pp. 189 and 194-195, 1912.

(33) Leonard, A. G., The Cretaceous and Tertiary formations of western North Dakota and eastern Montana: Jour. Geol., vol. 19, p. 515, 1911.

(34) Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation of Montana: Econ. Geol., vol. 5, p. 746, 1905.

(35) Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90-G, p. 62, 1914.

(36) Winchester, D. E., et al., The lignite field of northwestern South Dakota: U. S. Geol. Survey, Bull. 627, pp. 19-22, 1916.

part of Central Montana the Horsethief sandstone varies from 250 to 400 feet thick. In the upper Musselshell Valley, the Lennep sandstone is 315 feet thick. Farther east the Colgate and Fox Hills sandstone varies in thickness from 50 to 200 feet. In like manner the upper part of the Lance thins eastward, but more noticeably. Along the mountain front, the upper Lance varies from 1400 to 1700 feet thick. It thins so rapidly to the east that it is 700 to 800 feet thick in east Central Montana, 500 feet in southeastern Montana, and only 200 feet thick in northeastern Montana.

Detailed sections are given in nearly all of the United States Geological Survey publications dealing with the Lance formation, but vary so from place to place that they are of little value in a general description.

The Lance formation like the Fort Union, contains a rich flora, comprising about 125 forms, of which 87 species(37) have been positively identified. Invertebrate fossils are not numerous except in the basal marine beds. On the other hand, numerous fossil vertebrates, the most striking of which si the large three-horned **Triceratops,** have been found. It is quite certain that in places a portion of the basal beds seem to have been deposited in fresh or brackish waters. Cross bedding and ripple marks indicate deposition by streams and in places, even by wind. In Montana the upper beds appear to have been entirely of continental or fresh water origin, having been deposited in streams, lakes and possibly estuaries.

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(37) Knowlton, F. H., Science, p. 307, April 1, 1921.

MESOZOIC AND PALEOZOIC SYSTEMS

BY

ARTHUR BEVAN

Since it is the purpose of this part of the report to present the principal features of the Mesozoic stratigraphy of the Montana Great Plains the observations of the writer and other members of the State Bureau of Mines' field parties have been rather freely supplemented by the use of data from the published reports upon the region. Numreous publications have appeared, mainly from the United States Geological Survey, which treat of particular districts, although a few discuss stratigraphic units, but so far the great body of data afforded by the many field studies have not been conveniently assembled. Although the Mesozoic formations are here discussed in some detail the treatment is by no means exhaustive. The Paleozoic formations, in so far as they appear in this province, are discussed briefly with reference to the features that have a bearing upon the petroleum resources of the state. The articles which have been consulted are listed in the bibliography, and foot-note references to sources are made wherever appropriate.

THE MESOZOIC

Formations of Mesozoic age appear at the surface or underlie the surficial mantle of alluvium and glacial drift throughout approximately half of the Great Plains province in Montana. They cover all the area north of the Missouri River from the Rocky Mountains to Eastern Montana, with the exception of limited areas of Lance sediments adjacent to the mountain front, igneous rocks in the Bearpaw Mountains, the Sweetgrass Hills, and the Little Rocky Mountains, and Paleozoic sediments in the last two uplifts. The area between Missouri River on the north, Rocky Mountains on the west, and Musselshell and Little Bighorn rivers on the east is occupied mainly by Mesozoic sediments. A broad tongue reaches southeast from this area in the vicinity of Mosby on Musselshell River into Yellowstone Valley west of Forsyth, while a parallel embayment of Lance and Fort Union rocks extend northwest from this point through Bull Mountains and across Musselshell Valley beyond Roundup. Another broad area of Lance and Fort Union formations covers the Mesozoic along the Rocky Mountain front from the Crazy Mountains to the Wyoming boundary. Elsewhere in this part of the state the surface continuity of the Mesozoic is interrupted only by the isolated mountain uplifts, scattered outliers of younger sediments, or a relatively thin mantle of unconsolidated materials.

The Mesozoic group is now commonly separated into four subdivisions: The Triassic, Jurassic, Comanchean, and Cretaceous systems, all of which are present in the plains portion of the state(38). In this region it includes the formations that are between the Quadrant formation below and the Lance formation above. The Triassic is meagerly present, being restricted to the flanks of the Bighorn and Pryor mountains, where it consists of the Chugwater formation, or ''Red Beds.'' The Ellis formation, which is the main representative of the Jurassic system, is exposed only along the borders of the several mountain uplifts in Central Montana. It is overlain and paralleled in outcrop by the Morrison formation which appears to be transitional between the Jurassic and Comanchean systems. The latter is represented mainly by the Kootenai formation which has a surface distribution similar to that of the Ellis formation but has a wider outcrop due to its greater thickness and gentler dips. Overlying it is the Colorado shale of Cretaceous age, with vast areal extent in the Sweetgrass arch, and less extensive exposures in several of the major uplifts. The remaining formations of this system are included in the Montana group and consist of the Eagle sandstone at the base, the Claggett formation; the Judith River formation, and the Bearpaw shale. These formations, or their equivalents, occupy a considerable part of Central Montana. In the northwestern portion the upper part of the Eagle sandstone and the other formations below the Bearpaw shale are included in the Two Medicine formation. The Livingston formation, which is partly of undoubted Cretaceous and partly of Lance age, borders the Crazy Mountains and extends southeasterly beyond the Yellowstone Valley.

The Mesozoic formations are very largely composed of clastic sediments, mainly sandstones and shales, of which the latter are greatly preponderant. A striking feature of the sequence is the alteration of shale and sandstone formations, each of which has persistent lithologic homeogeneity. As a rule pronounced intercalation of the one kind of sediment in the other is rare except in a few places. Thin limestones occur sparingly but are mainly confined to the Ellis formation, with local lenses and thin beds in the Kootenai formation. Coal is widespread and abundant in some of the formations, especially in the Kootenai, although workable beds are present in several places in the Eagle, Judith River, and Two Medicine formations. The Chugwater formation contains thick gypsum beds at several localities. Igneous material is present in the Mesozoic group only in the form of tuffaceous beds intermixed with variable amounts of sediment at several horizons, chief of which is the Livingston formation.

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(38) Comanchean is here used as the equivalent of the former ''Lower Cretaceous'' in accordance with the prevailing current usage.

Inasmuch as the different formations vary in thickness from place to place throughout the state as well as being either partially removed by erosion or deeply buried in any particular area, it is somewhat difficult to estimate the total thickness of the Mesozoic sediments. However, it may be roughly placed between 2400 feet as a minimum and 8800 feet as a maximum. This includes all the Mesozoic formations of sedimentary origin no matter how widely separated the most complete or the thickest sections may be. The thickest more or less continuous sections that have been measured are in northwestern part of Central Montana, in the vicinity of Bighorn Mountains, and in Musselshell Valley, where a total of 7000, 5700, and 4700 feet respectively have been reported(39).

THE CRETACEOUS SYSTEM.

Formations of Cretaceous age occupy by far the greater part of the vast area over which Mesozoic sediments constitute the surface formations. The only places where older rocks crop out are in the mountain uplifts and over rather limited tracts adjoining a few of them.

The subdivisions of the Cretaceous system (as the term is here used) in the northern Black Hills and the adjacent Great Plains are as follows: Dakota sandstone at the base, Benton group, Niobrara formation, and Pierre shale(40). Farther north in South Dakota the Pierre is overlain by the Fox Hills sandstone which constitutes the youngest formation of positive Cretaceous age in this province. Some of the early surveys in mapping the Cretaceous formations of the Rocky Mountains and the bordering Great Plains of Montana used the divisions, Dakota, Colorado, and Montana, although the term Benton was widely used for the shales above the so-called Dakota sandstone.

Recent extensive detailed examination by the U. S. Geological Survey of many Cretaceous areas in the state has apparently demonrtsated beyond reasonable question that the Dakota sandstone is nowhere present in this state. Thus it is erroneous and misleading to call any beds in Montana the ''Dakota sandstone''(41). Inasmuch as the Niobrara can not be recognized in Montana as a distinct unit and the section between the Kootenai and the basal Montana includes more than the typical Benton group the use of the latter term has become inappropriate. It has therefore been supplanted by the Colo-

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(39) Stebinger, Eugene, Geology and coal resources of northern Teton County, Montana: U. S. Geol. Survey, Bull. 621-K, p. 124, 1916; Hares, C. J., unpublished data, and Darton, N. H., Geology of Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, Plate VI, 1906; and Reeves, Frank, Press Report U. S. Geol. Survey, 1921.

(40) Darton, N. H., and O'Hara, C. C., U. S. Geol. Survey Geol. Atlas, Aladdin folio(No. 128), 1905.

(41) The same criticism probably applies to the Cretaceous classification of southern Alberta, where the term ''Dakota'' has persisted from the early surveys. See Stebinger, Eugene, U. S. Geol. Survey, Bull. 641-C, pp. 61-62, 1916.

rado for the lower part of the Cretaceous section. The Montana group of this state appears to be the equivalent of the Pierre of South Dakota and may include also the Fox Hills sandstone of that region. Hence at the present time the two-fold division of the Cretaceous into the Colorado shale and the Montana group is accepted for Montana. The Montana group has been further subdivided throughout the state, and these divisions are discussed below.

THE MONTANA GROUP.—The Montana group includes all formations of undoubted Cretaceous age above the Colorado shale. The term was first applied by Eldridge to the Fort Pierre and Fox Hills formations near Denver, Colorado(42), and later to the similar section in the Bighorn Basin in northwestern Wyoming and southern Montana(43). Throughout the greater part of the region this group consists of Eagle sandstone at the base, Claggett formation, Judith River formation, and Bearpaw shale, each of which forms a distinct lithologic unit. The Claggett and Bearpaw, however, are so nearly identical in many places that they can be distinguished only by noting the stratigraphic sequence. There is no difficulty in doing this if the prominent Lance sandstones are taken as a datum plane, or if the Colorado shale and Eagle sandstone are recognized. The Eagle and Judith River sandstones are somewhat dissimilar but may be mistaken for each other in areas of obscure outcrops. The best method, then, of identifying the several formations of this group is to note the succession carefully. Where the strata are steeply dipping this can be done by a glance at the topography, as the Claggett and Bearpaw will then occupy conspicuous depressions between prominent sandstone ridges. These sandstones are invaluable aids in deciphering the structure of many areas, for the shales of this group seldom exhibit bedding clearly.

With a change in the nature of the sediments in the northwestern part of Central Montana the divisions of the Montana group become Virgelle sandstone, Two Medicine formation, and Bearpaw shale. In this section the Virgelle and the overlying Horsethief are the best key horizons. These two sandstones are nearly identical in composition and appearance but they can be readily distinguished by means of their distribution and stratigraphic relations.

In some areas it is almost impossible to identify with certainty any particular division of the Montana group owing to the meager and widely scattered outcrops of formations which change markedly in lithology within short distances. The difficulty is greatly increased by the existence of complex structure, due to pronounced folding or faulting, which has been generally concealed by widespread deposits of glacial drift or terrace gravels. Such tracts exist at several places,

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(42) Eldridge, G. H., Method of grouping the formations of the Middle Cretaceous: Am. Jour. Sci., 3d ser., vol. 38, pp. 313-321, 1889.

(43) Eldridge, G. H., A geological reconnaissance in northwest Wyoming: U. S. Geol. Survey, Bull. 119, pp. 23-24, 1894.

chiefly in the northwestern part of Central Montana. For mapping purposes the problem has been solved by designating such areas as "Montana undivided." There are a few other areas, as in the Bighorn Basin, where the typical characteristics of the individual formations change to such an extent that the Montana group can not be subdivided without a detailed survey of the region. The term "Montana undivided" is likewise used here in mapping the entire group or such part of it as may be present.

The thickness of the Montana group is so considerable that it can not be determined readily at a single locality or even in a small area. Complete sections that have been measured along the northwest side of Elk Basin and near Bridger, in Carbon County, where the group appears to be the thinnest, give a thickness of 1185 and 1069 feet respectively(44). A more recent measurement of the formations in Elk Basin gives a thickness of approximately 1815 feet to the Montana, but it appears that the summit of the Bearpaw has been taken at a higher horizon(45). A generalized section shows a thickness of 1750 feet in Lake Basin, 2000 to 3050 feet in Musselshell Valley, 2050 to 2275 feet in Phillips County, and 3020 feet in Glacier County.

Bearpaw shale.—The name Bearpaw shale was first applied to the thick body of shale that forms the upper part of the Montana group on the flanks of the Bearpaw Mountains(46). As a result of its stratigraphic position and the widespread erosion of younger formations it probably has a greater areal extent than any other Mesozoic formation. It is continuously exposed over thousands of square miles in the east- and south-central parts of the state and is present immediately beneath the mantle of glacial drift over a vast area north of the Missouri River. It is exposed along the valley of the lower Musselshell River and from there southeastward to the Porcupine dome. Another extensive area exists in Lake Basin northwest of Billings from which it crosses Yellowstone Valley east of Huntley and stretches southward between the Bighorn and Little Bighorn rivers. In the northwestern part of the region it occurs on the west flank of the Sweetgrass arch. The broad expanse of Lance and Fort Union in the eastern part of the state is undoubtedly underlain by it, as is shown by the belt of Bearpaw shale that surrounds the Porcupine dome, the belt of similar shale (Pierre) along the axis of the Cedar Creek anticline, southeast of Glendive, and the extensive area in southeastern Montana.

Throughout the greater part of the area which it occupies the Bearpaw shale rests upon the Judith River formation, but in the

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(44) Fisher, C. A., Southern extension of the Kootenai and Montana coal bearing formations in northern Montana: Econ. Geol., vol. 3, pp. 94-96, 1908.

(45) Section measured by C. J. Hares and quoted by E. T. Hancock. U. S. Geol. Survey, Bull. 691, p. 1. XVII, 1918.

(46) Stanton, T. W., and Hatcher, J. B., Scence, new ser., vol. 18, p. 212, 1903. See also, U. S. Geol. Survey Bull. 257, p. 13, 1905.

northwestern part of Central Montana it overlies the Two Medicine formation(47). In the latter area it lies beneath the Horsethief sandstone; in the Musselshell Valley from Lavina westward it is immediately below the Lennep sandstone; while elsewhere it underlies the Lance formation.

The Bearpaw shale is typically a dark gray, clayey shale that weathers into a distinctive alkaline, infertile gumbo soil. Small crystals and crystalline flakes of gypsum are abundant throughout the formation, being especially noticeable upon the weathered slopes. In consequence of the abundance of gypsum, water from the formation is commonly too alkaline for domestic use. Concretions of dark gray, fine-grained limestone are sparsely scattered through the shale in most places but in places they are grouped in bands or zones. They weather reddish-brown on the surface and after long exposure crumble to a scattered mass of small angular fragments which somewhat protect the shale at that place from erosion. Many of these concretions contain much sideritic calcite, and cone-in-cone structure is rarely present. As a rule they are one to two feet in diameter but some as large as 12 to 15 feet have been reported southeast of Havre(48).

In some districts the Bearpaw becomes distinctly sandy either in zones or throughout most of the formation and thus, to a greater or less extent, loses its characteristic lithologic nature. One phase of this change is well shown in the Lake Basin field(49). Here several sandstone beds appear at various horizons and form conspicuous ledges and gentle dip-slopes that break the monotony of the subdued topography that is generally developed on the shale. Sandy shales and sandstones are especially prominent as the adjacent formations, particularly the Judith River, are approached, but occur in some localities well within the main mass of typical Bearpaw shale. These sandstones are commonly yellowish though locally a layer is white. They are rather coarse-grained with local thin conglomerates, as a rule strongly cross-bedded, and contain plentiful plant remains in a more or less fragmentary condition. Some of the sandstones in many places weather into great numbers of conspicuous, hard, flattish, rusty concretions. A notable peculiarity in certain portions of Lake Basin is the occurrence of andesitic sandstones that cap long narrow ridges. Subordinate amounts of tuffaceous material are present at various horizons. Another noteworthy feature here is carbonaceous shale which passes locally into beds of lignite about a foot thick. There is considerable lateral variation in this field in the nature of the sediments, even in short distances, sandstones frequently giving way to typical clay shale in the same ridge or a thick section of dominantly sandy beds in one

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(47) The upper part of the Two Medicine formation is equivalent to the Judith River formation.

(48) U. S. Geol. Survey Bull. 257, p. 48, 1905.

(49) Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Montana: U. S. Geol. Survey Bull. 691-D, 1918.

place may be replaced near by with a sequence of interbedded thin sandstones and thick shales.

The sandy phase of the Bearpaw is exhibited west of the Lake Basin district between Harlowton and Big Timber and in Yellowstone Valley west of Columbus. In this region the sandstones become so preponderant that it is only by careful tracing of the formation from its typical development east of here that it can be separated from the underlying Judith River or the overlying Lance. Farther west and southwest the strata are entirely of sandstone and pass into the so-called Livingston formation, from which the Bearpaw can be differentiated, if at all, only by persistent detailed work.

A somewhat similar change takes place in the northwestern part of Central Montana in the vicinity of Dupuyer Creek in southern Pondera County. The Bearpaw is typically developed north of here to far beyond the Canadian boundary while to the south the "dark shale grades within a short distance into light-colored sandstones and clay shale that are identical with the prevailing materials in the Two Medicine formation and south of Dupuyer Creek can not be separated from that formation"(50).

Typical exposures of the Bearpaw are abundant throughout the area where it appears at the surface but owing to the fact that it weathers readily extensive sections are rare. This seeming defect is counterbalanced by the homogeneity of the formation from top to bottom in its typical development, and thus almost any cut bank in it gives a good idea of the whole formation. Several detailed sections of the sandy phases are given by Hancock in the Lake Basin field(51). A complete section is shown on the south flank of an anticline along the Harlowton-Big Timber road in the southwestern part of T. 15 E., R. 6 N. Other complete sections which include the entire underlying Judith River and Claggett formations are readily accessible along the steeply dipping south limb of the Devil's Basin anticline, northeast of Roundup.

In consequence of the universal occurrence of the typical Bearpaw between two prominent sandstone formations, the common topographic expression of the much weaker shale is a marked depression bounded by conspicuous dip slopes or escarpments. This is especially true where the dip is steep, as south of Lavina, in Musselshell (now Golden Valley) County. Where the strata are horizontal or nearly so the Bearpaw area is generally a monotonous expanse of low rounded ridges and hills beyond the base of a more or less prominent Lance escarpment. Resistant sandstones give rise in places to ridges and long dip slopes within the formation but these are exceptional outside of the Lake Basin district.

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(50) Stebinger, Eugene, Oil and gas geology of the Birch Creek-Sun River area, Northwestern Montana: U. S. Geol. Survey Bull. 691-E, p. 166, 1918.

(51) Hancock, E. T., Geology and oil and gas prospects of the Lake Basin Field, Montana: U. S. Geol. Survey Bull. 691-D, pp. 121-123, 1918.

The thickness of the Bearpaw has been measured at various places throughout the state. It is reported in the northwestern part of the region to have a total thickness of 500 feet which increases to 1000 feet in Valley County and reaches a maximum of 1150 feet in eastern Fergus County. Southward from here the formation gradually decreases to about 500 to 600 feet in Yellowstone Valley and to 130 feet in the northern part of Elk Basin.

The Bearpaw contains an abundant fauna, about fifty species of marine invertebrates having been identified from various collections in it. Most of the fossils occur in the calcareous concretions and become very conspicuous as these masses crumble upon exposure to the weather. Wherever these weathered concretions are present, a few specimens can nearly always be found and on many slopes several species can be collected in a few moments. Such a place is about six miles north of Melstone in Sec. 36, T. 11 N., R. 30 E. Other typical localities with representative lists of fossils collected therefrom are given in several previous reports(52). Of these numerous forms, among the most characteristic are **Baculites compressus, Baculites ovatus,** and **Scaphites nodosus,** but species of **Inoceramus, Mactra, Ostrea,** and **Placenticeras** are common. This invertebrate fauna is very similar to that of the underlying Claggett shale but differs in that the fossils are more abundant and the species are more diverse. Of 32 forms listed by Bowen from the Bearpaw only ten are present also in the Claggett. A few fossils other than invertebrates have been found in some parts of the state. Scattered remains of skeletons of gigantic marine reptiles have been collected in the western part of Valley County(53).

E. T. Hancock reports an abundance of **Halymenites,** petrified wood, and stems and leaves of plants from the sandstones and associated carbonaceous shales in the Bearpaw of Lake Basin(54).

Judith River formation.—Except in the northwestern part of the Great Plains province the Bearpaw shale is everywhere underlain by a series of sandstones and shales which has long been known as the Judith River formation. This name was originally applied by F. V. Hayden in 1871 to typical exposures of these strata near the mouth of Judith River(55), but it was not until more than thirty years later that the proper position of the formation as a member of the Montana group was definitely determined(56). Since then there has been considerable discussion in regard to the exact horizon of

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(52) U. S. Geol. Survey Prof. Praper 90-I, p. 102; Prof. Paper 120-B, p. 30; Bull. 647, p. 21.

(53) Collier, A. J., Geology of northeastern Montana: U. S. Geol. Survey Prof. Paper 120-B, p. 30, 1918.

(54) Op. cit. pp. 121-122.

(55) Hayden, F. V., Geology of the Missouri Valley: U. S. Geol. Survey Terr. Prelim. (Fourth Ann.) Rept., p. 97, 1871.

(56) Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, 1905.

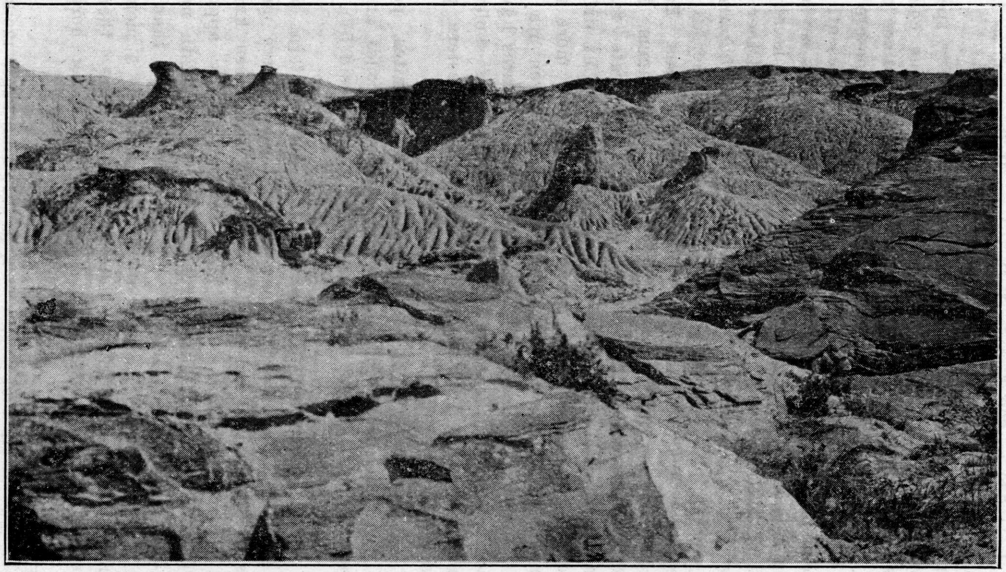

PLATE V.—JUDITH RIVER FORMATION.

Badlands developed in the flat-lying Judith River formation on Rattlesnake Creek, T. 27 N., R. 21 E.

these beds but much recent detailed work has confirmed the earlier conclusions(57).

The areal extent of the Judith River is much more restricted than that of the Bearpaw. Its distribution north of Missouri River is considerably obscursd by the widespread mantle of glacial drift but the numerous streams have cut sufficiently deep in many places to expose the formation on the valley slopes. An irregular belt of it several miles wide encircles the Bowdoin dome, from which a broad belt extends westward far up Milk Valley beyond Havre toward the Canadian boundary. Other branches which reach southward from various points along Milk River surround the Bearpaw and Little Rocky mountains before uniting in the broad embayment that occupies Missouri Valley for about fifty miles below the mouth of Judith River. The main outcrop of the formation continues south along the east side of Judith Valley and, growing rapidly narrower as the North Moccasin and Judith mountains are approached, swings sharply around their north slopes. Here it strikes southeasterly as a very narrow band along the north limb of the Cat Creek anticline, then swings around the east ends of the plunging Cat Creek, Flatwillow, and Devil's Basin anticlines, and continues west along the steep southern limb of the latter. It is exposed at several places south of the Big Snowy and Little Belt mountains and on the flanks of numerous local uplifts in Musselshell Valley as far west as Martinsdale. From this valley is continues in a southeasterly direction along the north side of Lake Basin, crosses Yellowstone River between Billings and Huntley, occupies Bighorn Valley in the vicinity of Hardin, then swings south along the east side of the Bighorn uplift to the Wyoming boundary. A branch of this belt swings around the east end of Lake Basin, crosses Yellowstone River a few miles west of Park City, and follows the west side of Bighorn Basin southward. The Judith River is the surface formation in the Ingomar and McGinnis Creek domes and forms the prominent encircling escarpment of the broad Porcupine dome. It also surrounds the northern extension of the Black Hills uplift.

The Judith River formation consists of a series of alternating sandstones, shales, and coal beds which vary greatly in relative proportions and sequence from place to place. In the northern part of the region the sandstones are commonly soft and friable, although locally quite hard, light gray to yellowish, thin-bedded to massive, and contain numerous iron and sandstone concretions, which are more abundant in the basal portion of the formation. The sandstones locally are distinctly cross-bedded and ripple-marked. The intercalated shales are predominantly clayey and as a rule are colored with tints of light gray or brown. With the appearance of dark gray to blackish colors thick beds of the clay shale may closely resemble the Bearpaw shale

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(57) Bowen, C. F., The stratigraphy of the Montana group: U. S. Geol. Survey Prof. Paper 90-I, 1915.

but the lack of characteristic concretions and the presence of thick sandstones render the discrimination less difficult. An oyster bed composed of shells and fragments of **Ostrea subtrigonalis** is a common feature near the top of the formation in many places, and where present forms an excellent horizon marker. Coal beds are prominent in some areas, such as in Milk River Valley between Havre and Harlem, east of Big Sandy, on the northeast side of the Bearpaw mountains, and along the Missouri. The Judith River formation contains most of the coal of this section of the state, but some is present in the Eagle and in a small tract of Fort Union east of Big Sandy. The most persistent bed is near the top of the formation, just below the oyster bed, but as a rule the coals exhibit the same lateral inconstancy as the sandstones and shales so that they may grade into clastic sediments within short distances.

The remarkable lack of lateral persistence of these beds in the original area is clearly pointed out by Stanton and Hatcher(58) in their excellent discussion of the geology of this formation. They state:

> The frequency with which the different strata of sandstones and clays replace one another, both laterally and vertically, together with the great disturbances that have taken place subsequent to the deposition of the Judith River beds, renders it extremely difficult, if not impossible, to fix upon any definite horizons or strata within the limits of the fresh-water series that may be followed and recognized with certainty, even in reasonably adjacent sections. A detailed section taken at any point is of little value, since a similar section made at a distance of only a mile or two would give a quite different sequence of the alternating strata of sandstones and shales.

Although similar conditions apparently exist along the Missouri and throughout the area north of it, in areas farther south the lithology is more constant. In the Porcupine dome the formation is composed of massive light-gray sandstones at the top and base with intervening grayish shales. In Musselshell Valley it consists of three fairly well-defined members: a lower massive, cross-bedded, gray to brown sandstone; a gray to buff clay shale with interbedded sandstones; and an upper series of alternating sandstones and shales with some carbonaceous shale and coal. The sandstones become markedly andesitic toward the Crazy Mountains as is evidenced by the greenish color of the fresh rock and the presence of fresh feldspar and quartz crystals in thin sections. The middle member contains considerable petrified wood and dinosaur bones, while the osyster-bearing horizon is present near the top of the uppermost member(59). This three-fold division is clearly exhibited by the steeply dipping beds between Lavina and Broadview. Coal seams are locally present in this part

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(58) Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 34, 1905.

(59) Bowen, C. F., Anticlines in a part of the Musselshell Valley: U. S. Geol. Survey Bull. 691-F, pp. 191-192, 1918.

of the state but as a rule they are thinner and much less common than in the northern portion.

South of Yellowstone Valley in Carbon County the Judith River becomes a part of the thick series of sandstones that overlies the Colorado shale. It can be readily traced from the north to its crossing of the river east of Columbus but south of here it is included in the "Montana undivided."

On the east flank of the Bighorn uplift the Judith River sandstone can be traced to the Wyoming boundary where it is correlated with the Parkman sandstone.

In the northwestern part of the plains province the Judith River loses its identity through a change in color and character and grades into the Two Medicine formation(60). It can be recognized as far west as Milk Valley several miles above Havre.

The topography of the Judith River formation nearly everywhere is quite distinctive. The massive, more or less firm, sandstones, in flat-lying beds, produce bold cliffs and ledges which are in conspicuous contrast with the soft shales of the overlying Bearpaw and the underlying Claggett. Extensive bad lands have been developed in many places, as in the vicinity of Havre and east of Rattlesnake P. O. Where the strata are considerably tilted the entire formation has been etched by erosion into a series of alternating hogback ridges and narrow depressions. The sandstones commonly form prominent escarpments in the domes, which are especially conspicuous if the underlying shales are exposed. Fine examples of these "Keys to the structure" are exhibited by the Porcupine and Ingomar domes, as well as by portions of several other anticlines.

Typical sections of the Judith River are exposed in many deep valleys, among the best of which are those exhibited in the steep slopes along the lower Judith River and down Missouri Valley for several miles. The exposures are especially fine on the south side of the river, in the area of sharp relief known as "Breaks of the Missouri." Excellent sections may also be observed on the steep limbs of several anticlines in Musselshell Valley, as the south flank of the Devil's Basin anticline and the east side of the Broadview dome. Many exposures occur in the vicinity of Havre, on the south and west sides of the Little Rocky Mountains and in the Bowdoin dome, but none of these afford complete sections.

A detailed section for the Lake Basin field about eleven miles northwest of Billings is reported by Hancock in U. S. Geological Survey Bulletin 691-D, page 118, while another a few miles southeast of Huntley is given by him in Bulletin 711-G, page 123.

The thickness of the Judith River is fairly constant throughout the greater part of the region, but it thins rapidly as its eastern limit is approached. It is estimated to be 400 to 425 feet thick in the

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(60) Stebinger, Eugene, The Montana Group of northwesstern Montana: U. S. Geol. Survey Prof. Paper 90-G, 1914.

Bowdoin dome, about 480 feet near Havre, and 600 feet in the western part of Musselshell Valley. Northwest of Billings it is reported to be nearly 400 feet thick and southeast of Huntley 500 feet thick, but it decreases to 125 feet in the northern part of the Porcupine dome, and still farther east is even thinner.

The Judith River contains an abundance of fossils of considerable variety, including about fifty known species of invertebrates, a similar number of vertebrates, and an extensive flora(61). Formerly all the known forms were brackish, fresh-water, and land types, but marine fossils have been discovered recently. Marine invertebrates are dominant on the northeast side of the Bowdoin dome (T. 33 N., R. 37 E), where the few fresh-water shells (Unios) are confined to the middle of the formation(62). An abundance of the marine seaweed, **Halymenites**, and some marine shells are present on the north side of the Porcupine dome (Sec. 8, T. 12 N., R. 38 E)(63). This fossil seaweed is also very plentiful several miles north of Billings, but farther west in Lake Basin, brackish-water mollusca, leaves, and bones of land animals are the only fossils yct discovered.

Claggett formation.—The Claggett formation, or Claggett shale as it may be called in some areas, is the thick mass of shale or shale and sandstone that is present between the Judith River formation above and the Eagle sandstone below. The name was given by Stanton and Hatcher, in their division of the Montana group, to the section in the vicinity of old Fort Claggett (now Judith) at the mouth of Judith River(64). The areal distribution of the Claggett is very similar to that of the overlying formation except that in the Milk River drainage it is present only in the Bowdoin dome, in a limited area on the northeast side of the Bearpaw Mountains, and from the vicinity of Big Sandy northward beyond the Great Northern Railway. It is exposed in the Ingomar dome but not in the McGinnis Creek dome. It apparently continues below younger formations to the eastern border of the state, and is exposed in the Black Hills uplift.

The Claggett exhibits marked changes in lithology in crossing the state from east to west. In the Bowdoin dome it consists of a dark gray, clayey shale which forms a typical gumbo soil and contains numerous large limestone concretions. Flakes of gypsum which are plentifully scattered throughout the shale, give an alkaline character to nearly all the water from the formation. The same characteristics

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(61) For an excellent recent discussion and tabulation of the fauna see C. F. Bowen, Stratigraphy of the Montana group: U. S. Geol. Survey Prof. Paper 90-I (1915). The flora and fauna have both been described by Stanton and Hatcher, Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257 (1905).

(62) Collier, A. J., Geology of northwestern Montana: U. S. Geol. Survey Prof. Paper 120-B, pp. 28-29, 1918.

(63) Bowen, C. F., Gradations from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125-B, p. 15, 1919.

(64) Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. p. 13, 1905.

exist on the slopes of the Little Rocky Mountains, and in the upper part of the Colorado-Claggett sequence in the Porcupine dome. In all these areas the Claggett is so nearly identical with the Bearpaw that it is recognized mainly by its stratigraphic position. In some places the concretions of the older formation have a well-developed cone-in-cone structure which is a feature that appears to be seldom present in the otherwise identical concretions of the Bearpaw.

In the type area the Claggett is composed of two facies—a typical lower shale member several hundred feet thick, and a thinner upper one of sandstone and shale. This two-fold division persists in variable degree for a considerable distance to the north and south of this locality.

The gradual increase in the proportion of sand from east to west is nowhere more clearly shown than in Musselshell Valley(65).

The Claggett is identical in appearance with the Bearpaw in the eastern part of the valley but near the western border of Musselshell County two thin sandy zones appear. Within 20 miles to the west the sandstones compose half of the formation, while still farther toward the Crazy Mountains the formation merges into the thick series of sandstone and sandy shale which here represents the Montana group and the overlying formation.

Southward toward Yellowstone Valley, and beyond, the sandstones are more variable in character. Along Canyon Creek (T. 1 N., R. 23 E.), sandy shales are interbedded with ripple-marked, thin-bedded sandstones but the latter gradually become less distinct as the river is approached. The sandstones reappear southeast of Billings in lenticular beds which become quite numerous in the valley of Pryor Creek. More persistent, massive sandstones occur to the southeast, which weather cavernous and into fantastic forms similar to the Judith River, but on a less elaborate scale.

There is common throughout the entire area of the Claggett, a sandy transitional zone to the overlying Judith River formation and to the underlying Eagle sandstone, even where the sandy beds otherwise have a very subordinate development or are entirely wanting. This makes it rather difficult in many places to determine the exact limits of the formation, especially where sandstones are prominent in its upper portion. Where this happens it has been customary to include these sandstones in the Claggett, but if all traces of marine fossils are absent in them it may be advisable to call them basal Judith River.

Where the Claggett is composed of shale its topography is identical with that of the Bearpaw, broad lowlands with low rounded hills or conspicuous narrow depressions, according to the dip of the formation. In areas of horizontal beds, as on the "Billings bench," there is a high frontal escarpment of Eagle sandstone with low hills of

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(65) Bowen, C. F., Anticlines in a part of the Musselshell Valley, Mont.: U. S. Geol. Survey Bull. 691-F, pp. 192-193, 1918.

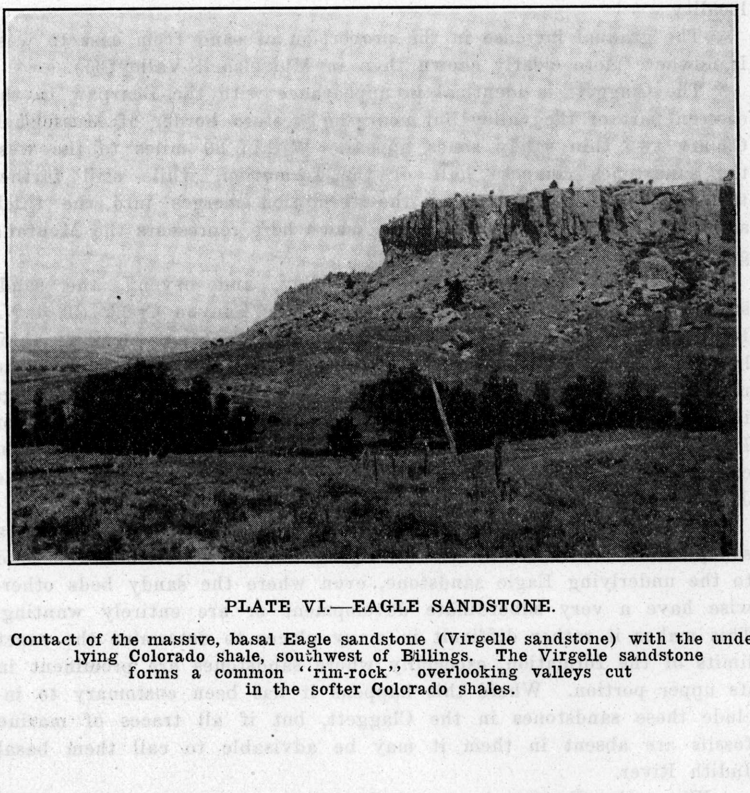

PLATE VI.—EAGLE SANDSTONE.

Contact of the massive, basal Eagle sandstone (Virgelle sandstone) with the underlying Colorado shale, southwest of Billings. The Virgelle sandstone forms a common ''rim-rock'' overlooking valleys cut in the softer Colorado shales.

Judith River far in the background. The more massive sandstones form high cliffs, and where the formation is folded most of them give rise to more or less conspicuous strike ridges.

Complete sections may be readily observed wherever the beds are tilted and the underlying Eagle is exposed, as on the south flank of the Devil's Basin anticline, and at several points in Musselshell Valley. Excellent exposures are present along the lower Judith River and for several miles in either direction in the bluffs along the Missouri.

Measurements made in several widely separated localities indicate that the Claggett as a rule does not vary greatly in thickness. The thickest sections reported are on the east flank of the Little Rocky Mountains and on the north side of the Crazy Mountains with 750 feet and 400 to 800 feet respectively. Along Cañyon Creek, northwest of Billings, it is 567 feet, near the western border of Musselshell County 467 feet, while in the Judith Basin north of Fullerton it is 620 feet thick. In the last-named locality the two-fold division is well developed,—the lower shale being about 500 feet thick and the upper sandy member 120 feet thick.

The Claggett contains a fairly abundant and varied marine fauna. Shells are found in both the shales and concretions but are more common in the latter. In a few places, as in the type area, the upper sandstones are fossiliferous. Some characteristic forms of the shale are **Baculites compressus, B. ovatus, Inoceramus barabini, Placenticeras whitfieldi,** and **Leda evansi.** The fauna is very similar to that of the Bearpaw shale but differs in that it is less diversified and fossils are less numerous.

Eagle and Virgelle sandstones.—The basal formation of the Montana group, in its fullest development, is the Eagle sandstone. This formation is of considerable interest as a possible reservoir of oil and gas. The name is derived from the section at the mouth of Eagle Creek, a northern tributary to the Missouri River in the northeastern part of Chouteau County(66.) The lower part of the Eagle has recently been called the Virgelle sandstone, from the exposures along the Missouri at Virgelle, about 25 miles below Fort Benton(67).

The Eagle sandstone has less extent than any other formation of the typical Montana group, being restricted to the western and southern portions of the plains province. North of the Missouri it appears as far east as the Little Rocky Mountains where thin encircling sandstones have been provisionally referred to the Eagle(68). In the northwestern part of the region only the massive basal sandstone, the Virgelle, can be recognized, the remainder of the Eagle, if present, having lost its identity and become a part of the Two Medicine for-

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(66) Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton Folio (No. 55), p. 2, 1899.

(67) Bowen, C. F., The Stratigraphy of the Montana Group: U. S. Geol. Survey Prof. Paper 90-I, p. 97, 1915.

(68) Collier, A. J., Geology of northeastern Montana: U. S. Geol. Survey Prof. Paper 120-B, p. 26, 1918.

mation. From the type locality the Virgelle makes a broad loop to the north as the rim of the Sweetgrass arch and swings as far north as Sweetgrass on the Canadian border. Each of the three uplifts of the Sweetgrass Hills is girdled with a narrow belt of the Virgelle. From Sweetgrass it trends almost due south along the western flank of the low arch to the Sun River at the northwest corner of Cascade County, then shortly disappears beneath lava beds near Cascade. South of the Missouri, from Virgelle the Eagle outcrop is approximately parallel to the Claggett except in the few areas of the latter where erosion has not yet uncovered the underlying sandstones. The formation cannot be recognized in the Porcupine dome. On the west side of Bighorn Basin the Eagle can be traced to the Wyoming line. It is also prominently exposed in the Dean anticline and although thin is well exposed on the northeast flank of the Bighorn uplift and around the northern end of the Black Hills uplift.

The Eagle sandstone is quite generally composed of three distinct divisions; a lower very massive sandstone, a middle zone of sandy shales, and an upper division of thin sandstones. The basal member retains its massive appearance with remarkable persistence over the greater part of the area occupied by the formation. It is on account of this feature and the ready identification of this division that it is commonly called the Virgelle member. Even north of the Missouri where the upper portion of the Eagle can not be identified, the Virgelle maintains its typical appearance. It varies in color from a conspicuous white in places in the Missouri River Valley to gray and light brown in other localities. The upper part of the Virgelle north of Teton River is deeply stained with iron due to the presence of thin layers of magnetite. Cross-bedding is not uncommon, and sandstone concretions of a rusty brown hue on the weathered surface are fairly plentiful in some areas. Weathering locally develops large caverns, and less commonly fantastic pinnacles and other forms. In western Musselshell Valley the lower part of the Eagle consists of thin-bedded sandstones, which give place to sandy shales in the Dean anticline many miles to the south. Southeast of Pryor Creek, on the Crow Indian Reservation, the massive sandstone which is so conspicuous to the northwest rapidly grades into soft sandy shales that are difficult to trace.

A microscopic examination(69) of the Eagle sandstone in Musselshell Valley reveals quartz, feldspar, and black chert as the principal constituents. The sand grains here are of medium size, and vary form angular to rounded,—about 10 to 15 per cent only having the latter form. In some other areas this basal sandstone is coarser-grained.

The middle member, while commonly composed of sandy shales, is somewhat variable, becoming in some places mainly thin-bedded

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(69) Bowen, C. F., Anticlines in the Musselshell Valley, Montana: U. S. Geol. Survey Bull. 691, p. 195, 1919.

or shaly sandstones. In the vicinity of the Missouri, and to a less extent in Lake Basin, carbonaceous shales and thin, lenticular coal seams are fairly abundant at this horizon.

The upper division of the Eagle exhibits a less constant nature than the others. Along Eagle Creek it consists of thin sandstones which partially pass into sandy shales south of Missouri River. In some parts of Musselshell Valley thick-bedded sandstones carrying an abundance of large rusty sandstone concretions predominate. The upper part of the formation in Stillwater Valley is a thick massive sandstone above which workable coal beds are locally present. Minable coal also occurs in the Eagle in the vicinity of Bridger and in the Elk Basin area(70). There are carbonaceous layers and thin coal seams in the upper member in the vicinity of the Bearpaw Mountains. A unique feature in part of Lake Basin is a thin bed of rounded black chert pebbles about an inch in diameter at the top of the formation. The long gentle dip slopes in places are reported to be covered with them. Another local characteristic of the member is the presence of andesitic material in western Musselshell Valley. The andesitic sandstones weather to a deep brown color and form ridges as the result of differential erosion.

The topography of the Eagle is very characteristic. The lower massive sandstone forms ledges and cliffs 25 to 100 feet high which are in striking contrast to the rolling surface of the underlying Colorado shale. It constitutes the prominent rim rock of basins in the latter formation. This is excellently exhibited in Yellowstone Valley just north of Billings. Picturesque canyons are developed where streams have cut through the gently dipping massive sandstones. Fine examples exist along Two Medicine River just above its mouth and along several small streams that cross the escarpment on the north side of Yellowstone Valley. Where the formation is steeply tilted differential erosion commonly produces a narrow strike valley bordered by a pair of hogback ridges.

The Eagle is commonly about 250 to 300 feet thick. It is estimated to be only 100 feet thick in the Little Rocky Mountains and to have a similar minimum thickness north of the Crazy Mountains. In the Blackfeet Reservation the Virgelle is reported to be 200 to 225 feet thick while farther south this increases to 380 feet. From its maximum development in this locality it decreases slightly into northern Fergus County then thins rapidly to the east, so that it is not exposed in the Porcupine dome.

Fossils are generally scarce or lacking in the Eagle. Leaves are present in places in the carbonaceous shales or are associated with the coals. In the Woman's Pocket anticline, northwest of Lavina, the marine shell **Cardium speciosum** is abundant near the top of the for-

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(70) Washburne, C. H., Coal fields of the northeast side of the Bighorn Basin, Wyoming, and of Bridger, Montana: U. S. Geol. Survey Bull. 341, pp. 183-195, 1909.

mation. The same form is sparingly present in the Big Elk dome south of Two Dot(71). Marine fossils also occur in the formation in Carbon County where they are more abundant in the lower part(72). The Virgelle is reported to be barren in places but in others to contain a marine near-shore fauna.

Two Medicine formation.—The middle portion of the Montana group undergoes a decided change in lithologic character as the extrsme northwestern part of Central Montana is approached. In the area between Sun River and the Canadian boundary, thence eastward to Milk River Valley, the Virgelle sandstone and the Bearpaw shale are the only divisions of the Montana group that persist in their typical aspect. The upper part of the Eagle, the Claggett, and Judith River here grade rapidly into a mass of light-colored clays and sandstones, mainly of continental origin, about 2000 feet thick. This deposit is called the Two Medicine formation from the typical and complete section exposed on the lower course of Two Medicine River in southeastern Glacier County(73).

The character of the formation is thus concisely described by Stebinger:

> It is composed principally of light-gray to greenish-gray clay and clay shale, so rudely bedded that it is impossible to follow a given stratum for any great distance. In places the beds of clay are variegated, red and yellow strata appearing. Thin nodular and non-persistent limestone, apparently of fresh-water origin, also occurs at irregular intervals. Probably 20 per cent of the total mass of the formation is made up of soft coarse-grained sandstone in lenticular beds which, even where 20 to 30 feet thick, cannot be traced more than 1 or 2 miles. At many localities these sandstones show the very irregular cross-bedding that is characteristic of eolian deposits. The lower 200 feet of the formation is more sandy than the remainder, probably half of this part consisting of massive sandstone in irregular beds, the thickest measuring 50 feet(74).

The formation contains carbonaceous shale at many horizons and three well-defined coal beds occur in some places. These coals are mined at several localities.

The succession of soft clays and more or less resistent sandstones provides ideal conditions for the formation of badlands, and consequently this type of topography is extensively developed along the numreous valleys of the region. Elsewhere the Two Medicine is characterized by a gently rolling surface.

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(71) Bowen, C. F., Anticlines in the Musselshell Valley, Montana: U. S. Geol. Survey Bull. 691-F, p. 194.

(72) Fisher, C. A., Southern Extension of the Kootenai and Montana Coal-bearing formations in northern Montana: Econ. Geol., vol. 3, p. 94, 1908.

(73) Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90-G, p. 62, 1914.

(74) Ibid., p. 63.

The fossiliferous character of the formation is well shown by the following description:

> Fossils are abundant in the Two Medicine formation and include vertebrate, plant, and mollusk remains of many species. Bone fragments of dinosaurs of Judith River types, both herbiverous and carniverous, and also of turtles can be found in almost any extensive exposure. Entire limb bones 4 to 5 feet in length belonging to the larger dinosaurs were found at several localities. The mollusks are represented mostly by brackish and fresh-water forms, especially the latter. Beds made up almost exclusively of unios are present at many horizons, in some places closely associated with dinosaur bones. A single marine invasion of brief duration while this formation was being deposited is represented by shells of the Claggett to Fox Hills near-shore fauna found in sandstone about 200 feet above the base of the formation. The plant remains are mainly leaf impressions and silicified wood. The leaves are all of modern-appearing conifer and broad-leaved types. The fossil wood is distributed throughout the formation, knots and entire sections of compressed tree trunks being common(75).

Livingston formation.—A thick mass of tuffaceous sandstone and shale constitutes the surface formation over an extensive area northwest of the Crazy Mountains, between Shields River and the Bridger Range, in Yellowstone Valley as far east as Greycliff, and for some distance south of Yellowstone River. These strata were called the Livingston formation by Weed(76), from exposures near Livingston. Stone and Calvert in their more recent studies of the Livingston throughout its entire area have determined its main lithologic features and its stratigraphic relations(77). They have shown too that the formation does not cover as broad a tract in the vicinity of the Crazy Mountains as is shown on the early maps of the region. The data for the following description are taken from their report.

The striking feature of the formation is the large proportion of volcanic material that it contains. Most of the shales and sandstones contain some, and many of them a great deal of andesitic debris. In the southern part of Stillwater County 320 feet of greenish to brownish tuffaceous beds intervene between the Eagle and the Lance. The formation is well-exposed along Stillwater River where a three-fold division is recognized: shale and sandstone 625 feet thick, volcanic agglomerate 2000 feet thick, and shale and thin sandstones 2500 feet thick(78). These members have a similar thickness on Boulder River

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(75) Stebinger, Eugene, Geology and coal resources of Northern Teton County, Montana: U. S. Geol. Survey Bull. 621-K, p. 127, 1916.

(76) Weed, W. H., The Laramie and the overlying Livingston formation of Montana: U. S. Geol. Survey Bull. 105, p. 21, 1893.

(77) Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation of Montana: Econ. Geol., vol. 5, pp. 551-557, 652-669, 741-764, 1910.

(78) Calvert, W. R., Geology of the upper Stillwater Basin, Stillwater and Carbon counties, Montana: U. S. Geol. Survey Bull. 641-G, p. 201, 1916.

to the west. The agglomerate is composed chiefly of andesitic pebbles and boulders, which rarely show signs of transportation by water. It occurs in the form of a great lense that extends westward from West Rosebud Creek on the east to Yellowstone River, near Springdale.

On the west side of Shields Valley and along the east flank of the Bridger Range the Livingston maintains its highly andesitic nature, the only conspicuous change being the disappearance of the agglomerate member. At some places, however, strata containing much andesitic material are interbedded with the underlying Eagle and the upper part of the Colorado. A number of species of marine fossils of probable Bearpaw age were discovered well up in the typical Livingston at one locality and elsewhere Judith River forms occur at lower horizons.

As the Livingston formation is traced around the north flank of the Crazy Mountains it is observed to become less and less andesitic at certain horizons, and to assume gradually the lithologic and faunal characteristics of the Montana group. In other words, in the upper Musselshell Valley there is a gradual and apparently unmistakable interfingering of the typical sedimentary series of the central part of the state with the typical Livingston formation of the Shields and Yellowstone valleys. Hence, it is concluded that the Livingstone formation is a peculiar lithologic unit which in its particular area corresponds to the Montana group plus a part of the overlying Lance formation. Whether it may be subdivided into these formations or their time equivalents remains to be determined by detailed stratigraphic work.

Colorado formation.—Immediately underlying the Eagle sandstone, or the Claggett shale where the Eagle is absent, is a thick body of shales with subordinate sandstones known as the Colorado formation. This formation not only appears at the surface over a vast area in Montana, but underlies all the territory occupied by younger formations. Moreover, it underlies thousands of square miles of the Great Plains of the United States and Canada. The name was first applied, with its present significance, to extensive exposures in northwestern Colorado(79). In consequence of its highly petroliferous nature in Wyoming and Alberta the Colorado is of considerable interest to the oil prospector in this state.

The Colorado shale is one of the most widespread formations of the Montana Great Plains, as it is exposed over approximately 9000 square miles, or nearly one-tenth of the whole plains province. The largest area occurs north of Great Falls where it is exposed by the erosion of the Sweetgrass arch throughout an area of 7000 square miles. It is brought to the surface in belts of variable width around each of the mountain uplifts as well as in most of the anticlines and

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(79) White, C. A., Report on the geology of northwestern Colorado: U. S. Geol. and Geog. Survey Terr., Tenth Annual Report, 1878.

domes of Musselshell Valley. It is also exposed in the Porcupine dome and in the northern extension of the Black Hills uplift.

The Colorado group of northwestern Wyoming has been subdivided into several formations: the Thermopolis shale at the base, the Mowry shale, the Frontier formation, the Carlile shale, and the Niobrara shale. These divisions have been identified in Elk Basin at the Montana boundary and similar divisions are recorded in the Black Hills uplift but, with the exception of the Mowry, have not been positively recognized further north. Owing to its peculiar nature the Mowry has been identified in many of the Colorado sections in Montana. It is rather probable that detailed stratigraphic study of the Colorado formation in this state will result in the recognition of some of the other divisions into which it is separated in Wyoming. On the other hand it is entirely probable that conditions of sedimentation were sufficiently diverse over such an extensive province that few, if any, horizons can be directly correlated over long distances unless they are marked by some unusual and persistent feature, as in the case of the Mowry shale. Since the Colorado sandstones exhibit great variation in number and character in the Wyoming fields, it is clearly inadvisable to consider sandstones in a particular section in this state to be the same as those that occur in some other section 50 to 100 miles distant, and thus expect them to exhibit the same features.

The Colorado everywhere is dominantly a dark bluish-gray to black, more or less fissile, clay shale. It contains variable amounts of sandy shales and sandstones; the latter as a rule being more numerous and thicker in the lower part of the formation. This is especially true in Bighorn Basin, Wyoming, but even here they are very lenticular. The sandstones appear to become less abundant and to be more limited in vertical range as the state is crossed toward the north. In the Elk Basin field the principal horizons are the Peay and Torchlight members of the Frontier formation, both of which are oil-bearing, while in the Bridger section the Torchlight is the only important sandstone(80). Well logs at Billings, southwest of Broadview, and southeast of Shawmut show several thin sandstones in the lower third of the Colorado section. In the western part of Musselshell Valley sandstones again become numerous and thicker, one sandy horizon in the Big Elk dome being sufficiently prominent to warrant the name Big Elk Sandstone(81). This member is about 1200 feet below the top of the formation, and is about 250 feet thick. It occupies the approximate position of the Frontier of Wyoming. Near the Crazy Mountains about 200 feet of sandstones are present in the lower third of the Colorado. The basal sandstones in the vicinity of the Big Snowy Mountains are thick-bedded and weather to

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(80) **Hares, C. J., unpublished data, quoted by Hancock, E. T., U. S. Geol. Survey Bull. 711, Plate XV, 1920.**

(81) **Bowen, C. F., Anticlines in a part of the Musselshell Valley, Montana: U. S. Geol. Survey Bull. 691-F, p. 196, 1918.**

a rusty brown color. These "rusty beds" are an excellent guide in drawing the lower boundary of the formation in this area.

Sandstones, many of which are 20 to 80 feet thick, are prevalent in the lower half of this formation in the northern part of the state. A section on the flanks of the Little Rocky Mountains that may be considered representative for the northeastern area consists of 100 feet of Mowry shale at the base, 325 feet of dark-blue shale, 60 feet of sandstone capped by a thin bed of fossiliferous limestone, and 875 feet of bluish-gray to black shale with numerous limestone concretions(82).

In the northwestern part of the plains the lower third of the Colorado has been designated the Blackleaf sandy member from the good exposure on Blackleaf Creek, in northern Teton County. A detailed section of it is given by Stebinger in U. S. Geological Survey Bull. 691-E, page 158. This division is 600 to 700 feet thick and contains all the conspicuous sandy horizons of the Colorado in this region. The sandstones are medium to coarse-grained, locally conglomeratic, and are somewhat lenticular. Numerous marine and brackish-water shells have been found in the sandy shales associated with them.

The beds immediately overlying the Blackleaf in the Sun River district are distinctly petroliferous. They "consist of compact black bituminous shale containing thin beds of impure limestone which in places is impregnated along the fractures with a soft tarry bitumen(83). Upon distillation the shales yield one to two gallons of oil to the ton. These beds are about 50 feet thick, with the several thin limestones occupying about one-quarter of the space.

The Mowry shale, which, owing to the abundance of fish remains that it contains, is a possible source of oil, has been identified at several places in Montana. Where typically developed it is readily recognized by the great numbers of fish scales and its peculiar weathering to a porcelain-like debris. This member is reported from the Little Rockies as constituting the basal 100 feet of the Colorado. It is present on the northeast flank of the Bearpaw Mountains and in the vicinity of Great Falls and Lewistown, but has not been recognized in the intermediate area. It apparently occurs only in the eastern part of Musselshell Valley, forming a 12-foot stratum about 680 feet above the base of the Colorado in the Devil's Pocket anticline and is also well exposed in the Cat Creek anticline. Near Bridger the Mowry is over 200 feet thick.

The upper part of the Colorado nearly everywhere consists of characteristic dark-colored fissile shale. Thin beds of sandstone, limestone, and sandy shale are present in places but they are relatively

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(82) Collier, A. J., Geology of northeastern Montana: U. S. Geol. Survey Prof. Paper 120-B, p. 26, 1918.

(83) Stebinger, Eugene, Oil and gas geology of the Birch Creek-Sun River area in northwestern Montana: U. S. Geol. Survey Bull. 691-E, p. 162, 1918.

unimportant. Calcareous concretions more or less filled with veins of calcite are rather common in this division. A bed of volcanic ash is a local feature on the south side of the Highwood Mountains, and tuffaceous material occurs near the top of the formation on the north side of the Crazy Mountains.

The summit of the Colorado is generally quite distinctly marked by a change from the dark shales to the light-colored massive sandstone or sandy shale of the basal Eagle, as well as by the conspicuous difference in topographic expression. These upper Colorado shales bear a rather close resemblance to the Claggett and Bearpaw shales but differ in that they are somewhat darker, bedding is much better developed, and a typical gumbo soil is more rarely produced.

Typical sections of the formation are well exposed at several places in the state, particularly on the flanks of the mountain uplifts, as along the northwest end of the Pryor mountains. For the details of several complete sections the reader is referred to the publications of the U. S. Geological Survey(84).

The Colorado formation has a rather uniform thickness throughout the state. It is approximately 1360 feet thick in the Little Rockies and in the northwestern part it varies from 1500 to 1900 feet. It is about 1300 feet thick north of the Crazy Mountains and ranges from 1500 feet north of the Judith Mountains to 2360 feet on the south side of the Big Snowy Mountains. The greatest thickness in Musselshell Valley approximates the latter figure. A section in the Elk Basin district nearly 2700 feet thick apparently records the maximum development of the formation in Montana.

Marine fossils are plentiful in the Colorado shale. Fish remains are exceedingly numerous in the Mowry shale member, but occur also at other horizons in some localities. Shells of invertebrates, chiefly pelecypods and gastropods, are not uncommon in most extensive sections, both in the shale and in the calcareous concretions of the upper portion. All the fossils are characteristic marine Cretaceous forms.

THE COMANCHEAN SYSTEM.

Kootenai formation.—The Kootenai formation consists of a widespread series of shales and sandstones that underlies the Colorado shale. The type locality is in southwestern Alberta, whence the name is derived from an Indian tribe that frequented the region(85). The formation passes beneath the surface before the international boundary is reached but reappears at several places in the plains province. North of Missouri River it crops out only in the Little Rocky Moun-

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(84) Bowen, C. F., Anticlines in a part of the Musselshell Valley: Bull. 691-F, pp. 196-197, 1918; Calvert, W. R., Geology of the Lewistown coal field, Bull. 390, p. 30, 1909; Hancock, E. T., Bull. 691-D, Pl. XVII or Bull. 711-G, Pl. XV, 1920.

(85) Dawson, Sir William, On the Mesozoic floras of the Rocky Mountain region of Canada: Trans. Royal Soc. Canada, vol, 3, Sec. 4, p. 2, 1885.

tains and along the Rocky Mountain front. The greatest surface exposure in the state is east and southeast of Great Falls where it occupies about 400 square miles. A much smaller area exists southeast of Lewistown, and a belt of the formation encircles each of the mountain uplifts in this part of the state. The only other outcrops in the plains is a narrow belt around the northern extremities of the Bighorn and Pryor mountains and small areas in the Devil's Basin and Cat Creek anticlines. That is underlies the younger formations, at least in the central part of the plains province, is shown by its having been penetrated by deep wells.

The Kootenai formation consists essentially of alternating, varicolored shales and light-colored sandstones. The sandstones are numerous and thick in the lower half and, as a rule, become thin and scattered in the upper portion although in many places there is a massive, coarse sandstone in the upper third of the formation, in which occurs the second and third sands of the Mosby oil field. It may correspond to the Greybull sandstone member of the Cloverly in Bighorn Basin. The sandstones are commonly gray to brown, medium to coarse-grained, in many places gritty to coarsely conglomeratic, and locally strongly cross-bedded. The lower ones vary in thickness from 10 to 60 or more feet, and thus afford good horizons for oil accumulation if other conditions are favorable. Some of the sandstones are rather nonpersistent in the central part of the state, but one stratum less than 100 feet above the base is so persistent in the vicinity of the Big Snowy Mountains that it makes an excellent horizon marker. It is as easy to trace owing to the numerous pines which grow upon it.

Just below this sandstone occurs the workable coal seam of the Lewistown and Great Falls fields, which in places is six feet thick. In other districts this horizon is represented by a thin coal seam or by carbonaceous shale.

Limestone is sparingly present in the Kootenai and occurs generally in the form of nodules in more or less definite zones, or as thin lenticular beds. It is commonly gray to buff, but locally is purplish.

The variegated shales are the striking and distinctive feature of the Kootenai formation. It is so similar to the underlying Morrison in this respect that the two formations are readily confused, and can only be differentiated by detailed work. The Kootenai shales are dominantly clayey, but are more or less sandy in places. The distinctive color is reddish to maroon, with bands of gray, blue and green. The maroon shales are present at several levels in the formation, but the bulk of them are in the upper portion, immediately underlying the "rusty beds" that mark the base of the Colorado. These upper shales weather to soils of a deep maroon color, which can be readily distinguished at great distances. The sharp change in lithology at the upper contact is very conspicuous along the east side of the Big Snowy Mountains, but is commonly less evident elsewhere.

The two formations appear to be everywhere conformable, but the absence of the Dakota sandstone indicates the existence of a marked hiatus at this horizon.

Good sections of the Kootenai are rather scarce. A full section may be measured in several deep ravines on the north and east flanks of the Big Snowy Mountains, on the north slope of the Little Belt Mountains, and in Bridger Canyon. A section at the last locality shows the following sequence(86).

	Feet
Sandstone and shale interbedded; sandstone micaceous, in paper-thin beds, in places cross-bedded, light buff to greenish yellow, marked by great number of worm burrows or tracks; shale light colored and sandy; at the top are great numbers of small rounded balls which contain phosphatic material and are pseudomorphs after marcasite. This member is ridge-forming and contains at the bottom the Greybull sandstone member	217
Shale, brilliantly colored, containing great numbers of gastroliths and a few bones. The different colors give the shale a banded effect and are well exposed in Rainbow Butte, just north of Bridger Canyon	95
Conglomerate, composed mostly of black chert pebbles 2 inches or less in diameter containing Paleozoic fossils. Toward the top the conglomerate becomes sandy and contains fewer pebbles. The conglomerate forms cliffs on each side of Bridger Canyon	35
	257

This section is of the Cloverly formation, which is approximately equivalent to the Kootenai.

A section on the east flank of the Little Belt Mountains illustrates the common features of the formation in the central part of the state(87).

Colorado Shale.	Feet
Shale, maroon, sandy, with an occasional thin sandstone layer	200
Sandstone, gray, weathering tan, coarse grained	8
Shale, maroon, sandy	60
Sandstone, gray, coarse grained, weathering irregularly and containing woody fragments	25
Shale, maroon, sandy	72
Sandstone, gray, massive, pebbly	50
Partly concealed; sandstone members in upper part	42
Shale, grayish brown, compact	6
Coal and carbonaceous shale	3
Concealed, probably greenish, sandy shale	87
Morrison formation.	
	553

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(86) Measured by C. J. Hares; quoted by E. T. Hancock, U. S. Geol. Survey Bull. 691-D, p. 110, 1918.

(87) Calvert, W. R., Geology of the Lewistown coal field, Montana: U. S. Geol. Survey Bull. 390, p. 26, 1909.

The Kootenai is about 500 feet thick in Fergus and Cascade counties, but increases to 825 feet in the Little Rocky Mountains and to approximately 2000 feet in the northwestern part of Central Montana. It becomes even thicker in western Alberta, where it attains a thickness of 2800 feet. It thins to the west and south, being about 235 feet thick north of the Crazy Mountains and 257 feet thick in Bridger Canyon. Farther south in the Bighorn Basin the Cloverly is only slightly more than 100 feet thick.

Fossils as a rule are scarce in the Kootenai, and present little diversity. The most common ones are leaves in the carbonaceous strata, which are abundant in the Great Falls district. A few fresh-water shells, mainly Unios and Gastropods, occur in some places. Reptilian bones have also been discovered. All the fossils indicate the terrestrial origin of the formation.

Morrison formation.—The Morrison formation is a widespread sheet of fresh-water deposits that extends from far south of Morrison, Colorado, the type locality(88), as far north at least, as Central Montana. Wherever present it underlies the Kootenai, to which it bears such a close resemblance that it is difficult to separate the two formations in most places. It has been identified only along the north slopes of the Little Belt, Big Snowy, Bighorn and Pryor mountains in this state, but probably is buried by younger formations in the intervening and adjacent territory.

The following description of the formation along the north flank of the Big Snowy Mountains will apply throughout the state(89):

> The Morrison formation consists of shales, sandstones, and argillaceous limestones, all apparently of fresh-water origin. The colors of these beds are extremely variable, greens and pinks predominating, but they are seldom, if ever, brilliant and possess a characteristic soft tint. In lithologic character and in thickness the formation is fairly uniform throughout the field, the various sections approximating 125 feet. Argillaceous members predominate. The shales are very clayey and the limestones also appear to contain a high percentage of silica. The limestone members are characteristically bluish gray and break into small blocks. The sandstones are usually brownish and granular in appearance, and in them comminuted bone fragments are of fairly common occurrence.

Good sections of the Morrison are available wherever sharp valleys have been cut into the underlying formation. The following section illustrates in detail its character near the east end of the Little Belt Range(90):

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(88) Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pike's Peak folio (No. 7), 1894.

(89) Calvert, W. R., Geology of the Lewistown coal field, Montana: U. S. Geol. Survey Bull. 390, pp. 22-23, 1909.

(90) Ibid., p. 23.

		Feet
	Kootenai Formation.	
1.	Sandstone, fine grained, tan-colored, weathering soft tan, containing bone fragments	12
2.	Shale, greenish, becoming sandy upward, with 1-foot layer of limestone, greenish gray, weathering russet 12 feet from top; shale contains many Unio shells	34
3.	Limestone, reddish brown, weathering russet, containing an abundance of clear calcite crystals	3
4.	Shale, greenish	8
5.	Limestone and variegated shale; limestone is in thin layers, reddish brown, unchanged by weathering, with calcite crystals as in (3)	11
6.	Limestone, fine grained, compact, containing small greenish particles resembling glauconite	2
7.	Shale, variegated, red and pink, predominating	75
	Ellis sandstone.	
		145

Another complete section southeast of Bridger shows the nature of the formation in the southern part of the state(91):

	Feet
Shale, light colored	13
Shale, reddish brown and maroon	7
Shale, light sandy	16
Sandstone, light colored, fine to medium grained; weathers yellowish. In places massive and locally in beds from 1 foot to 1½ feet thick	26
Shale, variegated, commonly light colored. Has a thin maroon streak near the base and a dark-gray streak near the top	26
Sandstone, single bed, very argillaceous	½
Shale, dark to reddish brown; weathers reddish; exhibits 1 foot of light shale near the top	10
Sandstone, light colored	5
Shale, variegated from light to reddish brown	13
Sandstone, light colored	13
Shale, maroon; contains some interbedded sandstone; weathers light to yellowish brown	10
Shale, dark; weathers light. Greenish, light brown and drab are common shades	10
	149½

The Morrison is a comparatively thin formation in this state, ranging from 60 to 120 feet in southern Cascade County to 150 feet in Elk Basin. It thickens to the south, and is nearly 600 feet thick along Shoshone River in northern Wyoming.

Fossils are very abundant in the formation in many places but only a few have been collected from the outcrops in this state. They consist of plant remains, invertebrates, and bones of several vertebrates, all of which denote its terrestrial origin. None of them,

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(91) Emery, W. B., quoted by E. T. Hancock, U. S. Geol. Survey Bull. 711-G, p. 112, 1920.

however, afford conclusive evidence of its precise position in the stratigraphic column, some geologists calling it Comanchean(92), whereas others consider it as Jurassic(93). It seems quite probable that it is largely transitional but is closely allied to the Kootenai.

THE JURASSIC SYSTEM.

Ellis formation.—The Ellis formation is the basal Mesozoic formation throughout the greater part of the plains province. Except in a small area in southern Carbon and Bighorn counties, where the Chugwater formation (Triassic) is present, it rests everywhere upon sediments of late Paleozoic age. In places it overlies the Madison limestone and the Quadrant formation with marked angular conformity; for example, in the vicinity of Stockett, southeast of Great Falls(94). Even where no unconformity is apparent the absence of strata that normally intervene between the Madison and the Ellis indicates a pronounced gap, or hiatus, in the sedimentary record.

The areal distribution of the Ellis is similar to that of the Morrison and Kootenai except that its outcrop is more restricted than that of the latter. It occurs in narrow belts on the flanks of the several mountain uplifts and as long narrow embayments that extend far down some of the narrow valleys on these slopes. The formation is exposed along the western margin of the plains in Teton County, and surrounds the Judith, Big Snowy and Little Belt mountains. On some of these slopes the outcrop varies in width from a small fraction of a mile to several miles. The Ellis forms the central area of several small domes in the vicinity of Lewistown. It is present on the flanks of the Bighorn and Pryor mountains where it passes into the Sundance formation of Wyoming. North of Missouri River it appears at the surface in the Little Rocky and Bearpaw mountains and in the Sweetgrass Hills. Its subsurface distribution is unknown but it probably is present under the greater part of the plains in this state.

The formation is composed of sandstone, shale, and limestone in variable proportion. The following section illustrates its character in the Little Rocky Mountains(95):

	Feet
Sandstone, massive, white, cross-bedded	50
Shale, variegated	50
Sandstone, yellowish and thinner bedded	100
Shale with interbedded sandstone and limestone	100
Limestone, thin bedded, shaly and calcareous shale	200
	500

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(92) Mook, C. C., A study of the Morrison formation: Annals N. Y. Acad. Sci., vol. 27, pp. 39-191, 1916.

(93) Schuchert, Charles, Bull. Geol. Soc. Am., vol. 29, p. 246, 1918.

(94) See U. S. Geol. Survey Bull. 356, Pls. I and VI, 1909.

(95) Collier, A. J., Geology of northeastern Montana: U. S. Geol. Survey Prof. Paper 120-B, p. 25, 1918.

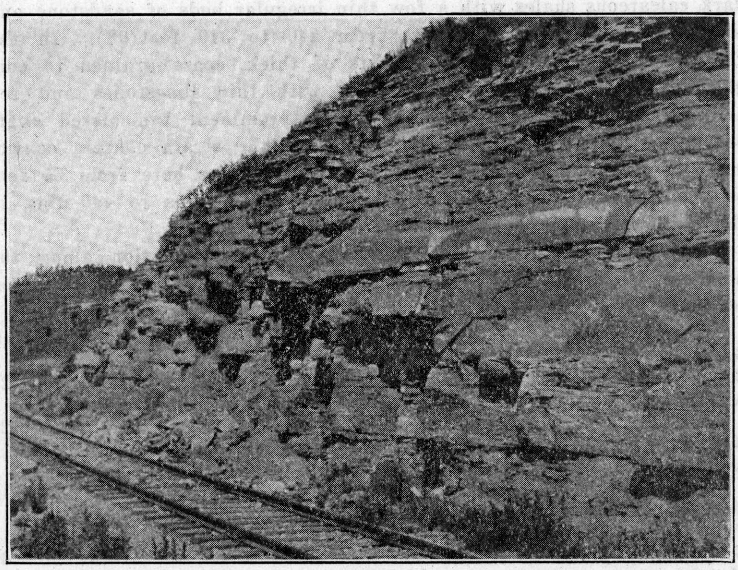

PLATE VII.—ELLIS FORMATION.

Fossiliferous limestones exposed in a railroad cut 3 miles west of Forest Grove. The thicker beds are overlain by thin-bedded calcerous shales.

In the Bearpaw Mountains it consists of a fine-grained, dark gray, highly fossiliferous limestone about 200 feet thick(96).

A section south of Great Falls in T. 17 N., R. 4 E. shows the common features for this region(97):

	Feet
Sandstone, gray, weathering brown, thin bedded	60
Sandstone, gray, conglomeratic, containing marine Jurassic fossils	29
Limestone, dove colored, massive; basal member brecciated and containing Jurassic fossils	60
	149

In western Teton County the formation is composed mainly of dark calcareous shales with a few thin irregular beds of sandstone and limestone, ranging in thickness from 240 to 310 feet(98). In the Lewistown district the Ellis consists of thick, coarse-grained to conglomerate sandstones which alternate with thin limestones and red and green shales. The sandstones form prominent tan-colored cliffs or ridges wherever well exposed. Some of the strata contain considerable gypsum. The formation ranges in thickness here from 65 feet on the northeast slope of the Little Belt Mountains to 440 feet in the South Moccasin Mountains.

Similar features characterize the Sundance formation along the northeast flank of the Bighorn Range, as is shown by this typical section(99):

	Feet.
Green to brown fossiliferous sandstones	3
Green sandy shale	20
Alternating layers of green and gray sandstones, fossiliferous at top	25
Gray sandy shale; red at base; concealed above, probably green	115
Light-gray limestone; oolite at base; thin-bedded above; fossiliferous	15
Gray massive fossiliferous sandstones	6
Thin-bedded limestone	12
Gray sandy shale	60
Massive gray sandstone; very fossiliferous	10
	266

The Ellis formation is nearly everywhere rich in fossils at several horizons, some beds being almost wholly composed of shells and shell fragments. This feature is especially exhibited in a cut along the Milwaukee Railway about 15 miles east of Lewistown. The forms are all marine or brackish-water invertebrates, among which

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(96) Bowen, C. F., The Cleveland coal field, Blaine County, Montana: U. S. Geol. Survey Bull. 381, pp. 51-52, 1909.

(97) Fisher, C. A., Geology of the Great Falls coal field, Montana: U. S. Geol. Survey Bull. 356, p. 28, 1909.

(98) Stebinger, Eugene, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana: U. S. Geol. Survey Bull. 691-E, p. 155, 1918.

(99) Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 45, 1906.

Beleminites densus, a cigar-shaped shell, and **Gryphaea calcaola**, an oyster-like form, are most characteristic. All the fossils indicate the late Jurassic age of the Ellis. It is thus stratigraphically and faunally the same as the Sundance formation of the Bighorn Mountains.

THE TRIASSIC SYSTEM

Chugwater formation.—The only rocks of Triassic age in the plains province of Montana are contained in the Chugwater formation, which extends northward from extensive exposures in Wyoming as a narrow belt around the northern extremities of the Bighorn and Pryor mountains. The name was first applied to the section on Chugwater Creek, near Iron Mountain, Wyoming(100). The formation is well exposed in Bridger Canyon, southeast of Bridger, just south of the Billings-Cody highway, where it forms the core of a small anticline. It crops out far down the long dip slope of Paleozoics at many other places in both mountain ranges. Typical features are likewise exhibited a few miles south of Pryor, on the Crow Indian Reservation, and in the eastern half of T. 6 S., R. 24 E. The formation also crosses the state line along the east base of the Beartooth Range; elsewhere it is not present in Montana.

The Chugwater is aptly called the "Red Beds," as it consists mainly of bright to dark red sandstones and sandy to clayey shales. These brilliantly colored strata form conspicuous cliffs and ledges wherever exposed and thus are an excellent horizon marker. A fine example of this is the "red wall" in Bridger Canyon. Several beds of massive gypsum from 6 to 50 feet thick are present in places. A few thin limestones are interbedded with the sandstones and shales.

A section in the eastern part of the Crow Reservation gives a thickness of 652 feet for the formation. It becomes thicker south of the state line, and reaches a maximum of 1200 feet.

Fossils are very rare in the Chugwater and thus its age is rather uncertain. Recent stratigraphic studies in the eastern part of Bighorn Basin have led to the conclusion that the true Chugwater is probably of Triassic age(101).

CORRELATION OF THE MESOZOIC

The succession and equivalency of the Mesozoic formations in various parts of the Montana plains are shown by the correlation chart on page 66. The overlying Lance and the underlying Quadrant and Madison formations are also included. Sections north of the

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(100) Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Bull. Geol. Soc. Am., vol. 15, p. 397, 1904.

(101) Condit, D. D., Relation of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263-270, 1916.

Correlation of the Mesozoic and Late Paleozoic formations of the plains province of Montana and adjacent states.

System	Southern Alberta	Northwest Montana	West-Cen. Montana	Elk Basin	East-Cen. Montana	Black Hills
	St. Mary River f.	St. Mary River f.	Livingston form. Lance form.	Lance formation	Lance formation	
	"Fox Hills" ss.	Montana Group Horsethief ss.	Lennep ss.		Fox Hills ss. (?)	Fox Hills ss.
	Pierre shale	Bearpaw shale	Bearpaw shale	Bearpaw shale	Bearpaw shale	Pisrre shale
	Belly River formation	Two Medicine formation	Judith River f.	Judith River fm.	Judith R.	
			Claggett sh.	Claggett shale	Claggett shale	
		Virgelle ss.	Eagle sandstone	Eagle sandstone	Eagls	
Cretaceous	Lower dark shales	Colorado formation Blackleaf Sandy member	Colorado formation	Colorado Group Niobrara sh.	Colorado formaton	Colorado Group Niobrara
				Carlile sh.		Benton Carlisle sh.
				Frontier form.		Greenhorn Ls.
				Mowry sh.		
				Thermopolis sh.		Greenhorn Ls.
•	?	(Absent)	(Absent)	(Absent)	?	Dakota ss.
Comanchean	Kootenai form.	Kootenai form.	Kootenai form.	Cloverly form.	Kootenai (n wells)	Fuson shale Lakota ss.
?	Fernie shale	?	Morrison form.	Morrison form.	Morrison (in wells)	Morrison form.
Jurassic		Ellis formation	Ellis formation	Sundance form.	Ellis (in wells)	Sundance form.
Triassic	?	(Absent)	(Absent)	Chngwater form.	(Absent)	Spearfish form. Minnekahta Ls. Opeche form.
?						
Permian		(Absent)	Quadrant formation	Embar form.	Quadrant formation (in wells)	
Pennsylvanian	?			Tsnsleep ss.		Minnelusa formation
				Amsden form.		
Mississippian		Madison Ls.	Madison Ls.	Madison Ls.		Pahasapa Ls.

Canadian boundary, in northwestern Wyoming, and in the northwestern part of the Black Hills are given for a comparison in order to show the relation of the formations in Montana to those in neighboring states.

The section in Alberta is taken along the western margin of the Great Plains, in the southern part of the province, and is based upon work by the Canadian Geological Survey. Several publications of the United States Geological Survey supply the data for the sections in Montana. The Elk Basin section shows the formations for several miles on both sides of the Montana-Wyoming boundary. The formations below the Colorado are exposed along the southwest slope of the Pryor Mountains and the east base of the Beartooth Range. The section in the Black Hills is taken from the Aladdin folio (No. 128) and exhibits the formations that are present in southeastern Montana.

THE PALEOZOIC

Formations of Paleozoic age crop out in the plains province only where mountain-making forces have greatly unwarped the strata and erosion has deeply dissected the uplifts. Good sections are exposed in several of the Rocky Mountain front ranges and the Little Belt and Judith Mountains. The later Paleozoics also occupy the greater part of the Bighorn, Pryor, and Big Snowy mountains, and a small area in each of the Sweetgrass Hills.

The only formations in this group of immediate interest to the oil prospector are those of Carboniferous age, mainly the Quadrant formation, as the older formations are not oil-bearing in the Great Plains nor Rocky Mountains. In many of the anticlines the Quadrant is too deeply buried to be economically accessible, but where reached by the drill it offers some encouragement for further exploration. The lithology of some of the older formations, however, is of pertinent interest in its possible bearing upon the source of the oil and gas that occur in younger formations.

THE CARBONIFEROUS SYSTEM

Quadrant formation.—The Quadrant formation, which receives its name from the section in Quadrant Mountain in Yellowstone Park(102), is the youngest Paleozoic formation in this province. It crops out extensively between the prominent Madison limestone and the Ellis formation in several mountain uplifts, but is absent in some localities. It is probably concealed over a broad area, but little is known of its distribution beneath the surface of the plains. The best exposures of the Quadrant formation occur on the lower slopes of the Little Belt and Big Snowy mountains, in the southern part of the Judith Mountains, and to a less extent in the Little Rocky Moun-

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(102) Peale, A. C., U. S. Geol. Survey Bull. 110, pp. 39-43, 1893.

tains. The formation is also present in the various front ranges of the Rocky Mountains. The Amsden and Tensleep formations, which are approximately equivalent to the Quadrant formation, occupy a similar position in the Bighorn and Pryor mountains.

As described by Weed the Quadrant in the Little Belt Mountains consists of basal reddish sandy clays and sandstone with some gypsum in a few places, overlain by several hundred feet of bright green and gray shale with interbedded gray limestones(103). In this area the formation is commonly between 300 and 400 feet thick, but it is reported to be 1400 feet thick on Judith River above Utica.

The following section shows the character of the formation at the east end of the range(104):

		Feet
	Jurassic; red shale.	
1.	Limestone, light gray, weathering almost white, fossiliferous in upper portion	55
2.	Shale, green, alternating with limestone members near top; beds partly concealed	105
3.	Sandstone, white, soft, saccharoidal, basal members alternating with limestone layers, all weathering like limestone	40
4.	Shale, red, containing an abundance of irregular cherts; beds partly concealed	225
	Madison limestone.	
		425

The Quadrant in this area contains many fossils in its upper strata, all of which are marine invertebrate shells of either late Mississippian or early Pennsylvanian age.

Madison limestone.—The Madison limestone wherever well exposed is one of the most conspicuous formations of the region. Like the Quadrant it is exposed only in the mountain ranges, being present in each of the uplifts of the plains province as well as in the front ranges of the Rocky Mountains.

It consists of 1000 to 1500 or more feet of gray to bluish-gray, thin-bedded to very massive, fine-grained limestone which contains more or less chert and numerous fossils. In some areas the basal portion is composed of shales and shaley limestone. The massive members everywhere give rise to a rugged topography,—narrow box canyons and high steep cliffs and walls being common. In some of the uplifts, as in the Little Rocky Mountains, it forms a striking encircling girdle broken here and there by picturesque canyons.

The diversified marine invertebrate fauna of the Madison indicates its Mississippian age.

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(103) Weed, W. H., Geology of the Little Belt Mountains, Montana: U. S. Geol. Survey, Twentieth Ann. Rept., pt. 3, pp. 294-296, 1899.

(104) Calvert, W. R., Geology of the Lewistown coal field, Montana: U. S. Geol. Survey Bull. 390, p. 16, 1909.

OLDER FORMATIONS

Beneath the Madison limestone there is a thick series of alternating shales and limestones with few interbedded sandstones which comprises the Devonian and Cambrian systems. Rocks of Silurian and Ordovician age apparently are absent except in the Bighorn and Pryor mountains where strata of the latter age are present. These earlier Paleozoic formations are well-exposed in the mountain ranges in the vicinity of Lewistown. Only the Devonian formations, the Jefferson limestone and the overlying Three Forks shale, are of interest in this report. In the central part of the state they consist of a few hundred feet of alternating limestones and shales, which are commonly light- to dark-gray, brown, or black and emit a strongly fetid odor when freshly broken. Both the color and odor are due to considerable finely disseminated organic matter. Fossils, however, are rarely present. Some of the beds are more or less sandy, and a few sandstones as well as most of the limestones have a distinct saccharoidal or granular texture.

Whether these beds are the source of some of the oil and gas of the plains province is unknown, but such an origin is not improbable. If this be the case, the sub-surface distribution of these formations is of great importance, but at present this is almost wholly conjectural. Since Devonian formations are exposed in all the mountain ranges, it seems fairly certain that they underlie the intermediate areas and much of the adjacent territory. Thus they probably extend far eastward beneath the younger formation of the plains, but their eastern limit is unknown.

PART III

ECONOMIC GEOLOGY

BY

G. S. LAMBERT

COAL

Although this bulletin is particularly concerned with the oil and gas possibilities of Central and Eastern Montana, the value of the coal resources of the area justifies a short description of the coal deposits. Coal is known to occur in the Kootenai, Eagle, Two Medicine, Judith River, Lance, and Fort Union formations, ranging in age, therefore, from the Lower Cretaceous, or Comanchean, to the Tertiary. In quality it ranges from brown, woody-fibered lignites in Eastern Montana to sub-bituminous and bituminous coals nearer the mountain front.

Kootenai coal.—Kootenai (Comanchean) coal is found at a horizon about 60 feet above the base of the formation in the Great Falls and Lewistown areas, the former being the more important. The seam is from 3 to 12 feet in thickness, is characteristically irregular, and consists of alternating coal, clay, and bone ash beds(105). It is a medium grade bituminous coal but its value, especially in the Lewistown area, is greatly diminished by the inclusion of a large amount of slate.

Eagle coal.—Eagle (Cretaceous) coal is mined in the Bridger and adjacent fields, and in the Livingston, Trail Creek, Electric, and Stillwater Valley fields, all of which are located in the southwest-central part of Montana. In northern and eastern Montana, the Eagle formation is relatively barren, although small seams of coal are reported north of Black Butte in the vicinity of Deerfield, Fergus County(106). The Eagle coal, which is found in the sandy beds overlying the massive Virgelle sandstone member, is bituminous, but the seams are variable in thickness and most of them high in ash. Only

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(105) Fisher, C. A., Geology of the Great Falls coal field: U. S. Geol. Survey Bull. No. 356, pp. 50-51, 1909.

(106) Bowen, C. F., Coal between Musselshell and Judith, Montana: U. S. Geol. Survey Bull. No. 541-H, p. 45, 1912.

that coal which has been crushed during deformation and converted into a coking coal, can be profitably mined.

Two Medicine coal.—Two Medicine (Cretaceous) coal, correlated with the Belly River coal of Canada, is mapped only in the northwest central part of the state, around the Sweetgrass Hills. It occurs at three horizons, at the base, 250 feet above the base, and at the top of the formation. Elsewhere there is coaly matter in carbonaceous shales 2 to 5 feet thick(107). There is but little production of Two Medicine coal but it is medium grade bituminous and does not weather materially and hence is a fair fuel when mined clean.

Judith River coal.—The productive coal areas of the Judith River (Cretaceous) formation, the equivalent of part of the Two Medicine formation, are the Milk River, Cleveland, Big Sandy, and Judith Basin fields, the first two being by far the most important. The most extensive mining is at Havre in the Milk River field. The Milk River and Cleveland fields are situated, respectively, along Milk River, north of the Bearpaw Mountains, and at the east end of the Bearpaw Mountains. The Big Sandy field is situated at the southwest end of the Bearpaw Mountains and the Judith Basin field lies about 30-35 miles farther south. The coal occurs between 15-150 feet below the top of the formation in lenticular seams which vary in thickness from a fraction of an inch to 9 feet(108). The coal is sub-bituminous and contains a large amount of impurities. It has a low heat value, high moisture and high volatile content, and disintegrates rapidly, hence is a poor railroad or shipping coal, but is a valuable producer gas coal.

Lance coal.—There is no coal being mined from the Lance formation, as mapped by this survey, except for local household use, as the formation contains only thin, unimportant lignite seams and carbonaceous material.

Fort Union coal.—The Fort Union (Tertiary) coal fields include the well known Red Lodge-Bear Creek and Bull Mountain (Roundup) coal fields, as well as the extensive lignite fields of Eastern Montana. These fields, if considered as bounded by the Lance-Fort Union contact as shown on the accompanying geologic map, total about 30,000 square miles in area.

Ths Fort Union formation consists of alternating sandstones and shales with numerous lignite and sub-bituminous coal seams. It has, however, been determined by the U. S. Geological Survey that only those seams which are 30-36 inches in thickness can be profitably mined. Whereas, a great many seams do not attain this thickness, at

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(107) Stebinger, Eugene, Geology and coal resources of northern Teton County, Montana: U. S. Geol. Survey Bull. No. 621-K, p. 126, 1915.

(108) Pepperberg, L. S., Milk River coal field, Montana: U. S. Geol. Survey Bull. No. 381-A, pp. 82-83, 1908.

least 10-15 seams do. It is reported that in the Sidney Lignite field, situated in the extreme eastern part of the state, 980 feet of Fort Union strata contains 49 feet of lignite in seams varying in thickness from 1 inch to 21 feet. The ratio of coal to the entire measures is, therefore, 1 : 20, whereas, the ratio in the Appalachian fields is about 1 : 40(109). Eleven of the lignite seams are considered economically important.

In the Bull Mountain field in Central Montana are 26 coal seams, all of which are more than 1 foot in thickness. In contrast with the typical woody-textured lignites of the more easterly Fort Union fields, the coal of the Bull Mountain and Red Lodge-Bear Creek coal fields is sub-bituminous. This is undoubtedly due to the metamorphism of the lignites during deformation of the Fort Union rocks of Central Montana. This coal may be shipped without significant deterioration and is good steaming coal, hence it has become important both as domestic fuel and for use by the railroads. The mines in the Bull Mountain and Red Lodge-Bear Creek fields are now the principal coal producers of Montana, producing over 63% of all the coal mined in the state. The production in the two districts during 1918 was 2,810, 196 tons(110), and from information available at this time, it appears that the 1919 production was equal to that of 1918(111).

The utilization of the vast reserves of lignite in the more eastern fields constitutes one of Montana's most interesting problems. Among the economic possibilities are these: Briquetting of the lignite to furnish domestic fuel, burning of the lignite at the place of production to generate electric power, and distilling of the lignite into various commercial products such as producer gas and coal tars. Commercial products resulting from the distillation of coal are of increasing importance and although heretofore they have been derived almost entirely from the by-products of coking plants, it is not improbable that, in the near future, they will be obtained from lignite such as is found in Montana. Among the more important products secured are creosote oil, light oils, benzols, solvent naphthas, and heavy tars and pitch products. These furnish dye stuffs, various chemicals and drugs, tars and pitches used in many industries, motor fuels, and raw materials used in the manufacture of explosives.

OIL AND GAS

Development

The search for oil and gas in Montana began in 1897 when four shallow wells were drilled in Carbon County, (Section 32, T. 6 S., R. 18 E). The next year a well was drilled in Blaine County, near

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(109) Stebinger, Eugene, Sidney lignite field, Montana: U. S. Geol. Survey Bull. No. 471-D, p. 287, 1912.
(110) Mineral Resources of the U. S., 1918, Part II, p. 769.
(111) Mineral Resources of the U. S., 1919, Advance coal data.

Chinook. In 1901 wells were drilled in Flathead County, at the western edge of Glacier National Park, and in Beaverhead County, ten miles south of Dillon. The rather desultory prospecting which followed the failure of these first efforts carried the search into Teton and Chouteau counties. These first ventures lacked some of the essentials that make for success, and in no instance was there any production of oil or gas.

Baker-Glendive (Cedar Creek) anticline.—The first production of gas in Montana was from Dawson County, near Glendive (T. 15 N., R. 55 E.), when in 1913 a well owned jointly by the Consolidated Oil and Gas Co. and the Mid-West Oil Co. was drilled to a depth of 2345 feet, and at a depth of 840 feet gas was obtained, the estimated production being 1,000,000 cubic feet per day(112). The drill began in the Bearpaw shales on the Cedar Creek anticline, and probably went through the Colorado formation. The production came mainly from the sand 840 feet deep and to a less extent from two other sands in the same zone, which consists of about 30 feet of alternating shales and sands belonging to the Judith River formation.

Further development has proved three productive districts on the Cedar Creek anticline, the Glendive (Cedar Creek) field, the Baker field near Baker, Montana, and the Cabin Creek field which is located about half way between Baker and Glendive. Fourteen wells were drilled in the Glendive district, eight of which were productive. The gas is all used in Glendive for domestic and industrial purposes. Two wells have been completed and capped in the Cabin Creek field, one of them having an estimated production of 1,000,000 cubic feet daily. There are four productive wells in the Baker district which supply Baker with gas for domestic purposes and for the manufacture of carbon black, the production of which is estimated at 450 to 500 pounds daily.

Havre district.—Shortly after the discovery of gas at Glendive, a large gas well was drilled at Havre, Montana. Two wells had been drilled in 1914, which produced a little gas, but in July, 1915, a well in the SE¼ Section 33, T. 33 N., R. 16 E., about 2 miles northeast of Havre, assured commercial production by coming in with an estimated flush production of 10,000,000 cubic feet per day(113). This well was drowned shortly after by water from a rival well, but the completion of a fourth well with an initial production of 1,000,000 cubic feet per day, partially made good the loss. This fourth well still produces 250,000 cubic feet per day and with 500,000 cubic feet per day from the ninth well, completed in 1921, furnishes the entire supply

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(112) U. S. Geol. Survey Min. Resources of the U. S., Part II, Non-Metals, 1913, p. 1454.

(113) U. S. Geol. Survey Min. Resources of the U. S., Part II, Non-Metals, 1915, p. 980.

of the Havre district. The wells were begun in the Judith River formation and were drilled into the Eagle sandstone from which the gas is derived.

Sweetgrass Hills area.—Prospecting near the Montana-Canadian line was stimulated by the discovery of gas in Alberta and the area between the Sweetgrass Hills and the International Boundary, was the site of considerable activity in 1915-1916. The first well drilled, the Montana-Canadian Well No. 1, was started in the Two Medicine formation, 200-300 feet above the Eagle sandstone, and at a depth of 1860 feet in the basal Colorado sandstone, a flush production of gas estimated at 4,000,000 cubic feet per day was obtained(114). The well was capped. Three other wells were drilled from two of which only "shows" of gas and oil were found, but from the third, known as No. 4 well, which went to a depth of 2085 feet, an estimated flush production of 600,000 cubic feet of gas per day was obtained at 1887 feet, and 2 barrels of oil per day at 1955-7 feet. The casings were pulled from the three wells drilled last and the field was abandoned, but it is understood that the present season will see further testing of the region.

Elk Basin.—The first productive oil field in Montana was discovered in 1915 when the Elk Basin wells were drilled. The development of the district was rapid and by the end of 1916 the peak production was reached, ten producing wells having been completed and the limits of the field determined. The immediate effect was to turn attention to the Montana extension of Bighorn Basin. Wells were drilled in various localities, but none were successful and the period from 1916 to 1919 witnessed a marked decline in prospecting.

Present stage and development.—The recent revival of interest in oil and gas began when the well drilled by the Tri-City and Van Duzen Oil Companies in Section 29, T. 8 N., R. 21 E., on the Woman's Pocket anticline went through the red beds of the Kootenai formation and found a little heavy black oil in the underlying Quadrant sands. Although there was no commercial production, the finding of oil was the basis of a hope that production could be secured from the Quadrant in other places and in November, 1919, the Van Duzen "Discovery Well" in Devil's Basin (Sec. 24, T. 11 N., R. 24 E.), found showings of oil in the Quadrant. It was not until the spring of 1920, however, that commercial production of oil was really assured from other than the Elk Basin field. Prospecting on the anticlines lying north of the Devil's Basin anticline resulted in the discovery of a high grade paraffin base oil in the Mosby dome. The Mosby structure is situated on the Cat Creek anticline, which extends from Black Butte (one of the Judith Mountain laccoliths) easterly and southeasterly beyond

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(114) Billings, Paul, Personal communication.

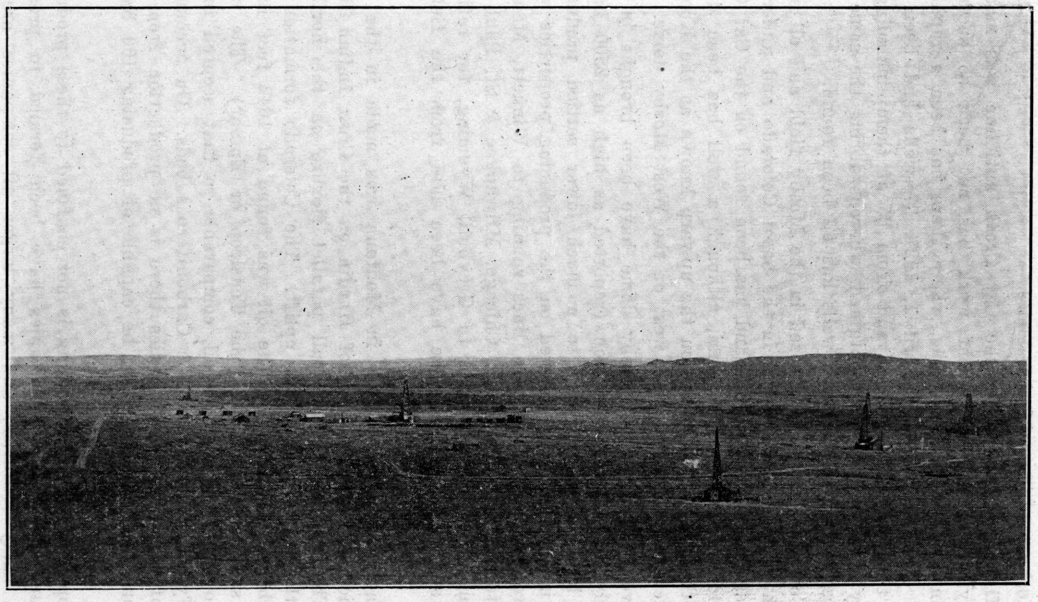

PLATE VIII.—WEST MOSBY DOME.

This shows a typical exposure of Colorado shale along the low hills in the background being formed by the Eagle sandstone which here dips northeasterly rather steeply.

Musselshell River. Along the crest of the anticline are several upwarps or domes. The largest upwarp situated at the east end of the anticline is itself further subdivided into three domes, called the West Mosby, Mosby, and East Mosby domes.

The first discovery along the Cat Creek anticline was made in the Mosby dome, but subsequent work has not been so successful there as in the West Mosby dome, where there has been a rapid and successful development. By April 1, 1921, 27 wells had been completed in the West Mosby dome and from 25 of them, including the "discovery" well, oil is being obtained, whereas during the same time in the Mosby dome in only two wells has oil been found.

The Colorado shales are exposed in the Mosby field and oil occurs at a depth of 1100 to 1300 feet in the basal Colorado and underlying Kootenai sands. As yet no oil sand has been found on the Cat Creek anticline lower than the Kootenai, although a well has been drilled part way through the Quadrant on the upwarp known as the Kootenai dome, which lies about 24 miles west of the West Mosby dome.

The wells in the West Mosby dome have been brought in with a uniformly high flush production (reported as high as 2500 barrels per day) but decrease rapidly to a much lower settled production. The flow is held in tanks situated on the producing properties which in turn are connected with pipe lines running to Winnett, Montana, a branch terminal station on the Chicago, Milwaukee & St. Paul Railroad, whence the oil is shipped to Greybull, Wyoming, for refining. A 2-inch and a 4-inch pipe line have been laid from the field to Winnett.

The latest discovery of oil in Montana was made in the Soap Creek anticline, 28 miles south of Hardin on the Crow Indian Reservation. The structure is a small parallel flexure on the northeast flank of the Bighorn Mountain uplift. The Colorado formation outcrops at the surface(115) and the oil was found at 1642 feet in the Quadrant sands (equivalent to the Tensleep or Embar). The oil is reported to be a heavy, black oil, comparable to that secured in the Lander, Wyoming field, from the Carboniferous beds. On account of the lack of transportation facilities there is no production from this well, although it is estimated to be capable of producing 100 barrels per day.

Development work in Montana is not confined to these producing areas. Hundreds of local companies have been formed to prospect for oil in many localities, and many larger oil companies are engaged in extensive exploration. The whole of the plains area of Montana is receiving attention and the development of the oil and gas resources should be rapid.

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(115) Billingsly, Paul, Personal communication.

Production.

The amount and value of gas and petroleum produced in Montana is shown by the following tabulations which have been made as accurate as possible by consulting all available data.

Gas.—There are three productive gas fields in Montana: Glendive, Havre, and Baker. The production of each is not shown separately but has been totaled to give the yearly production from Montana.

Year	M. Cu. Ft. Produced	Ave. Price Per M Cu. Ft.	Value	Consumers		Wells Drilled		Wells Abandoned	Producing Wells
				Domestic	Industrial	Dry	Productive		
1915	5,555	$0.4500	$ 2,500.00	1	1	....	2	....	†5
1916	213,315	.1821	38,855.00	727	6	....	9	....	‡11
1917	334,421	.2434	81,406.00	1216	12	2	3	1	13
1918	177,039	.3510	62,148.00	1198	....	....	....	....	§
1919	*240,000	No data	*110,000.00	....	....	....	....	....	**
1920	*240,000	No data	*100,000.00	....	....	....	....	....	**

*Estimated.
†Three poductive wells drilled in 1914.
‡Three wells not utilized.
§No data on drilling operations.
**Complete data lacking.

Petroleum.—Until 1920 the total production of oil in Montana came from Elk Basin but the production from the West Mosby dome now overshadows that from the older field, totaling in 1920, 236,832½ barrels, at an average price of $3.10 per barrel, valued at $734,180.75.

Year	Bbls. Produced	Ave. Price Per Bbl.	Value	Wells Drilled		Abandoned Wells	Wells Producing	Reramrks:
				Dry	Productive			
1915	0	....	$........	0	4	0	....	No facilities for ship'g oil
1916	44,917	$0.98	44,019	1	2	0	6	Began shipping in June
1917	99,399	1.47	146,272	1	1	0	7	
1918	69,328	1.81	125,828	....	....	....	....	
1919	*84,000	No data	*170,000	....	....	....	....	
1910	*336,000	No data	*1,000,000	....	....	....	....	

*Estimated.

The price of crude Elk Basin oil at the beginning of 1919 was $1.85 and was $2.25 at the close of 1919, but rose to about an average of $3.00 during 1920.

Theoretical Considerations

A knowledge of the conditions controlling the accumulation of oil and gas is essential to an intelligent exploration of new oil and gas fields. The essential conditions are: (1) a source of oil and gas, (2) a porous stratum, known as a reservoir rock in which the oil and gas can accumulate, (3) an impervious stratum, cap rock, sealing the reservoir rock, so as to prevent the escape of oil and gas, and (4) an enclosed structure into which the oil and gas may migrate from adjoining areas to form pools. Other factors or conditions may also affect the commercial accumulation of oil and gas, such as: the size of the drainage area, the absence of water in the oil sands, the depth of the oil sands, and the temperatures and pressures existing during the distillation of the oil and gas from their source. Following a discussion of the conditions enumerated, their application to the oil and gas possibilities of Montana is taken up.

Source of oil and gas.—Mineral oil, or petroleum, and natural gas are complex compounds of hydrogen and carbon, containing various impurities such as sulphur, nitrogenous substances, and oxidation products. They are classified into series such as the Methane or paraffin base series. To each series a generalized formula can be given, for example, that of the Methane series, $CnH2n+2$. The series begins with Methane gas ($CH4$) and progresses according to the generalized formula, through the gaseous and liquid bitumens to the solid(116). When found in underground reservoirs, the gaseous bitumens form gas pools and the liquid bitumens oil pools.

Oil and gas have their source either in the distillation of organic material or in certain inorganic reactions. Belief in the inorganic theory would lead one to seek for oil and gas in areas more greatly deformed through mountain uplift or volcanic activity rather than in such areas as are now, through a general belief in the organic theory, considered promising.

There are three organic theories: (1) that oil and gas is derived from animal remains; (2) that it is derived from vegetal remains; and (3) that it is derived from both animal and vegetal remains. The last theory, called the Engler-Hofer Dual theory(117), is most generally accepted. The attempt to prove that oil and gas are derived from coal on account of the similarity between petroleum and natural gas and the distillation products of coal, is refuted by geologic evidence which shows that the oil producing horizons in most fields are not the coal horizons and are not in any way genetically connected with them. Furthermore, oil and gas are generally associated with marine formations and salt water, whereas coal is associated with continental deposits and fresh or brackish water. The part played by salt water in the origin of petroleum is uncertain. Some authors hold that it is essential as a preservative and precipitant, others hold that its pres-

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(116) For details the writer is referred to Clarke, F. W., Data on Geol.-chemistry, U. S. Geol. Survey Bull. 695, or to various text books on Oil Geology or Chemistry.

(117) Engler and Hofer, "Das Erdol." Vol. 2, pp. 59-142, 1909.

ence is not necessary but only coincidental. The elimination of coal forming and land plants as a source of oil and the recognition of the association of oil and gas with marine sediments leads to the conclusion that plant and animal remains, which are deposited with marine sediments, are the source of oil and gas. These remains include spores, sea weeds, and soft parts of animals that yield waxy, fatty, gelatinous, and resinous products(118), and are ordinarily deposited with muds to form black shales. Although oil and gas may result from bacterial action it is not until the black shales have been heavily covered by younger sediments which, with the covering of salt water serve to prevent the rapid destruction of the organic matter by oxidation and to retain the products of decomposition, that, through heat and pressure, resulting from deep burial or deformation, oil is distilled from the organic matter(119). The presence of petroliferous rocks may be detected at the surface by the occurrence of oil or gas seeps or asphaltic residium or by actual outcrops of the petroliferous rocks, which may be recognized by their color, odor, or by chemical analysis.

Reservoir rock.—The formation of deposits of commercial importance requires the presence of porous rocks in which the oil and gas generated from the organic matter can accumulate. The amount of oil and gas, and the ease with which it can be secured, depends directly upon the number, size and shape of the pores. The most common reservoir rocks are sandstones, those having the largest capacity consisting of loosely cemented, medium-sized, rounded quartz grains. Other porous rocks in which oil and gas may be found are porous limestones, fractured shales and vesicular lavas.

Since oil and gas migrate upward, the reservoir rocks are found above the source of the oil and gas. Therefore, the ideal reservoir bed is situated above the petroliferous shales, which are the source of the oil and gas. However, where the rocks have been folded into anticlines with steeply dipping limbs, oil and gas may migrate upward through cross fractures toward the crest of the anticlines, and enter porous beds, which normally occur below the petroliferous shales, the source of the oil, but which along the anticlines have been uplifted above the petroliferous shales on either side. Thus, in Montana and Wyoming oil is derived from the Kootenai and Cloverly sandstones which are stratigraphically lower than the Colorado shales, which are probably the source of the oil.

Cap rock.—A relatively impervious bed, usually of shale, must overlie the porous, reservoir bed in order to retain the oil and gas in the reservoir rock. Even a slight leak may have completely

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(118) White, David, Late theories regarding the origin of oil: Bull. Geol. Soc. America, vol. 28, p. 778, 1917.

(119) White, David, Genetic problems affecting search for new oil regions: Bull. 153, Am. Inst. Min. Eng., 1919; and McCoy, A. W., Notes on the principles of oil accumulation: Journ. Geol., vol. 27, pp. 252-254, 1919.

drained the reservoir. Hence, where open fractures exist commercial accumulations of oil and gas are unlikely. On the other hand, some good fields, notably the Elk Basin field of Wyoming and Montana have been greatly broken by faults, which must have been closed or sealed by clay gouge, rock flow, or cementation.

Enclosed structures.—To prevent the farther migration of the oil and gas upward along the contact of the reservoir rock with its cap rock, it is essential that the cap rock completely surround the upper sides of the reservoir as well as cap it, so as to form an enclosed reservoir. Enclosed reservoirs are formed in several ways as is illustrated by figures 1 to 6, plate IX. The various enclosed structures or reservoirs have been classified by F. G. Clapp(120) as follows:

Class I—Where anticlinal and synclinal structure exists.
  (a) Strong anticlines standing alone.
  (b) Well defined anticlines alternating with synclines.
  (c) Structural terraces.
  (d) Local warpings on monoclinal dip.
  (e) Accumulations on monoclines, due to thinning out or change in texture of the sand.
  (f) Broad geanticlinal folds.
  (g) Overturned folds.

Class II—Quaquaversal structures.
  (a) Anticlinal bulges, or "cross anticlines."
  (b) Saline domes.
  (c) Volcanic necks.
  (d) Perforated domes.

CLASS III—Joint cracks.
  (a) Joint cracks in sedimentary rocks.
  (b) Joint cracks in crystalline rocks.
Class IV—Sealed faults.
Class V—Oil sealed in by asphaltic deposits.
Class VI—Contact of sedimentaries with crystalline rocks.

Drainage area.—As a reservoir is assumed to drain all the surrounding area which is underlain by beds that slope upward to the reservoir, the amount of oil and gas in any reservoir is controlled by the size of the drainage area. Hence it is clear that other things being equal that oil field is most productive which has the largest drainage area.

Water in oil sands.—It is uncertain what is the cause of the migration of oil and gas from their source to the reservoir, but it is generally conceded to be due to the migration of water carrying oil and gas with it, or forcing the oil and gas ahead of it. The compacting of the petroliferous muds into shales may force the water

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(120) Bacon, Hamor, and others; Amer. Pet. Industry, p. 48, McGraw-Hill, 1916.

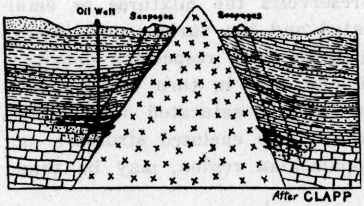

Fig 1.—Hypothetical cross-section of a Volcanic Neck in Mexico, showing the occurrence of petroleum according to Sub-class II (c).

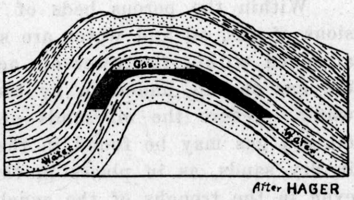

Fig. 2. Illustration of ideal anticlinal conditions, shsowing the occurrence of petroleum according to Class I.

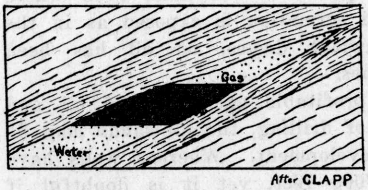

Fig. 3. Ideal section of a lenticular sand, showing the occurrence of gas and oil according to Sub-class I (e).

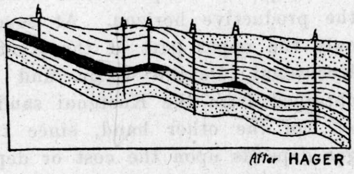

Fig. 4. Theoretical section, showing the occurrence of petroleum according to Class I. Note that the lower fold is non-productive, the oil having migrated up the slope.

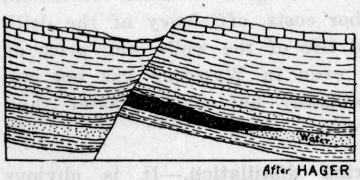

Fig. 5. Theoretical section normal to a fault plane, showing the occurrence of petroleum according to Class IV.

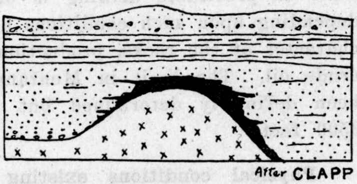

Fig. 6. Theoretical section of unconformable contact of Arkose on Granite, showing the occurrence of petroleum according to Class VI.

PLATE IX.—GEOLOGIC STRUCTURES FAVORABLE TO OIL AND GAS ACCUMULATION.

and oil and gas into the more porous beds that are not compacted so readily as the weaker muds(121), or as has been pointed out(122) water may through its greater capillary attraction replace the oil and gas in shales forcing the oil and gas into more porous beds.

Within the porous beds of the reservoirs the mixtures or emulsions of gas, oil and water are separated and the various constituents arranged within the reservoir according to their respective densities, the gas on top, underlain by the oil, and that in turn underlain by water. Where the oil sands are only partly saturated with water, oil and gas may be found in the limbs of the enclosed structure and in dry sands, as in places in the Appalachian region, may be found even in the troughs of the synclines.

Depth of oil sands.—Where, within the enclosed structure, erosion has progressed to such an extent that the oil sands occur at the surface, the oil and gas which may have been in the sand would have escaped. In almost every oil district there are usually monuments, in the shape of non-productive wells, where drilling began at or below the productive horizon. At several places in Montana, even where only the upper part of the Kootenai formation is exposed as in the Koontenai, Devil's Basin and Shawmut domes, no oil has been obtained from the Kootenai sandstones.

On the other hand, since the profitable extraction of oil and gas depends upon the cost or depth of drilling, the oil sands may be so deep as to preclude profitable development. Whereas wells have been drilled to a depth of over 7000 feet, yet it is doubtful if profitable wells can be drilled anywhere at the present time to more than 5000 feet. Furthermore, since the per foot cost of drilling increases rapidly below a few hundred feet with increasing depth, deep wells to be profitable must be large, long-lived producers. The limit of profitable drilling is of course subject to much variation, depending upon such conditions as labor costs, efficiency of the drill, character of the rocks, production and life of the wells, and price of crude oil. The limit in Montana or even in Wyoming has not yet been definitely determined but is probably not much greater than 3500 feet.

Physical conditions existing during distillation.—It is obvious that the character and amount of the oil and gas in any region is also dependent upon the physical conditions, temperatures and pressures, existing during the distillation of oil and gas from their source, since distillation results largely from heat and pressure. Because the character of a coal is also dependent largely upon the temperatures and pressures to which it has been subject, passing under their influ-

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(121) Daly, M. R., The disastrophic theory: Bull. Am. Inst. Min. Eng., No. 115, pp. 1137-1157, 1919.

(122) McCoy, A. W., Notes on principles of oil accumulation: Journ. Geol., vol. 27, pp. 252-262, 1919.

ence from its initial stage of peat through lignite, sub-bituminous and bituminous coals and to the higher grade coals and even to graphite, White(123) has suggested the use of the character of the coals in any region as an index or gauge of the physical conditions. Coals are classified according to the ratio, called the fuel ratio, of the amount of fixed carbon to the amount of volatile matter they contain, or by the percentage of fixed carbon in pure ash and water-free-coal. Thus lignite usually contains less than 50 per cent fixed carbon, sub-bituminous coal from 50 to 60 per cent, bituminous coal from 55 to 75 per cent, and the higher grade coals more than 75 per cent. Detailed study by White as well as by Fuller(124) and Gardner(125) in the Appalachian and Mid-Continent fields with a more general study of the other oil fields of the world has shown that although fields of heavy oils occur, as in the coastal plain of Texas, where the percentage of fixed carbon is less than 50 per cent, in the principal fields of medium oils like those of the Ohio-Indiana and Mid-Continent fields, the amount of fixed carbon varies from 50 to 55 per cent and in the principal fields of light oils and gas of the world, like the Appalachian field, the amount of fixed carbon varies from 55 to 60 per cent. Where the amount of fixed carbon varies from 60 to 65 per cent, commercial pools are rare, but the oil is exceptionally high grade when found; gas wells are common but are usually isolated. Where the amount of fixed carbon exceeds 70 per cent, oils, if present, will be "white oil" (approximately kerosene) in pockets too small to be of commercial importance though gas pockets may exist.

Although first advanced in 1915, practically no exception to Dr. White's principle of the distribution of oil has been discovered. Since the heat and pressure causing the devolatization of coals and the distillation of oil and gases results largely from deformation, in greatly deformed, mountain built regions, the carbonization of the coals is usually above the 65 to 70 limit, or "dead line." Although as White(126) points out, the carbonization ratio applies only to areas in which alteration is regional, that is caused by deformation, not contact metamorphism resulting from the intrusion of igneous rock bodies, yet igneous intrusives such as occur throughout the mountains of Montana, although more local in their effect bring about similar changes to deformation. Furthermore, the escape of hot waters or solutions from the igneous intrusions, usually fill the pores of the adjoining rocks with mineral matter converting reservoir rocks into

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(123) White, David, Some relations in origin between coal and petroleum: Wash. Acad. of Sci., vol. 6, pp. 189-212, 1915.

(124) Fuller, M. L., Relation of oil to carbon ratios of Pennsylvanian coa's in North Texas: Econ. Gsology, vol. 14, pp. 536-542, 1919, and Carbon ratios in Carboniferons coals of Oklahoma, and their relation to petroleum: Econ. Geology, vol. 15, pp. 225-235, 1920.

(125) Gardner, J. H., The Mid-Continent oil field: Bull. Geol. Soc. America, vol. 28, pp. 685-720, 1917.

(126) White, David, Genetic problems affecting search for new oil regions: Mining and Metallurgy, No. 158, Sec. 21, p. 7, Fsb., 1920.

firm, impervious rocks such as quartzites, in which no accumulation of oil and gas can take place.

In conclusion it is well to consider that owing to the many conflicting or compensating conditions, many of them imperfectly understood, affecting the commercial accumulation of oil and gas, "it is not surprising that some concentrations of oil and gas occur where, from all surface indications (especially where the productive rocks are obscured by a mantle of younger, unconformable sediments) the conditions are unfavorable, whereas, some areas that appear to have the most favorable structure are barren."(127)

Possibilities of Oil and Gas.

This chapter on the possibilities of oil and gas must serve as a guide in detailed work rather than as a final report on any area, as the reconnaissance nature of the field work precludes detailed discussions. As already noted, the possibilities will be discussed by applying the theoretical conditions presented in the previous section, to Montana.

Sources of oil and gas.—The marine shales of the Claggett and Bearpaw formations are the only rocks above the Colorado formation which need to be considered as sources of oil and gas as the sediments of the Eagle, Judith River, Lance, and Fort Union formations were deposited under littoral or continental conditions and are not known to contain any black, bituminous shales. Some such shales do occur in the Claggett and Bearpaw formations and Hancock(128) has reported surface indications of oil and gas in the vicinity of Hardin and in the northwest corner of Yellowstone County. However, no commercial amount has ever been found and it is doubtful if either the Bearpaw or Claggett shales can furnish any significant quantity of oil or gas. Furthermore, to the west the shales grade into alternating sandstones and shales typical of near shore or litoral deposits.

The source of most of the oil and gas produced in Wyoming and southern Alberta is generally conceded to be the black shales of the lower portion of the Colorado formation. The uninterrupted continuation of the Colorado formation from Wyoming through Montana into Alberta has long been considered the most favorable indication that Montana would produce oil. Recent drilling has shown, however, that in places the lower black shales are absent. Stebinger's field work(129) in the northwestern part of the plains area has shown some of the Colorado shales to be petroliferous to such an extent that

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(127) Hancock, E. T., Geology and ol and gas prospects of the Huntley field, Montana: U. S. Geol. Survey Bull. 711-G, p. 146, 1920.

(128) Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Montana: U. S. Geol. Survey Bull. 711-G, p. 144, 1920, and Geology and oil and gas prospects of the Lake Basin field, Montana: U. S. Geol. Survey Bull. 691-D, p. 126, 1918.

(129) Stebinger, Eugene, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana: U. S. Geol. Survey Bull. 691-E, p. 157 and pp. 161-164, 1918.

they offer an unquestioned source for commercial quantities of petroleum. The main petroliferous horizon seems to be confined to the lower 150 feet of shales which overlie the Blackleaf sandy member. Collier(130) states of the Mowry member, "it seems almost certain that the formation would yield oil if properly sampled and tested." These reports from the northwestern and northeastern parts of Central and Eastern Montana, in connection with the fact that the major production from Wyoming and the entire production from the Mosby dome in Central Montana is from associated sands, indicate that the Colorado formation and in particular the Mowry member, is the important source of oil and gas in Montana. In all places the oil is a high grade, light oil with a paraffin base and in Central Montana consists mainly of gasoline and kerosene.

Since the Mesozoic sediments below the Colorado formation are predominantly sands and shales of continental and near shore origin it is doubtful that any petroliferous beds competent to serve as sources of oil or gas will be found. Furthermore no oil or gas other than that which has migrated from other sources, have been discovered in these formations.

Two possible sources of oil and gas are found in the Paleozoic sediments. Although the more northerly exposures of the Quadrant formation in Central Montana do not show a dominately petroliferous zone, yet some black shales which may have furnished oil and gas are found and the more westerly and southerly exposures are of a more favorable character. The phosphatic black shale member of the Quadrant, which contains the oil shales of southwestern Montana is reported to thin to the eastward(131) and whereas the Quadrant sands have not yet furnished commercial production in Musselshell Valley, yet these beds are productive in the Soap Creek anticline. Along Mackenzie River in Canada, numerous seeps of light to heavy asphaltic petroleums are found in the Devonian limestones. To the south, along Athabasca River, these beds are overlain by Dakota sandstones which are known as "tar sands" due to their saturation with asphaltic bitumens which appear to have been derived from the underlying limestones. Southward, in Montana, the Devonian beds are exposed only in the western mountainous area but underlie at least a part of the plains area. Peale(132) describes them as black magnesian limestones "crowded with Devonian fossils," and shales which in places form carbonaceous phases of sufficient richness to form an impure coal.

Reservoir rocks.—Porous beds which may serve as erservoirs are known at various horizons in the upper Paleozoic and Mesozoic forma-

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(130) Collier, Arthur J., The Bowdoin Dome, Montana, a possible reservoir of oil or gas, U. S. Geol. Survey Bull. 661-E, p. 199, 1917.

(131) Condit, D. Dale, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 711-B, p. 20, 1919.

(132) Peale, A. C., Three Forks Folio, U. S. G. S., Folio 24, 1986.

tions. The oil that might be generated in the Paleozoic sediments finds suitable reservoir rocks in the Quadrant formation, correlated with the Tensleep, Amsden, and Embar formations in Wyoming. The most important reservoir rocks belong to the Comanchean and Cretaceous series and serve as collecting sands for oil and gas derived from the associated Colorado shales. The present productive sands occur in the Colorado and Kootenai formations underlying the Colorado shales, in the Eagle sands overlying the Colorado shales, and in the Judith River formation overlying the Claggett shales. The Frontier sands, from which most of the oil in Wyoming is obtained, are only locally developed in Montana and have not yet proved to be productive in Montana except in the Elk Basin dome. The basal Colorado sandstone or "Rusty Beds" is the first of the three oil sands of the Mosby district, and the first and second Kootenai sandstones are the two lower sands. The production from the West Mosby dome is almost entirely from the upper sand, whereas the production from the Mosby dome proper, or middle dome, is from the middle sand. Oil has been obtained from the lowest sand in the Ten Spot well on the West Mosby dome near the edge of the productive area. The chances for production from the two lower sands in the West Mosby dome are therefore favorable.

The Eagle sandstones are productive of gas in the Havre district but are not known to contain oil. Since they are separated from the basal petroliferous beds of the Colorado by 1500 to 2000 feet of clay shales, which are not readily traversed by fractures open sufficiently to allow the migration of oil through them, it is doubtful if the Eagle sandstones contain any significant amounts of oil anywhere in Montana. Where traversed by large faults, as in the Havre district, gas can doubtless migrate through the Colorado shales, and may collect in the Eagle sandstones in commercial quantities.

The Judith River sandstones also contain commercial amounts of gas in the Cedar Creek anticline, but are still farther separated from the source of the oil and gas than the Eagle sandstones, and hence are not likely to contain oil. In fact it appears as if the Judith River sands are productive of gas in the Cedar Creek anticline because the Eagle or other sands are lacking between the Judith River sands and the source of the gas in the basal Colorado shales. It would be unwise, therefore, to prospect only the Judith River sands in those areas also underlain by the Eagle sands.

Cap rocks.—Extensive thick beds of shale occur throughout the sedimentary series of Central and Eastern Montana. Most of the shales are weak and incompetent and hence, will flow when under the weight of only a few hundred feet of overlying sediments. Therefore, although they may be broken by faults in many places, they may still serve to cap the underlying sandstones effectively.

Favorable structures.—With a minor exception in southwest Wyoming, the only structures which have proved to be productive of oil in Montana or Wyoming are domes or enclosed anticlines, although within these structures the actual distribution of oil is controlled in places by faults. The uplifts terminated on one side by faults, to the north and south of the Bearpaw mountains, contain gas but have not yet been proved to contain commercial amounts of oil. The major structural features have already been described(133) and are shown and named on the accompanying structural map. Whereas the possibilities of oil and gas in each of the structures can not be discussed, on account of the lack of detailed knowledge, yet the application of the facts and theoretical principles already given may be considered further, profitably.

Since, as already described, the principal sands, the basal Colorado and Kootenai, in which oil is now found in Montana occur lower in the geologic column than the principal source of the oil, the Mowry member of the Colorado, the most favorable structures are those with steep limbs, affording a chance for the oil to migrate upward through cross fractures toward the crest of the fold where the sands have been uplifted above the petroliferous shales. Even in Wyoming where the Frontier sands are well developed, no large oil fields have been found except where the dips exceed at least 10 degrees in places. In Montana the folds of steep dips occur chiefly in connection with the main Rocky Mountain uplift, the major axis of deformation of Central Montana south of the Little Belt mountains, and the synclinal area between this axis and the main mountain uplift, the Big Snowy Mountains anticlinorium, and in the north and south of the Bearpaw Mountains as well as in the Sweetgrass Hills, Bearpaw Mountains, and Little Rocky Mountain uplifts. In the Sweetgrass arch, and west to the area of greatly folded and faulted rocks near the Lewis overthrust fault and in Eastern Montana the dips are usually less than 5 degrees. However, the western limb of the Cedar Creek anticline dips at an average angle of 20 degrees. On the Sweetgrass arch, and the Porcupine dome as well, a few minor uplifts or domes are reported, and it is possible that some of them will have sufficiently steep dips to be worth testing.

However, it must be borne in mind that in general where the folds have the steepest dips they are close together and only a relatively few enclosed anticlines and domes with steep dips have a sufficiently large drainage to have collected commercial amounts of oil and gas. It is doubtful if any of the folds within the main mountain area, or even close to the main mountain front, have a sufficiently large drainage area, and doubtless this cause is one of the reasons for the failure resulting from drilling in the Woman's Pocket and Shawmut anticlines, Big Coulee-Hailstone dome and the domes on the Elk uplift, all situated along the axis of major folding in Central Montana between the Bighorn and Little Belt and Big

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(133) See pages 18-24.

Snowy mountains. This element in the problem should also be given careful consideration in the location of test wells on the faulted structures to the north and south of the Bearpaw mountains. On the other hand, the domes along the north and south margins of the Big Snowy anticlinorium, on the flanks of the Bighorn mountains, and in the synclinal area to the west, and in Eastern Montana all have large drainage areas.

Virtually all of the sandstones of Central and Eastern Montana are saturated with water throughout their entire extent and although one or two wells have been driven into dry sands, yet the chances are that within nearly all the enclosed structures of Central and Eastern Montana, the sands contain sufficient water to have caused the migration of oil and gas from the surrounding drainage area to the apex of the structure.

In all of the mountain groups of Central Montana, with the exception of the western portion of the Bearpaw, and the Highwood and Crazy mountains which are largely volcanic in character, Madison limestone and older Paleozoic rocks and even igneous rock cores are exposed. Hence, they cannot be considered favorable to the accumulation of oil and gas. Furthermore, in some of the otherwise fairly favorable structures, such as the Kootenai and Devil's Basin domes and the West and Middle domes of the Shawmut anticline, the Kootenai formation is exposed and drilling has failed to secure oil from the shallow Kootenai sands although some oil has been obtained from the much more deeply buried Quadrant sands.

The lowest rocks exposed in the structures of Eastern Montana, and in several of the structures of Central Montana, except in the Porcupine dome and in northern extension of the Black Hills uplift in southeastern Montana, occur above the Colorado formation. Therefore, to test the basal Colorado and Kootenai sands, the highest known oil horizons in Montana except the Frontier sand in the Elk Basin dome, it will be necessary to go through the Colorado formation which has a thickness of 1500 to 2200 feet. Where the Bearpaw shales are the lowest exposed formation, as in several of the structures of Eastern Montana, and a few in Central Montana, it will be necessary to go through the additional thickness of the Eagle, Claggett, and Judith River formations amounting from 600 to more than 1200 feet. Throughout Central and Eastern Montana, the base of the Colorado formation is at least 2000 feet below the base of the Bearpaw shale and in most places is nearly 3000 feet or more. Where the Lance formation is the lowest rock exposed, the Bearpaw shales must also be penetrated so that the depth to the base of the Colorado will vary from 3000 to more than 4000 feet. Since it is doubtful if oil can be produced at a profit in Montana from depths of more than 3500 feet, drilling for oil in structures where the Lance is the lowest exposed rock cannot be recommended at the present time and not until further development has proved the existence of oil in neighboring structures where the oil sands are shallower. Gas, however, may be sought at shallower depths, 1500 to 2000 feet less in the Eagle sand, and 2000 to 2500 feet less in the Judith River sand.

On the accompanying index structural map, the lowest exposed formation is given with the name of the structure and also four type geologic sections, referring in particular to those parts of the state where the corresponding figures are shown. Thus, by the use of the data given, a rough estimate of the depth of the various sands in any structure may be made.

There are an insufficient number of analyses of coal from carefully selected places to determine accurately the physical conditions under which oil and gas might have been distilled in various portions of the state by plotting the carbon contents of the pure coals. In general the carbon content of the lignites of Eastern Montana is slightly less than 50 per cent, hence, any oil which may be found in Eastern Montana will probably be of a heavy character. The carbon content of the sub-bituminous coals of the western part of Eastern Montana and the sub-bituminous and bituminous coals of Central Montana, except close to the mountain uplifts, ranges from 50 to 60 per cent and hence represent ideal conditions for the distillation of medium and high grade oils such as have already been found. Close to the mountains and in the eastern part of the Rocky Mountains the carbon content of the bituminous coals range from 60 to 72.5 per cent, although in places, as in the Trail Creek field(134), the carbon content may be as low as 53.5 per cent, and hence the region cannot be considered as favorable in general to the occurrence of oil in quantity although some high grade oil and gas may be found. There are virtually no analyses from which to judge the carbon content of coals, hence the metamorphic conditions, existing well within the mountain region, but in most places it would doubtless exceed the "dead-line" of 70 per cent.

It cannot be denied that the results of drilling during 1920 and the first half of 1921 have been disappointing. Several structures where apparently the surface indications have been favorable have not yet been proved to contain oil and possibly some have been definitely disproved, and by June 1st, 1921, only the Elk Basin dome, the West and Middle Mosby domes, and the Soap Creek dome, have been proved to contain oil in profitable amounts. On the other hand it can be said in all fairness that where competent examination shows in Central or Eastern Montana an enclosed structure with steeply dipping limbs, with a good drainage area, and with Judith River or lower Cretaceous rocks exposed, there is ample justification for a test well.

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(134) Calvert, W. R., The Livingston and Trail Creek coal fields, Montana; U. S. Geol. Survey Bull. 471-E, p. 402, 1912.

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