Geology of Montana

Stanley G. Olson

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GEOLOGY OF MONTANA

by

Stanley G. Olson

A Thesis
Submitted to the Department of Geology
in partial fulfillment of the
Requirements for the degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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INTRODUCTION

A vast amount of information has been published by many workers on particular features of the geology of the state of Montana, as well as on local geology of many smaller divisions. However, a satisfactory summary of the geology in general, which would include all phases of geology as they apply to the greater area of the entire state, has not been published. This thesis has been written as a greatly abbreviated summary of these various phases applied to the state as a unit.

The large size of the state, and the large volume of work published on the subject, renders it impractical to go into detail with local features or with smaller areal subdivisions. Hence, in the present report, an attempt has been made to present each major geological heading in its broader application to the state as a whole.

No claim is made by the writer for originality in field observation of any portion of the text or accompanying illustrations and charts, since material for the paper is primarily abstracted from previously published reports.

Work in the preparation of this thesis was facilitated by the assistance of Dr. Eugene S. Perry, Department of Geology, Montana School of Mines. Much information has been
made available to the writer by Dr. Perry in personal communication, and in a course of study of the geology of Montana. Also to Mrs. Loretta Buss Peck, Librarian, Montana School of Mines, sincere appreciation is expressed for skillful assistance in the research necessary for this report.

PHYSIOGRAPHY

With an area of nearly 150,000 square miles, and geographically located to include gradational features between the northern Great Plains and the Rocky Mountains, Montana has topography ranging from the gently rolling plains areas in the eastern part of the state to areas of striking relief in the western part. Drainage, vegetation and climate vary with the changes in topographic relief.

TOPOGRAPHY AND DRAINAGE

The area of Montana is readily divisible into three approximately equal portions, each characterized by a different type of topography. These approximate divisions are indicated in Fig. 1, Page 3.

The eastern part of the state, though generally thought to be relatively flat as compared to a mountainous region, is far from being a uniformly smooth surface. Although some flat tracts and large gently rolling areas do exist, much of the plains region along the Missouri and Yellowstone rivers and their tributaries has large areas of very rough country. Typical badlands occur in the "breaks" along the Missouri and Yellowstone rivers, and relief is commonly in the order of 500 feet or more.
The western portion of the state is truly a mountainous region. The many mountain ranges have a general northwest to southeast trend, although local marked variations in this trend may be noted. Continuity of this mountainous landscape is broken by occasional wide intermontain valleys with nearly flat floors from 2,000 to 5,000 feet or more below the crests of the enclosing mountains. These large valleys are 10 miles or more in width and have a length much greater. Approximate locations of some of the principal intermontain valleys is shown in Fig. 1.

![Fig. 1. Topographic Divisions of Montana](image)

In the central portion of the state, lying just east of the area of intense deformation, is an area of primarily flat plains within which isolated mountains rise above the nearly level surrounding country. Thus, the topography of the
central portion is intermediate between that of the eastern and western parts of the state and contains elements of both.

Montana is drained by streams which form headwaters for rivers that drain into both the Atlantic and Pacific oceans. The drainage of most of the western mountainous portion of the state is of a youthful type. Examples are found which indicate that the drainage patterns of the mountainous areas are superimposed—the mountains having risen after the drainage pattern was established. The rivers of the eastern plains area within the states are characterized by deep trenches in which they flow. In some places they have cut 100 to 500 feet below the general land surface.

CLIMATE AND VEGETATION

A great diversity of climate in Montana may be accounted for by the extreme ruggedness of the state. The average annual temperature is around 43 degrees. Most recording stations have reported maximum temperatures in excess of 100 degrees, and minimum temperatures as low as 20 degrees below zero occur almost every winter. Daily temperature ranges are fairly large and are quite marked during the warm periods in the summer.22.

The average annual precipitation for Montana is about fifteen and one-half inches. Here again the natural division of the state into eastern and western portions separated by the continental divide has had an influence. On the eastern plains, the precipitation ranges from 12 to 16 inches. West of the divide the averages are somewhat higher.22.
Vegetation in the state ranges from the short grass of eastern prairies to extensive stands of pine and fir in the mountains. In the eastern part of the state, vegetation is predominantly short grass, with small amounts of yellow-pine and Douglas fir in the southeastern corner. The central portion also predominates in short grass, but with increasing amounts of yellow pine, lodgepole pine, Douglas fir and spruce. Approximately half of the western part of the state is forested with lodgepole pine. Spruce, yellow pine and Douglas fir are represented in subordinate amounts. Short grass and bunch grass grow on the floors of the intermontain valleys.

**STRATIGRAPHY**

Rocks of all types representing all geologic periods of time from Archeozoic to Recent, excepting Silurian, are exposed in Montana. Variations in rock types in different sections of the state and naming of similar units by individual workers have resulted in a number of local stratigraphic columns within the state. For correlation of formational names, see Plate 8, following Page 37.

Distribution of strata is shown in the series of maps, Plates 2, 3, and 4, following Page 30.

**ARCHEOZOIC**

Rocks of Archeozoic age have been identified in several isolated areas of the state. Douglass listed six areas of southwestern Montana in which he observed rocks generally recognized as Archean. The rocks represented in this list are highly metamorphosed schists and gneisses.
Tansley and Schafer have described a series of highly metamorphosed schists and gneisses in the area of the Tobacco Root Mountains. A group of schists and gneisses interbedded with much marble and quartzite had previously been described by Peale and called "The Cherry Creek Beds". The series of rocks without marbles and quartzites, described by Tansley and Schafer, were named the Pony series from the good exposures in the vicinity of Pony. No attempt was made in the paper to classify these rocks, except that it is stated that the Pony series is undoubtedly older than the Cherry Creek series, and unconformably underlies it.

The extreme complexity in the geology, and the difficulties encountered in the field work and correlation of these ancient rocks, have been limiting factors in the amount of information concerning them. Much remains to be done on Archeozoic rocks in Montana before the geologic picture can even approach completeness.

PROTEROZOIC

The Algonkian period is widely represented in Montana by the Belt series, a tremendous thickness of sedimentary rock of shallow water deposition. It has been estimated that the exposures of Belt in Montana cover an area of more than 6,000 square miles. In speaking of the deposition of these beds in western Montana, Deiss states, "All known evidence indicates that deposition continued uninterrupted until 50,000 feet, or more, of clastic sediments and impure sideritic limestones had accumulated in the central part of the trough."
A correlation table of Belt rocks of Montana prepared by Clapp and Deiss shows exposed Belt sediments which aggregate in excess of 40,000 feet in thickness. This work was in the extreme western part of the state, probably very near the center of the trough of ancient deposition. These sediments thin out rather rapidly to the east. Near Helena, in west-central Montana, Walcott has estimated the total thickness of the Belt at 12,000 feet, and formation disappears from between the older gneisses and the younger Cambrian some 60 miles south of Helena. It also disappears to the east and north of Helena.

Barrell, in a study of sedimentation environments, concludes that "...the Belt gives an illustration of two sedimentary cycles, each of which contains a strongly marked formation of mud-cracked red shales, the shales alternating with sandy strata, and both judged to have been deposited on the flood plains of rivers whose deltas had gained over the subsidence, finally filling up and displacing the shallow epicontinental sea. The cycle is thus seen, not only to pass from arenaceous and argillaceous to calcareous formations and back again, but to pass from land to sea, and back again to land."

PALEOZOIC

Lowest Paleozoic sediments in Montana are separated by an unconformity from subjacent Beltian deposits. This unconformity was first recognized and described by Walcott and was subsequently confirmed by the work of Clapp and Deiss.
Only middle and upper Cambrian sediments are recognized in Montana. Reference to the correlation chart (Plate 7) shows a variety of different formational names applied to Cambrian rocks. In central and southern Montana, where most of the Cambrian outcrops are found, the names originally given by Weed in the Little Belt Mountains (Flathead sandstone, Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, and Dry Creek shale, top) are applicable and, according to Deiss and others, should be retained for Cambrian strata.

As stated by Perry, the lithology of the Cambrian of Montana consists in general "of a basal sandstone or quartzite, a micaceous shale series, a dolomitic limestone series (with shale zones), and an uppermost shaly, sandy, limestone formation. Flat-pebble (edgewise) limestone conglomerates are characteristic of the limestone series in central Montana, and trilobites are the dominating type of fossil."

Upper Ordovician strata (Richmond epoch) occur throughout the southern half of Montana, and consist essentially of the massive Bighorn dolomite. Thickness of the strata ranges from 200 to 300 feet in most localities. The Bighorn is a hard, massive rock of light gray color, and has a granular or sugary texture. On weathered surfaces, it shows a coarse, irregular pitted or honeycombed surface. Rocks of the Ordovician are absent in northwestern Montana and have not been recognized in the region of the Sweetgrass arch. No Silurian strata have been recognized in Montana.
Devonian sediments are widespread throughout most of the state. They are missing in the extreme western and in the southeastern portions. The lower part of Montana Devonian (middle Devonian in age) is a brown or black crystalline limestone or dolomite called the Jefferson limestone (or dolomite) and first described by Peale 24/. In the vicinity of Three Forks an upper shale member called the Three Forks formation is present, but it grades into limestone away from the area. The thickness of Devonian strata in Montana averages consistently around 1,000 feet 27/.

East of Glacier National Park, the upper part of the Devonian contains anhydrite interbedded with the limestones. Dissolution of the anhydrite, allowing the overlying crust to sink, has given rise to "solution breccias" in some portions of the area 27/. Peale 24/ and others have shown that the upper portion of Montana Devonian yields abundant recognizable fossils.

Mississippian strata in Montana are characterized and their study complicated by marked facies changes from west to east. In the western portion, under geosynclinal conditions of deposition, a great thickness (2,000 feet or more) of massive limestone (Hannan) was deposited. Toward the east and south, in central and southern Montana, the upper part of this limestone (middle and upper Mississippian) grades into the Big Snowy group, a clastic series with predominating shales 3.27/. Overlying the Big Snowy group in central and southeastern Montana is the Amsden formation, which grades from a shaly
sandstone in the south to a thin-bedded limestone in central Montana. Scott originally assigned the Amsden to Mississippian, but in a subsequent work, Thompson and Scott recognized that the Amsden included strata of both Pennsylvanian and Mississippian ages and placed the Pennsylvanian portion in the Quadrant. The Sacajawea formation was established to include the Mississippian portion. Perry and Sloss show that the subdivision made by Thompson and Scott leaves strata which are neither entirely Pennsylvanian nor entirely Mississippian in age, and thus represent a transitional phase. They contend that the name Amsden should be retained for these in-between sediments, because they constitute a lithologic unit.

In central and western Montana, the lower Mississippian limestones are called the Madison group, and are divided into two members—the Lodgepole limestone (lower) and the Mission Canyon limestone (upper). The Lodgepole member is a dark-gray to black, fine-grained cherty limestone. The Mission Canyon member is a gray, massive cliff-forming limestone. Both strata are highly fossiliferous. Thickness of the Madison group ranges from 600 to more than 2,500 feet.

The Big Snowy group is composed of three formations—the Kibbey, the Otter, and the Heath at the top. Black petriferous shales and sandstones characterize the Heath formation which forms the uppermost beds of the group. The Otter is a series of gray to green shales intercalated with thin oolitic and fossiliferous limestones. The Kibbey is essentially a
red shaly and dolomitic sandstone. Total thickness of the Big Snowy group is 700 to 1300 feet 35/.

Seager 36/ introduced the term Charles to describe the beds lying between the Big Snowy group and the Madison, and included this formation in the Big Snowy group. The Charles is not exposed in Montana but has greater subsurface distribution than any of the Big Snowy units 28/. As described by Perry and Sloss, the Charles formation is characterized by "light-colored earthy limestones and dolomites (in places oolitic, commonly anhydritic), interbedded with evaporites (chiefly anhydrite) in beds approaching 100 feet in thickness. Minor amounts of red shale are present in most sections penetrated." The thickness of the formation averages approximately 600 feet.

As shown by the correlation charts, Pennsylvanian sediments in Montana are restricted to the central and southern sections of the state. The strata, which are lower Pennsylvanian in age, range from west to east from hard, massive, firmly-cemented quartzite to very friable sandstones. Peale 24/, in a study near Three Forks, described the general character of the Quadrant to be that of limestones, but of markedly arenaceous nature. More recent works describe the Quadrant in the southwestern section as a hard sandstone or quartzite with interbedded crystalline limestone. The formation here ranges between 500 feet and 800 feet in thickness. The hard quartzite has been traced eastward, and in south-central Montana it grades into 50 to 100 feet of a friable, cross-bedded sandstone.
In this area (south-central Montana and central Wyoming) the name Tensleep sandstone has been applied. Scott shows that a red zone above the Madison in south-central Montana, commonly classified as basal Quadrant, is actually Amsden (see Page 10).

Eastward, in southeastern Montana (and northwestern Wyoming) the Tensleep is correlated with the Minnelusa formation which consists of a calcareous sandstone with limestone and shale zones. This formation has been subdivided into an upper coarse-grained sandstone and a lower fine-grained sandstone with limestone and red beds.

Strata of Permian age are represented in Montana by limited exposures of the Phosphoria formation in the southwestern portion and by the Minnekahta limestone and the Opeche formation in the extreme eastern and south-central sections of the state. Richards and Mansfield showed in a paper written in 1912 that the Phosphoria of Idaho had been correlated with the phosphate beds above the Quadrant formation in southwestern Montana. These beds are now generally called the Phosphoria formation in Montana as well as in Idaho.

The Phosphoria of the southwestern corner consists of a gray limestone and shale series in which black chert is found in abundance. The formation is commonly 400 to 500 feet thick. Two horizons of oolitic phosphate beds are found. A black, fissile, somewhat phosphatic, shale of Permian age is found south of Dillon, in southwestern Montana.

In south-central Montana a dense gray limestone about 50
feet thick has been tentatively correlated with the Embar formation of Wyoming. (The upper part of the Embar has previously been correlated with the Phosphoria of Idaho.) The Minnekahta limestone and the Opechee formation (Permian) are believed to be present in the southeastern part of Montana.

Hard, flexible limestones characterize the Minnekahta; the Opechee formation consists principally of thin bedded, soft, red sandstones.

**MESOZOIC**

Although Mesozoic strata are absent in extreme western Montana, probably due to Tertiary erosion, they are abundantly exposed throughout the rest of the state, particularly in a north-south belt through central Montana (see Plate 3,B).

Recognized Triassic sediments are limited to southern Montana. In the southwestern portion, 400 feet of gray shale with some limestone and sandstone has been correlated with the Woodside, a lower Triassic sediment described by Boutwell in southeastern Idaho. In south-central Montana are a series of red beds forming a striking horizon. These are called the Chugwater formation from the name given to similar strata in Wyoming. These strata are mainly bright red sandy and shaly beds, 200 to 450 feet in thickness and thickening southward. In southeastern Montana, deep well records show the presence of red beds containing salt and anhydrite. These are correlated with gypsiferous red beds of Triassic age which crop out in the Black Hills of South Dakota. No figures are found for the thickness of the southeastern Montana Triassic strata, due
probably to the fact that definite separation of these red beds from overlying and underlying red sediments is accomplished only with difficulty 27.11/.

With the exception of the extreme western portion of the state, Jurassic sediments have wide representation in almost all sections of Montana. These strata are of middle and upper Jurassic age. Middle Jurassic is present in most exposures as the Ellis formation, generally containing a basal sandstone overlain by argillaceous and arenaceous limestones with much shale, and with a thickness ranging from 300 to 500 feet. The Ellis has been correlated with the Sundance formation of Wyoming and south-central and southeastern Montana. The Sundance is typically a series of shales and sandstones, with a massive red sandstone frequently appearing at the base of the formation. The strata range from 60 to 400 feet in thickness.

Overlying the middle Jurassic Ellis and Sundance formations in Montana is the upper Jurassic Morrison formation. These deposits are generally considered to be uppermost terrestrial Jurassic. Darton 11/ has described the Morrison deposits as "mainly massive shale or 'joint clay,'" somewhat more fissile and darker to the east than to the north and west. The predominant color is a light greenish gray merging into chocolate and maroon tints. Thin beds of fine-grained, white or light gray sandstone are included, and some thin local layers of impure limestone. The Morrison ranges in thickness up to 200 feet.
Cretaceous sediments, widespread in Montana, are absent in the extreme western and northwestern portions of the state, but are represented in all other portions. Several local stratigraphic sections with many different formational names may be noted. No attempt is made in this report to cover these various sections in detail, and only very general descriptions of larger units are included. Reeside 29/ has compiled a series of maps with a stratigraphic table and descriptions of Cretaceous strata. For more detailed discussions of the stratigraphy, this reference should be consulted.

Lower Cretaceous strata are designated in most areas as the Kootenai formation, which is correlated with the Cloverly formation of south-central Montana and the Dakota group in the southeastern corner 3/. The Kootenai consists of about 1,000 feet of coarse clastics and pebble conglomerate in western Montana, but thins to 300 feet or less eastward. Locally, distinct sandstone beds are encountered and are given names not in general use. Thus, in the region of the Sweetgrass arch, a sandstone horizon is known as the Sunburst sand. In central Montana, there are the Second and Third Cat Creek sands (the First Cat Creek sand is a bed which lies in the Colorado group immediately overlying the Kootenai formation). In some portions, a basal sandstone containing intermixed grains of quartz and black chert, have given rise to the term "salt and pepper sandstone". The Cloverly formation of south-central Montana has been described by Darton 11/ as consisting of a coarse-grained, buff or gray limestone, overlain
by a reddish to ash-colored clay. Total thickness of the formation averages about 60 feet. In southeastern Montana, the Dakota group (known only from well cuttings) is shown by Rubey (32) to be 150 to 350 feet of conglomerate, shale and sandstone.

Overlying the Kootenai are 2,000 feet of predominantly shaly strata, known generally as the Colorado group. Some sandstones and clays are found in limited quantity (southern Montana) and the uppermost member of the group (Niobrara) is generally shale throughout all parts of the state where it can be recognized. In the south-central section, the Colorado group has been divided, in descending order, into Niobrara shale, Carlile shale, Frontier formation (sandstone, overlain and underlain by clay and shale), Mowry shale, and Thermopolis shale (lowest) (3). In traveling north and west from the section mentioned, the individual units above lose their identity, and, due to the difficulty encountered in distinguishing between them, are grouped by most workers as undifferentiated Colorado group.

The Montana group, lying immediately above the Colorado group is recognized in most sections having outcrops of Cretaceous sediments. In the southwestern portion, the Montana group is undifferentiated but in other sections this group is divided (in descending order) into the Lance formation (a shaly sandstone named by Hatcher (17)), Fox Hills sandstone, Bearpaw shale, Judith River formation (light ash-colored sandstone alternating with shales and clays), Claggett
shale, and Eagle sandstone 15, 17, 18, 46. The alternation of sediments, shale and sandstone, clearly represents a type of sedimentation resulting from the fluctuation of the sea level during this period. The Montana group is generally about 2,000 feet thick. Toward the Dakotas the group grades into the Pierre shale and is correlated with this shale in southeastern Montana. In some sections (south-central and northeastern Montana) the Lance has been further divided into the Hell Creek member (lower) and the Tullock member. These two members were, in 1935, raised to the rank of formation 3.

During late Cretaceous and early Tertiary times, in the central and southwestern parts of the state, the Livingston formation, consisting of waterlaid and assorted volcanic material, was laid down. The formation includes sandstones, shales, conglomerates, grits and intercalated beds of true volcanic agglomerate. In western Montana lava flows are present. Thickness of the formation is variable, ranging between 1,000 and 7,000 feet. Work done on the Livingston by Stone and Calvert 39 indicates that the formation may be correlated with the Lebo member of the Fort Union at the top and with the Claggett shale as the lower limit 39, 45.

CENOZOIC

In general, Cenozoic sediments have their greatest representation in the central and eastern regions of Montana, western strata consisting in the main of alluvium and lake beds in the great intermontain valley areas, locations of which are shown in a previous section of the report (Fig. 1, Page 3).
Under Cenozoic age, the correlation charts show the oldest sediments, the Fort Union formation, to be of Paleocene age. However, most geologists are now agreed that the Fort Union is Eocene in age and that it unconformably overlies the Lance. Lithologically, this formation is generally clay and arkosic sand with a number of coal seams as discussed in a later section of the report. Fort Union strata are restricted to the central and eastern sections of the state. The Sphinx conglomerate (exposed to very limited extent in the Three Forks Quadrangle), consisting of red sandstones and coarse limestone pebble conglomerates, has been correlated with the Fort Union.

Overlying the Fort Union in the southern part of the state is the northernmost portion of the extensive Wasatch formation of Wyoming, Colorado and Utah. This formation consists of variegated sands and clays, the color generally being a shade of red. Lake beds and gravels constitute most of the remaining Tertiary rocks in Montana. During the middle part of Tertiary time, uplift dammed the southwesterly flowing rivers and gave rise to intermontane lakes, with accompanying deposition of lake beds (Oligocene and Miocene epochs). Of late Tertiary age are the Flaxville gravels, found in the northern sections of the state. These have been described by Alden 1/ and also by Collier 10/. According to Collier, the Flaxville is composed "of brownish to ash gray silt, sand and gravel, and white marl from a few feet to 100 feet thick. It is generally noncoherent but locally cemented
with calcite and forms prominent outcrops, often marked by crossbedding."

Glacial drift and alluvium with some lake beds and terrace gravels represent the Quaternary in virtually all of the sections of the state. Bench or terrace gravels above the present river levels are also defined as Quaternary stream gravels.

**IGNEOUS ROCKS**

Most of the varieties of the igneous rock, ranging between the felsic and mafic extremities, are present in outcrop in Montana. These igneous rocks are of ages ranging from pre-Cambrian to Tertiary. During pre-Cambrian time, granitic masses were intruded into the Big Horn Mountains and in the Neihart and Yellowstone National Park regions. A great number of scattered dikes and pegmatites also have origins of pre-Cambrian age.

In addition to these felsic rocks, there were a number of basic sills intruded during pre-Cambrian time. The best representation of this end of the igneous rock series is the Stillwater igneous complex, a report on which has been written by Howland, Peoples and Sampson. The complex lies in the area of the Beartooth-Absaroka Mountains north of Yellowstone National Park. More specifically, the outcrop lies largely in Stillwater and Sweetgrass counties, but has a small projection in Park county. The complex consists of dunite, harzburgite, norite, gabbro, anorthosite and troctolite—all of the ultramafic group of igneous rocks. Interest
in this series of complex rocks stems from the possible economic significance of the presence of commercial bodies of chromite, (see section on the mineral resources of the state). In this connection, an interesting chart comparing the Stillwater complex and the Bushveld complex of South Africa (areal extent, thickness, and metalliferous deposits), has been included in the report mentioned above.

There is no evidence to indicate any extensive igneous activity in Montana following Huronian time until the Cretaceous. During the Cretaceous, however, eruptive rocks were spread over portions of western and central Montana. These rocks form a part of the Livingston formation mentioned in the section dealing with stratigraphy.

Intrusion of the Boulder batholith, the most economically important igneous body in the state, has been placed in earliest Eocene. Detailed reports have been written regarding the time and method of intrusion and the petrology of this large granite mass. Early writers limited the extent of the batholith to a relatively small area, bounded on the north by Helena and on the south by the Highland Mountains, and with a short east-west dimension. Later papers, however, show that many granite extensions to the south and west may be included in the greater mass of the batholith. By these standards, therefore, the batholith has, according to Billingsley, "a width of 75 miles, from Philipsburg to Elkhorn, and a length, from Marysville to Dillon, of well over 100 miles." The granite was apparently intruded in a dome-shaped mass with
high points east of Butte and north of Basin and sloping gently away from these centers. Erosion is continually exposing additional areas of the underlying granite. Billingsley shows that three types of contact phenomena are exhibited. On the south, an original crust has solidified and has been included as fine grained diorite as the original mass advanced. On the north, the original cooled crust, showing gradation from granite through diorite and gabbro to pyroxenite, remains. In the third type, outlying sills and dikes grade from the parent to rocks of successively increasing acidity.

The Boulder batholith has, within its bounds, the greatest concentration of mineral wealth of the state, and includes the famed Butte district. Its outstanding economic importance has led to many investigations and reports. The papers used as the basis for the preparation of this section treat the subject in a most comprehensive manner, and, for more detailed information, reference is made to these publications.

Plate 2, which shows the distribution of igneous rocks in Montana, delineates several areas of igneous rock, mostly extrusive, in the central portion of the state, east of the Rocky Mountain front. These outcroppings generally assume a gently rounded shape and are commonly thought to be laccolithic in nature. They occur rarely as individual units; more commonly the occurrence is multiple--groups of several units. A number of these laccolithic forms have been mapped in the area of the Little Rockies (north-central Montana). In addition to the extrusive bodies, there are many small exposures of
intrusives, characteristically porphyritic, throughout central Montana. These are thought by some workers to be related, in some manner, to each other. This relationship, if it exists, has not yet been worked out.

An interesting fact, from a petrological point of view, is that the intrusives in Montana are rarely found to be true granites. Most frequently, these rocks have the composition of monzonites or granodiorites.

GLACIATION

The Wisconsin stage of the Pleistocene epoch is considered to be the time of most extensive glaciation in Montana, although an older decomposed till indicates a period of glaciation somewhat earlier.

The areas of Pleistocene glaciation in Montana are shown by Lense to be grouped into three categories: (1) continental glaciation which spread over the Great Plains; (2) continental glaciation which spread across the mountainous northwestern section of Montana; and (3) isolated areas of local mountain glaciation.

In the first category (the Keewatin ice sheet), all the plains area of the state, east of the Rocky Mountains, north of the Missouri River, was covered. The Highwood, Bearpaw, and Little Rocky mountains were obstructions which retarded the southerly flow of ice. Cordilleran glaciation (second category) consisted of a series of interconnected valley glaciers in the mountains of northwestern Montana. To the west, glacial drift on many points of high elevation indicate ice
coverage complete even in areas of great topographic relief. Mountain glaciation, so defined, is shown in isolated areas of the mountainous regions where glaciation has clearly been of limited local extent. Specific localities of mountain glaciation are: the Big Horn area; the Mount Tory area; the Red Mountain area; the Tobacco Root Range; the Madison Range; and the Philipsburg area.

The correlation charts (Plate 8) indicate that, with the exception of the southeastern portion, Pleistocene deposits include glacial drift in all parts of the state north of Yellowstone River and west of Little Big Horn River.

**STRUCTURAL GEOLOGY**

Any discussion of the geologic structure of Montana may best be accomplished on the basis of the arbitrary divisions set up in a previous section dealing with the physiography of the state. In a manner similar to that of topographic relief, the structural aspects range from the complex pattern of the Rocky Mountains in the western portion to the comparatively simple structures found in the eastern portion of the state.

The structure of western Montana presents an extremely complex problem, and only very general descriptions of the major structural zones are here included. Most structures of the Rocky Mountains date to the Laramide revolution of late Cretaceous time, although folding and faulting may have continued in localized areas into the Eocene. Zones of block faulting on a tremendous scale, as well as low angle reverse
faults, have been mapped. The block faulting is believed to be much later than the thrusting.

In the northern half of western Montana, there is found a series of parallel northwest-southeast trending structures. These consist primarily of large scale parallel folds with axes of a northwest-southeast strike. Major faults strike roughly parallel to the axes of these folds. A zone consisting of a series of radiating structures, converging toward the southeastern edge of the Boulder batholith, characterizes the southern half of western Montana.

Several major thrust faults have received attention in the mountainous western area of this state. Of these, the Lewis overthrust is the largest described and perhaps the best known. This great thrust fault follows a general northwest line along the mountain front in the northwestern part of the state. The relationship, which was first described by Willis 49/, consists of pre-Cambrian Belt deposits thrust up over late Cretaceous sediments. This thrust has been accurately mapped for 135 miles in Canada and northern Montana, and probably has length of more than 300 miles. The maximum stratigraphic throw is 40,000 feet and the minimum net slip is some 15 miles 4/.

C. H. Clapp 8/, in an abstract of his paper dealing with the structure of the northwestern section of Montana, states, "northeasterly dipping rocks are repeated in successive fault blocks formed by longitudinal thrust faults dipping northeast more steeply than the rocks. The front ranges are synclinal
and are sharply limited by the eroded fault scarp of the Lewis Overthrust. East of the Lewis Overthrust a number of parallel longitudinal thrust faults, dipping steeply to the southwest, produce a series of thin fault blocks. The southwesterly dipping thrust and overthrust faults are convex to the northeast, and the northeasterly dipping thrust faults are convex to the southwest. Both sets of longitudinal faults are broken by transverse faults, one set having an east-west trend and the other a north-south trend, and by still younger longitudinal normal faults."

Normal faults in abundance characterize all of the mountainous region of the state. The normal faults, most of which are of later occurrence than the thrust faults, were presumably caused by increases in vertical pressures as a result of the relaxing of the compressive forces which caused the folding and thrusting.4/

The structures of the central part of Montana contain some of the elements of the structures in the mountainous portions, but on a smaller scale. In this section, the continuity of the Rocky Mountain front is broken and the tremendous horizontal stresses which caused the formation of mountains and their structures, manifest themselves in local uplifts and short detached ranges. These have resulted in isolated structures (basins and domes), some of which appear as island-like forms in a relatively flat land surface.41/

Thom 41/, in a paper dealing with the structures of central Montana, presents a very comprehensive summary in which
he states, "The dominant structural feature of central Montana is the uplifted block called by Lupton and Lee (21/) the Big Snowy anticlinorium, which extends from the Big Snowy and Judith mountains to include the Porcupine dome. The Little Belt Mountains, which seem to be a slightly offset continuation of the same general uplift, are also a pronounced structural feature, as are the Crazy Mountain, Bull Mountain, and Blood Creek synclines. The Little Rocky, Moccasin, and Judith mountains, the domes southeast of the Little Belts, and presumably the Porcupine dome, are laccolithic uplifts, and the Highwood and Crazy mountains are the products of volcanic activity and of dike and plug intrusion. A number of small bodies of igneous rock are scattered here and there over the region and seem to have been intruded without reference to visible structural features except that their orientation is roughly parallel both to the Lake Basin and Cat Creek surface faults, and to the dominant joint system of northeastern Montana. In general there seems to be a genetic relationship between the structure and vulcanism of the area. To a less evident degree the smaller igneous bodies are also probably products of the same forces."

The structures of this central section of Montana have attracted considerable attention, since, in a belt through the central part of the state little more than 100 miles wide, virtually all of the commercial oil fields and many of the producing gas fields are located. This subject comes under further discussion in a later section of this report.
The geologic structure of eastern Montana is far more simple than that of either the western or central sections. This vast plains area, although deeply dissected by streams and presenting some relief, is underlain by nearly flat-lying strata rarely disturbed from their nearly horizontal attitude. Four regions of significant structural deformation are found in eastern Montana. These areas are: (1) the Boddoin-Saco dome, located in the northern portion on the Milk River; (2) the Porcupine dome (included in Thom's discussion of central Montana); (3) the Baker-Glendive anticline, a commercial gas producer in the easternmost region of the state; and (4) the Black Hills uplift, a small section of which is present in the southeastern corner. Deformation of the strata by these features indicates uplift of the order of 2,000 to 4,000 feet. With the exceptions noted, the structure of eastern Montana resolves itself into a relatively simple problem.

**GEOLOGIC HISTORY**

The basal complex of Montana is an extremely complex series of metamorphosed rock—schists, gneisses, quartzites, and marbles. The presence of the quartzites and marbles indicates the deposition of a vast series of sedimentary beds during the Archeozoic era. Some igneous intrusions, notably the Cooke-City-Jardine granite and the Big Horn granite, are considered to be of Archean age. Toward the end of the Archeozoic, a period of mountain building (perhaps the Laurentian revolution) folded and metamorphosed the sediments that
were previously deposited. Following this period of crustal disturbance ensued a long period of erosion, peneplanation, and gradual submergence. Deposition of the Cherry Creek beds followed, and again mountain making, which may have been the Grand Canyon disturbance, folded and metamorphosed the newly deposited sediments. The Cherry Creek may be of lower Proterozoic age.

Encroachment of an Arctic sea from the north, as the Rocky Mountain trough subsided, accounts for the deposition of Beltian rocks, a series composed mainly of clastics, the thickness of which is shown to be over 40,000 feet in some sections. Emergence from the sea and subsequent erosion of the Belt sediments mark the end of the Proterozoic era in Montana.

The Paleozoic era began with Montana as a low flat land surface, and there is, therefore, no lower Cambrian in the state. However, as the seas started a transgression of the land, widespread sandstones (Flathead) were deposited. The entire era was characterized by these fluctuating inland seas which, in some instances, were hundreds of miles across. The absence of Silurian strata is attributed to the complete emergence of the region from the seas during this period. Throughout the remaining part of the Paleozoic era (post-Silurian), these seas continued to fluctuate in depth and in areal extent, resulting in a thick series of shales and limestones. There was no folding during the Paleozoic, but the area was subjected to gentle regional warping which caused
the strata of certain periods to be missing in some areas. Paleozoic sediments are all nearly parallel. Abundant life prevailed in the Paleozoic seas, and certain fossil forms (corals) indicate warm waters at certain times during the era. This era ended with widespread sand deposition and a recession of the seas. Sediments of the Paleozoic era are approximately 60 per cent limestones with 40 per cent sandstone and shale.

Land conditions prevailed at the beginning of the Mesozoic era and, during the Triassic period, the Chugwater (continental) beds were deposited. The Mesozoic era was characterized by retreating and advancing seas, resulting in thick series of both continental and marine deposits. Montana was completely submerged during the Jurassic and almost entirely inundated again during the Cretaceous. A fluctuating shore line at this time accounts for the alternating marine and continental deposits of upper Cretaceous and lower Tertiary times. During the latter part of Cretaceous time, mountain building took place on a grand scale (Laramide revolution); it was at this time that the major uplift of the Rocky Mountains took place. Piedmont plain deposits were laid down to the east. Late Cretaceous volcanoes explain the volcanic portions of the Livingston formation of upper Cretaceous. Mesozoic sediments are preponderantly sandstones and shales (99 per cent).

The Laramide revolution brought large scale folding and attendant thrust faulting from the west toward the east.
This folding and faulting continued into the Tertiary and was accompanied by the intrusion of large granitic masses such as the Boulder batholith and related stocks. Most of the ore bodies of Montana were formed at this time. Following the Laramide revolution, relaxing of the compressional forces which built the Rocky Mountains caused large scale block faulting in the mountainous areas. Deposition to the east was of a continental nature; the strata here are shale and sandstone with beds of coal. During the period following mountain formation, erosion had nearly leveled them. The Cascadian revolution at the end of Tertiary time resulted in raising the whole mass of the mountains to elevations of 10,000 to 11,000 feet. Rejuvenation of the streams caused a re-excavation of the valleys and a sculpturing of the mountains to their present forms.

The land surface of the state at the beginning of the Quaternary is considered to be about the same as at present. Following the ponding of streams by middle Tertiary uplift, (resulting in the formation of intermontane lakes), downcutting of these streams in later Tertiary time, prior to Pleistocene, drained the intermontane lakes and established new drainage lines and patterns. The drainage underwent further modification during the glaciation of Pleistocene time, when north-flowing rivers were pushed to the south to cut new channels. An example of this is the Missouri, which, it is believed, formerly emptied into Hudson Bay. (References: 27, 33, 34).
A. Distribution of Igneous Rocks

B. Distribution of Pre-Cambrian Rocks

DISTRIBUTION OF IGNEOUS AND PRE-CAMBRIAN ROCKS IN MONTANA
A. Distribution of Paleozoic Rocks

B. Distribution of Mesozoic Rocks

DISTRIBUTION OF PALEOZOIC AND MESOZOIC ROCKS IN MONTANA
A. Alluvium and Lake Beds, Western Part

B. Tertiary Deposits, Eastern Part

DISTRIBUTION OF CENOZOIC ROCKS IN MONTANA
GEOLOGIC MAP OF MONTANA

Published by MONTANA BUREAU OF MINES AND GEOLOGY

Francis A. Thomson, Director
in cooperation with
U.S. GEOLOGICAL SURVEY

Prepared by George W. Stose, O. A. Ljungstedt, and A. J. Collier

Scale
25 20 15 10 5 0 25 50 75 100 Miles

1933

EXPLANATION

Alluvium

Miocene and Pliocene continental deposits
(See Tertiary fault-basin deposits included)

White River group

Wasatch group

Fort Union formation

Lower formation

Montana group

White River group

Colorado group

Dakota sandstone and Lower Cretaceous

Dakota sandstone

Lower Cretaceous

Bear Paw and Judith River formations

Clayey and Eagle formations

Pennsylvanian rocks

Mississippian rocks

Devonian to Cambrian rocks

Devonian in Cambrian rocks

Claggett and Eagle formations
The mineral resources of Montana are abundant. Those of the metallic group include antimony, chromium, copper, gold, iron, lead, manganese, molybdenum, platinum, silver, tungsten, vanadium, and zinc. Fuels listed among the non-metallics are coal, natural gas, and petroleum. The list of non-metallics also includes arsenious oxide, asbestos, barite, calcite, cement, clay, corundum, diatomite, graphite, gypsum, limestone, mica, phosphate rock, precious stones, silica, stone, and vermiculite. It is manifestly impossible to treat each of these mineral products in detail in a report of this nature and limited scope. Thus, only a broad general picture of the industry is here presented.

The charts which accompany this section are intended to show the comparative overall values of the more important economic products, as well as to give an indication of the total wealth accruing to the state from these natural commodities. Attention is called to the difference in scales used in plotting the two graphs.

Montana is well known for its production of metals such as copper, gold, lead, silver, and zinc. Less widely known are the minor metal and non-metallic minerals industries. As evidenced by the charts which follow, these products represent a smaller fraction of the total production than do the major metals. They are, however, a valuable asset and represent a vast source of potential wealth. An example of an important, but largely undeveloped, deposit is the extensive chromite deposit.
"belt" of Stillwater, Sweetgrass, and Carbon counties. With the exception of three years during the war, these deposits remain unworked. Improvements in metallurgical processes will undoubtedly make possible further development of this valuable resource in the future.

Perry 22/ states, in a summary of the geology of the metal resources, "The general geology of the metal deposits is not greatly different from that of other regions, although of course, in detail each area is individual. Most of the ore deposits resulted from emanations from igneous masses intruded during early Tertiary time. The mineralized 'juices' from granitic masses deposited their load of metalliferous material mainly as veins in the host-rock of the intrusives, or within the intrusive itself after partial solidification. Limestone beds frequently were susceptible, but elsewhere ore minerals were deposited in limey shales or in quartzites or lava beds. The host rock ranges in age from pre-Cambrian to Tertiary, and includes many rock types."

Although the metal deposits are restricted to the mountainous areas, no county of Montana is without natural resource. Coal occurs in 90 per cent of the counties; oil and gas fields are widely scattered throughout the plains area. Other non-metallics, including cement materials, building stone and gravels are available in most sections 22/. The non-metallics are of growing financial importance to the state (total production in excess of $32,000,000 in 1947). Plate 7 shows the distribution of mineral resources in Montana.
Of the non-metallic resources, coal represents one of the greatest. A chart included in this section gives the details of distribution of Montana coal. Thomson \(42^{\prime}\) states, "eastern and central Montana contains, according to estimates of the United States Geological Survey, 400 billion tons of known minable coal which represents one-eighth of the United States supply and one-twelfth of the known world supply." Montana coals are sub-bituminous and lignites with about 90 per cent of all known coal in the state being lignite. It has found both domestic and industrial usage. A large railway company has a unique stripping process at Colstrip for fuel on their coal-burning locomotives. With improvement of the process of producing oil economically from soft coals, the vast coal reserves of Montana may assume tremendous commercial importance.
Fig. 2

Production Totals* — Mineral Resources of Montana
(Products of total sales greater than $25,000,000)

*Totals in millions of dollars

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This plate originally published as Plate 29, Memoir No. 20, Montana Bureau of Mines and Geology.


34. Schuchert, Charles and Dunbar, Carl O., A Textbook of Geology, Part II, Historical Geology, 1941.


-36-


43. Thompson, M. L., and Scott, H. W., Fusilinids from the Type Section of the Lower Pennsylvanian Quadrant Formation, Jour. Paleontology, Vol. 15, 1941, pp. 349-353.


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