Stratigraphy of the Little Rocky Mountains and Encircling Foothills Montana

GEOLOGICAL SURVEY BULLETIN 1072-N

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By MAXWELL M. KNECHTEL

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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Bedrock formations and surficial deposits mapped and described in relation to regional stratigraphy

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CONTRIBUTIONS TO ECONOMIC GEOLOGY

STRATIGRAPHY OF THE LITTLE ROCKY MOUNTAINS AND ENCIRCLING FOOTHILLS, MONTANA

By Maxwell M. Knechtel

ABSTRACT

Rocks exposed in the Little Rocky Mountains and encircling foothills range in age from Precambrian to Quaternary and are of sedimentary, igneous, and metamorphic types. The bedrock formations range in age from pre-Belt (Precambrian) to Tertiary; the surficial materials, which include alluvium, glacial debris, and soil, were deposited in later Tertiary(?) and Quaternary time.

INTRODUCTION

The stratigraphic information presented in this report was largely gathered, and the geologic mapping (pl. 52) performed, during intermittent field studies conducted by the U.S. Geological Survey since 1921 in and near the Little Rocky Mountains, in Blaine and Phillips Counties, Mont. (fig. 32). Supplementary data have been taken from publications listed on pages 747–749, and from unpublished records furnished mostly by geologists engaged in exploration for oil. The report represents an amplification of data that have appeared in two earlier publications of the U.S. Geological Survey (Collier and Cathcart, 1922; Knechtel, 1944).

The rocks exposed in the Little Rocky Mountains and the encircling foothills are of sedimentary, igneous, and metamorphic types. The bedrock formations range in age from pre-Belt (Precambrian) to Tertiary; the surficial materials—comprising alluvium, glacial debris, and soil—were deposited in late Tertiary(?) and Quaternary time. The columnar section (pl. 53) shows the nature of the rocks in the stratigraphic units that have been recognized in outcrops—excluding those of igneous origin—as well as their names and approximate thicknesses, and tentative correlation with subsurface units recorded in the electric and radioactivity logs and the sample logs of Continental Oil Co. South Zortman well 1 (hereafter designated dry hole SZ-1) in the SE¼SE¼NW¼ sec. 29, T. 23 N., R. 26 E., about 7 miles south of the area shown in plate 52. The areal distribu-

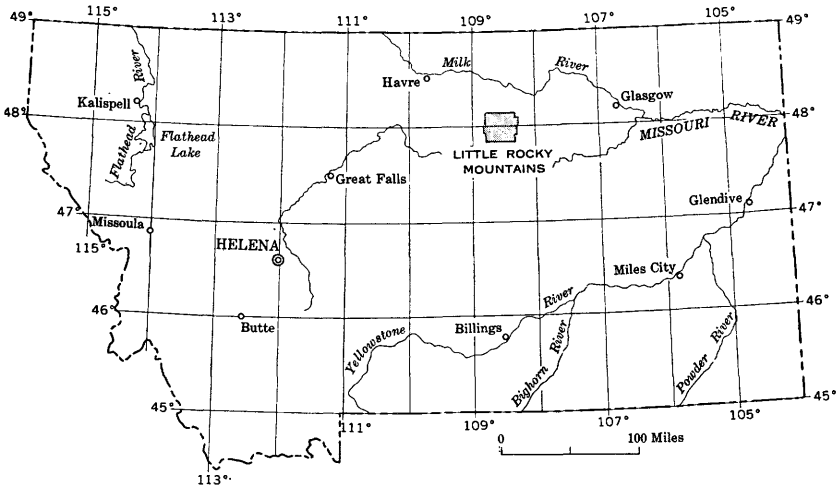

FIGURE 32.—Index map of Montana.

tion of the units in and near the Little Rocky Mountains is presented on plate 52; interpretations of their correlation with units that are recognized in the surrounding region are given in a chart and sections by Brinker and others (1953, p. 14). Figure 33 is a map of the general geologic structure of the area shown on the geologic map. Following are brief descriptions of the different units shown, with comments on their relation to the regional stratigraphy and to the igneous rocks and surficial deposits in and around the Little Rocky Mountains.

PRECAMBRIAN ROCKS

The Precambrian rocks in this area consist of pre-Belt metamorphic rocks and pre-Belt(?) younger intrusive rocks.

PRE-BELT METAMORPHIC ROCKS

The oldest rocks exposed in the Little Rocky Mountains are believed to be older than the Belt series (Precambrian). These rocks, which are well exposed in sec. 7, T. 25 N., R. 25 E. (loc. *J*, pl. 52), along the Zortman-Lodgepole road near the Ruby Gulch gold mine, include metasedimentary and metavolcanic rocks, all of which are more or less foliated, though few of them show evidence of extreme metamorphism. The alteration evidently took place in Precambrian time, inasmuch as it did not affect any of the Cambrian and younger rocks exposed in the Little Rocky Mountains. The rocks that are believed to have been sediments originally are biotite schists and gueisses, interbedded with quartzites in which most of the grains of quartz are rounded (Dyson, 1939, p. 202). Volcanic rocks, thought to

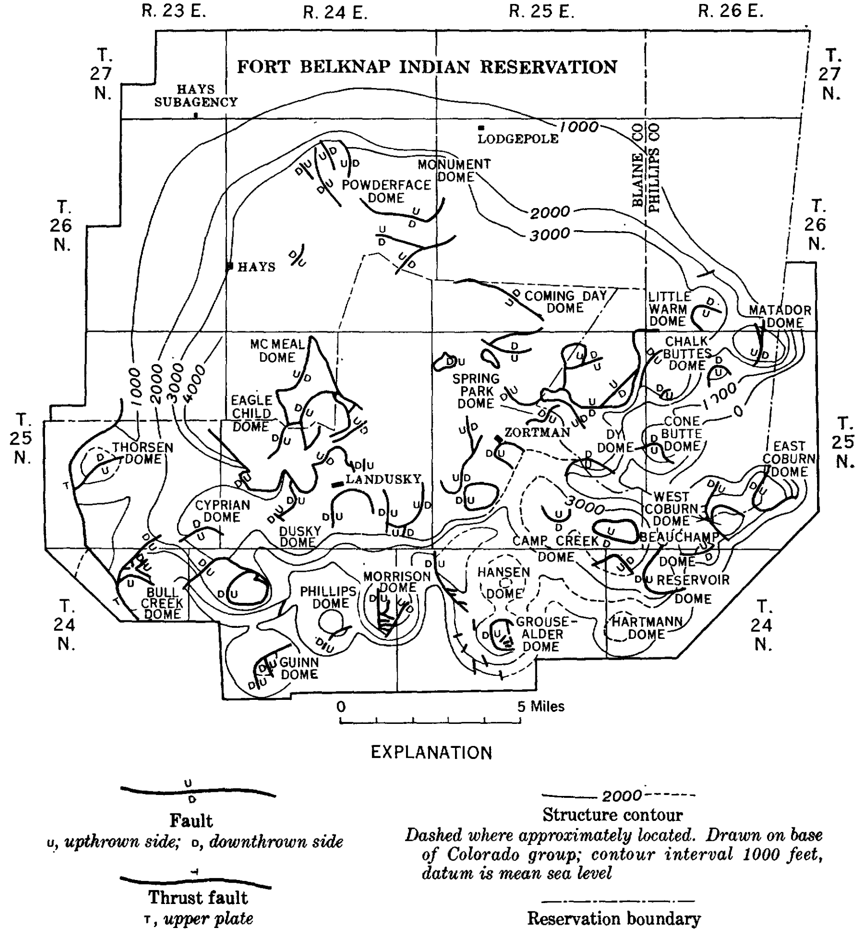

Figure 33.—Map of Little Rock Mountains and encircling foothills, Montana, showing structure contours and faults.

have been extruded while the sedimentary materials were accumulating, are represented by hornblende gneisses and foliated amphibolites. The aggregate thickness of the outcropping pre-Belt rocks is at least several hundred feet, but the thickness has not been accurately determined.

Nearly all the rocks of the pre-Belt unit contain quartz and feldspar as essential constituents but include varying proportions of biotite, muscovite, hornblende, chlorite, garnet, and kyanite; accessory constituents are apatite, zircon, magnetite, and pyrite. The feldspar is largely microcline and orthoclase but includes some albite and oligoclase and, in a few specimens, a small amount of andesine. The least schistose varieties are fine-grained quartzites, which are somewhat arkosic and massive. They consist of quartz, feldspar, scarcely discernible amounts of mica, and other minerals; the most schistose varieties are biotite gneisses, in which mica and hornblende commonly are conspicuous constituents and the proportion of quartz and feldspar is much smaller. Common intermediate types are crystalline rocks of moderate coarseness in which quartz and feldspar are by far the most abundant and prominent constituents.

The material of some of the pre-Belt layers has essentially the composition of granite, except for a slightly excessive content of quartz; the local abundance of "augen" and small quartz veins extending along foliation planes suggests that this rock is an injection gneiss, which may have consisted, prior to its alteration, of sedimentary materials such as arkose, sandstone, and shale. Under the microscope, the rock appears to have been crushed, and its alteration may have been somewhat intensified by the effects of deformational movements and associated igneous activity that took place in the Little Rocky Mountains in early Tertiary time.

According to E. W. Heinrich (oral communication, 1953), much of the material of the pre-Belt unit resembles parts of the Cherry Creek group of south-central Montana. The Cherry Creek rocks underlie the Belt series and overlie the Pony group and other units "which probably are not time equivalents of the Pony" (Heinrich, 1953). The Belt series is not present in the Little Rocky Mountains, and the pre-Belt rocks are overlain disconformably by the Flathead sandstone (Middle Cambrian). Available evidence thus suggests that the pre-Belt rocks are partly, if not entirely, younger than the Pony group of Heinrich (1953). Possibly even older rocks of the subsurface are represented in the swarms of small fragments of Precambrian rock locally included as xenoliths in the intrusive porphyry of Tertiary age that crops out extensively in the Little Rocky Mountains; however, all such fragments so far noted resemble the exposed pre-Belt rocks that have been intruded by the porphyry.

PRE-BELT(?) YOUNGER INTRUSIVE ROCKS

A few dikes and sills, made up chiefly of ferromagnesian minerals, are enclosed by the Precambrian rocks previously described. These intrusives are younger than the enclosing rocks but not younger than the porphyry of Tertiary age. Part of them, however, exhibit distinct foliation and may, therefore, antedate the Belt series.

PALEOZOIC ROCKS

Paleozoic sedimentary formations with an aggregate thickness of more than half a mile crop out in large areas in the Little Rocky Mountains and in several small isolated tracts in the foothills. These formations originated largely, if not entirely, under marine environmental conditions that existed here during parts of the Cambrian, Ordovician, Devonian, and Mississippian periods. They are characterized by preponderance of limestone and dolomite, though shale, sandstone, and conglomerate are present, especially in the rocks of Cambrian age. The limestones and dolomites are more resistant to erosion than most of the other materials and, consequently, form many prominent buttes, ridges, and cliffs. A disconformity at the base of the Paleozoic succession represents a hiatus involving much of late Precambrian and early Cambrian time; another at the top of the succession bridges much of the Mississippian and all of Pennsylvanian and Permian time, as well as a large part of early Mesozoic time. Still other disconformities involve much of the Ordovician, all of the Silurian, and parts of the Devonian and Mississippian periods.

MIDDLE AND UPPER CAMBRIAN AND LOWER ORDOVICIAN SERIES

Sedimentary strata of this area that were once assigned to the Deadwood formation (Collier and Cathcart, 1922, p. 173) comprise two formations. The lower of these is the Flathead sandstone (Middle Cambrian); the upper one, to which the name Emerson formation was recently given (Knechtel, 1956), is much thicker and includes rocks of Middle and Upper Cambrian and of probable Lower Ordovician age. Assignment of the strata of these two formations to the Deadwood formation is considered misleading, inasmuch as they are partly of Middle Cambrian age, whereas the Cambrian portion of the typical section of the Deadwood formation in the Black Hills of South Dakota is reported to be Upper Cambrian in age (Furnish, Barragy, and Miller, 1936; Thomas, 1949, p. 43). Both formations crop out rather extensively in the Little Rocky Mountains, whereas in the surrounding foothills the Cambrian rocks are exposed only at Cyprian Butte, T. 24 N., R. 24 E. The Emerson formation is the oldest unit reached by the drill in dry hole SZ–1.

FLATHEAD SANDSTONE

The Flathead sandstone is the oldest formation of Paleozoic age present in the Little Rocky Mountains. The Flathead consists mainly of light-gray, green, and tan sandstone; it is partly argillaceous and has some interbedded fine-grained conglomerate. The thickness of the Flathead varies from place to place but is not known to exceed 50 feet anywhere in the mountainous area. In almost all its exposures it is largely concealed by soil, alluvium, and talus.

The Flathead rests disconformably on the pre-Belt metamorphic rocks and is overlain by the Emerson formation. As the Flathead has yielded no fossils, its assignment to the Middle Cambrian series is tentative and is based on: (a) its apparent conformable relation to beds of known Middle Cambrian age in the lower part of the overlying Emerson formation, and (b) its correlation with the Flathead quartzite (Middle Cambrian) of central Montana mainly because of lithologic resemblance.

EMERSON FORMATION

The Emerson formation derives its name from exposures in Little Chief Canyon (loc. *E*, pl. 52) at and near the mouth of Emerson Gulch in the SW¼ sec. 30, T. 26 N., R. 25 E., Phillips County, where it consists chiefly of gray to greenish-gray shale with thin intercalated beds—increasing in number upward—of shale, limestone, dolomite, and edgewise intraformational conglomerate. The rocks of a topmost zone, ranging in thickness from 50 to 100 feet, are more highly colored and include many more dolomite beds than any other part of the formation. Most, if not all, of the rocks of the Emerson formation are believed to have consolidated from sediments that accumulated in a shallow-marine environment. As the Emerson is extensively concealed by surficial debris and is disrupted at many places by faults, measurement of its total thickness involves considerable uncertainty. At the type locality, where the most complete section is exposed, its thickness is estimated to be not less than 950 feet nor more than 1,100 feet.

Paleontologic data (Lochman, 1950a) indicate that most of the Emerson formation belongs to the Middle and Upper Cambrian series, but some of the highly colored, largely dolomitic topmost layers are probably early Ordovician in age. According to Lochman (1950a), the upper half of the Emerson encompasses faunal zones that are similar to beds which, in areas farther south and southwest, have yielded the Early Ordovician *Bellefontia* fauna from an uppermost zone (Lochman and Duncan, 1950). Christina Lochman Balk (written communication, 1956) regards the upper part of the Emerson as closely comparable in age to the Deadwood formation as restricted by McCoy (1952) to beds underlying his Aladdin sandstone (Scolithus sandstone of former usage).

UPPER ORDOVICIAN SERIES

BIGHORN DOLOMITE

The Bighorn dolomite of Late Ordovician age is a prominent ridge-forming unit resting disconformably on the Emerson formation and overlain disconformably by strata of Devonian age. It is similar, both lithologically and in its faunal content, to the Bighorn of the type section in north-central Wyoming. As exposed in Browns Gulch in secs. 11 and 14, T. 26 N., R. 24 E. (loc. *B*, pl. 52), the Bighorn is 275 feet thick; but the logs of dry hole SZ-1, about 19 miles farther southeast, show only 57 feet of rock assignable to this formation. In some exposures, as in the cliffs north of Ruby Gulch above Zortman, the topmost beds of the Bighorn show evidence of channeling, which indicates removal of part of the formation by erosion before the overlying Devonian strata were deposited.

As exposed in the northern part of the Little Rocky Mountains, the lower half of the Bighorn formation is made up almost entirely of massive dapple-gray dolomitic limestone and has a distinct bluish cast in some exposures. Surfaces of this rock that have undergone little or no weathering show many closely spaced, irregular-shaped dark-gray spots averaging about 1 inch in diameter. The light-gray dolomite of the interspaces is more readily corroded than the finer grained dark dolomite of the spots, commonly giving the rock a distinctive pitted appearance on weathered surfaces. The rock of the lower half of the formation contains numerous tiny segments of crinoid stems and less abundant remains of other organisms that include corals, brachiopods, mollusks, trilobites, and spongelike forms (*Receptaculites*).

The upper half of the formation is composed mainly of thinly bedded gray to white dense, hard dolomite, the uppermost beds of which contain corals, including a form tentatively identified by H. M. Duncan (oral communication, 1954), as *Palaeophyllum*, which is considered to be diagnostic for the Upper Ordovician series. This part of the formation may be equivalent to the Leigh dolomite member of the Bighorn dolomite (Tomlinson, 1917, p. 118) of western Wyoming.

The rocks of Late Ordovician age cropping out in the Little Rocky Mountains have long been called Bighorn dolomite (Collier and Cathcart, 1922; Knechtel, 1944). Retention of that name herein is appropriate notwithstanding recent correlation of these rocks with the Red River formation of Manitoba (Rader, 1953, p. 64) and notwithstanding current usage whereby the name Red River is applied to approximately equivalent Upper Ordovician rocks of the subsurface farther east in Montana and North Dakota. The name Red River, however expedient its use in regional subsurface studies may be, cannot properly be applied to Ordovician rocks cropping out in the United States because: (a) the name Red River (Shumard, 1860, p. 583, 588) was previously assigned to a Cretaceous unit exposed in northeastern Texas, and (b) the name Bighorn, for Upper Ordovician rocks cropping out in Wyoming and Montana (Darton, 1904, p. 395, 396), was adopted and generally accepted long before the name Red River was proposed for their Canadian correlatives (Foerste, 1928, p. 26).

DEVONIAN SYSTEM

No rocks of Silurian age are known to be present in the Little Rocky Mountains, but the Devonian system is represented by three subdivisions: (a) a basal variegated shale unit that is tentatively correlated with the Maywood formation, (b) the Jefferson limestone, and (c) an upper shale unit that is tentatively identified as Three Forks shale but may be wholly or in part of Mississippian age. The Devonian rocks total about 650 feet in thickness and rest disconformably on the Bighorn dolomite (Upper Ordovician); they underlie the Little Chief Canyon member, which is the basal unit of the Lodgepole limestone (lower Mississippian).

MAYWOOD FORMATION

A unit approximately 175 feet thick that is made up largely of silty strata differing from one another in thickness, color, and content of lime and magnesium carbonate is exposed in Browns Gulch (north of loc. *B*, pl. 52) and in Little Chief Canyon (half a mile northeast of loc. *E*). The unit is represented by 143 feet of rock in dry hole SZ–1. The strata include thinly bedded calcareous shale and siltstone, as well as slabby to rather thickly bedded impure limestone and dolomite. The upper two-fifths of the unit consists largely of bright-red platy calcareous shale and a few thin beds of impure limestone. The lower three-fifths of the unit is mainly light gray, light green, yellow, and brown, and it includes limestone and dolomite as well as calcareous silt and clay. The lowermost 5 feet of the unit is platy silty pinkish dolomite containing a little sand and a basal layer of brecciated dolomite about a foot thick.

This unit was designated by Knechtel (1944, fig. 1) as the "basal variegated member" of the Jefferson limestone and is the "basal Devonian unit" of Sloss and Laird (1947, p. 1413). The name Maywood formation, originally applied to rocks cropping out in the Philipsburg quadrangle, Montana, (Emmons and Calkins, 1913, p. 64, 65), is believed by Lochman (1950b, p. 2213) to refer to "the same lithic unit as Sloss and Laird's basal Devonian unit of central Montana and their unit C of northwestern Montana." The variegated shale unit of the Little Rocky Mountains Devonian sequence is believed to be approximately equivalent to the Maywood formation. The unit is regarded as equivalent to all or parts of two Williston basin subsurface units: the Elk Point formation of McGehee (1949) and the Beaverhill Lake formation of Layer (1950, p. 1823–1824). The lowermost beds closely resemble those of the Ashern formation of Baillie (1950).

JEFFERSON LIMESTONE

The Jefferson limestone is one of the most conspicuous units cropping out in the Little Rocky Mountains, forming the crests of high ridges in some localities. The Jefferson, which is 420 feet thick in the northern part of the Little Rocky Mountains and is represented by 525 feet of rock in dry hole SZ-1, is divisible into a lower, an intermediate, and an upper member.

LOWER MEMBER

The lower member of the Jefferson is about 365 feet thick in Browns Gulch north of locality *B* (pl. 52) and is represented by about 470 feet of the rock logged in dry hole SZ-1. The member is made up chiefly of thin beds of dark-gray and brownish-gray finely crystalline limestone, whose weathered surfaces are light gray to nearly white. The lower part includes a few thin partings of red shale and thin limestone beds that show small irregular pinkish areas. The freshly fractured rock of many beds emits a fetid odor. Colonies of *Stromatopora* and algal remains, which are conspicuous on many weathered surfaces, provide a fairly satisfactory means of identifying this member in the field. Other fossils are a few species of corals and brachiopods. In sec. 6, T. 25 N., R. 25 E., rock from the member has been quarried and burned for production of lime.

The lower member of the Jefferson limestone of the Little Rocky Mountains comprises the "limestone member" and the lower part of the "dolomitic member" described by Sloss and Laird (1947, p. 1414) and is believed to represent all but the uppermost (Ireton) beds of the unit designated Woodbend or Duperow in current subsurface studies of the Williston basin (Rader, 1953, p. 65).

MIDDLE MEMBER

The middle member of the Jefferson is about 15 feet thick. It is made up of beds—mostly bright red, green, and buff—of shale, siltstone, and thinly laminated silty dolomite and limestone. This member has been correlated with the subsurface unit known as Ireton (Rader, 1953, p. 65).

UPPER MEMBER

The upper member of the Jefferson limestone comprises about 50 feet of the strata measured in Little Chief Canyon, half a mile northeast of locality *E* (pl. 52), and 43 feet of those logged in dry hole SZ-1. The member is made up of massive beds, ranging in thickness from 1 to 6 feet, slabby where greatly weathered, of light-gray to buff fine-grained limestone and dolomite, some of which contains fine sand. In some places this top member forms cliffs resembling many outcrops of the lower member of the Bighorn dolomite. A bed near the top of the upper member of the Jefferson contains numerous corals. The member has been correlated with the Devonian unit known as Nisku in the regional subsurface terminology (Rader, 1953, p. 65).

DEVONIAN AND MISSISSIPPIAN SYSTEMS

THREE FORKS SHALE(?)

The unit referred to as the Three Forks shale(?) in this report is tentatively classified with the Devonian rocks although it may include rocks of Mississippian age. The rocks consist, in part if not wholly, of light-gray to light-green calcareous clay and siltstone that is locally sandy. The unit ranges in thickness from about 40 to 85 feet; although its full thickness is rarely exposed, it can be traced in many localities by following characteristic topographic furrows that form because it is more susceptible to erosion than the Jefferson limestone below and the Lodgepole limestone above.

The unit is tentatively correlated with the Three Forks shale, though it is possibly equivalent to the sequence of beds, including the Three Forks shale with its Sappington sandstone member, which occupies the interval between the Jefferson and Madison limestones in southwestern Montana (Berry, 1943, p. 14–16; Holland, 1952, p. 1704–1709). It may include strata equivalent to all but the uppermost part of the Bakken—a formation in the subsurface of the Williston basin comprising two black shale units that are separated by about 60 feet of sandstone, siltstone, dolomite, or cryptocrystalline limestone (Nordquist, 1953, p. 72). However, the Bakken, unlike the surface unit, rests on strata that are correlated with the Three Forks shale; the black shale in the top of the Bakken is believed to be equivalent to the conodont-bearing Little Chief Canyon member of the Lodgepole Limestone (Knechtel and others, 1954, p. 2,399; Knechtel and Hass, 1938; Sloss and Hamblin, 1942, p. 321). The best and most accessible outcrops of this unit occur along a tributary of Peoples Creek, which branches southward from Mission Canyon (loc. *G*, pl. 52) in the NE¼ sec. 5, T. 25 N., R. 24 E., and in Little Chief Canyon of Lodgepole Creek in the N½ sec. 27, T. 26 N., R. 25 E., three-quarters of a mile northeast of locality *E*. At both these localities, however, the unit is largely concealed by surficial debris.

CARBONIFEROUS SYSTEMS—LOWER MISSISSIPPIAN SERIES

MADISON GROUP

The Mississippian system is represented in the Little Rocky Mountains by two lower Mississippian formations of the Madison group.

The lower of these is the Lodgepole limestone; the upper is the Mission Canyon limestone. Both of these formations were named by Collier and Cathcart (1922) with reference to localities in the Little Rocky Mountains. The Madison group of this area, with a total thickness ranging from about 900 feet to 1,100 feet, rests on the Three Forks(?) shale and is overlain disconformably by the Rierdon formation (Upper Jurassic).

LODGEPOLE LIMESTONE

The Lodgepole limestone, the lower formation of the Madison group, crops out extensively in the Little Rocky Mountains and in a few localities in the foothills. It is represented by 630 feet of rock in dry hole SZ–1. A complete section of the formation is exposed at its type locality in sec. 29, T. 26 N., R. 25 E., along the part of Lodgepole Creek known as Little Chief Canyon, a mile northeast of locality *E* (pl. 52) and about 3 miles south of the Lodgepole subagency of the Fort Belknap Indian Reservation. According to Sloss and Hamblin (1942, p. 320–321), the thickness of the Lodgepole at the type locality is 572 feet, but a more recent measurement by J. E. Smedley, (oral communication, 1953) shows only 478 feet. Probably the discrepancy between the two measurements is due to choice of different horizons in defining the contact between the Lodgepole and the overlying Mission Canyon, as well as to displacement of the Lodgepole strata of the type section on many subvertical faults that were taken into account in the more recent measurement.

The Lodgepole is chiefly thin-bedded limestone but includes some massive limestone ledges, many small lenses of chert, and thin partings of shale. Most of the formation is dark to light gray, but two zones in the upper half, one of which is more than 100 feet thick, are predominantly red, owing to the coloration of many limestone beds and thin partings of shale. Along Peoples Creek, at the head of Mission Canyon—the type locality of the Mission Canyon limestone—the red zone of the Lodgepole forms picturesque cliffs. The Lodgepole limestone is rich in fossil remains of marine organisms, including sponges, corals, echinoderms, bryozoans, brachiopods, mollusks, trilobites, and conodonts.

The Lodgepole is overlain by the Mission Canyon limestone, with which its contact is gradational; the base of the Lodgepole is formed by a thin black fissile conodont-bearing shale unit to which the name Little Chief Canyon member has been applied (Knechtel and others, 1954). This shale unit, which rests on the Three Forks shale(?) is exposed in Little Chief Canyon, three-quarters of a mile northeast of locality *E* (pl. 52), and in a tributary of Peoples Creek (loc. *G*, pl. 52) in sec. 5, T. 25 N., R. 24 E., and at the Beaver Creek mine (loc. *H*, pl. 52) in the NE¼ sec. 5, T. 25 N., R. 25 E. The thick succession of strata between shale of the Little Chief Canyon member and the base of the Mission Canyon limestone probably includes rocks equivalent to both the Paine member and the overlying Woodhurst member of the Lodgepole limestone as exposed in parts of Montana farther to the south and southwest. Strata near the middle of the formation that contain abundant crinoidal remains are thought to represent the basal beds of the Woodhurst. The rocks between these strata and the Little Chief Canyon shale are more thinly bedded and contain less crinoidal material than the beds above them and in these respects resemble the Paine of other areas. As noted by Sloss and Hamblin (1942, p. 317), however, these two members are not clearly separable in the type section of the Lodgepole. Oil residue in the form of albertite has been reported as occurring in a fissure in the Lodgepole limestone near Landusky (Collier and Cathcart, 1922, p. 178).

Conspicuous "chimney rocks" in the NE¼ sec. 15, T. 25 N., R. 24 E., on the east side of the Landusky-Hays road about half a mile north of the Little Ben mine, are composed almost entirely of jasperoid that has resulted from silicification of beds of Lodgepole limestone, probably by aqueous solutions that ascended along faults nearby in early Tertiary time.

MISSION CANYON LIMESTONE

The Mission Canyon limestone, the uppermost formation of the Madison group that is present in the Little Rocky Mountains, crops out as great ridges at the outer rim of the mountains, as well as in several prominent ridges and buttes within the mountainous area and in the foothills. This formation is largely composed of fairly pure limestone, most of which is rather coarse grained and massively bedded. Some beds, particularly in the lower half, contain nodules and lenses of cherty material, some of which has a texture resembling that of novaculite. Many of the beds are made up almost entirely of bioclastic detritus consisting predominantly of stem plates of crinoids and a few corals, brachiopods, and mollusks. At some places the limestone shows distinct crossbedding. The Mission Canyon, except for a few thinly bedded zones in the basal part, is easily distinguished from the underlying Lodgepole limestone, whose beds are characteristically thinner, less massive, finer in texture and much more fossiliferous.

The Mission Canyon limestone is well exposed at its type locality in Mission Canyon in sec. 32, T. 26 N., R. 24 E. (loc. *F*, pl. 52), a mile southeast of St. Paul's Mission. Here and in Little Chief Canyon, 1½ miles northeast of locality *E*, it is approximately 325 feet thick, but its thickness evidently increases toward the southeast. The log of dry hole SZ–1, 7 miles south of the Little Rocky Mountains, shows 502 feet of rock that is assigned to this formation. The difference in thickness that is indicated may be due to erosion that took place before deposition of the Rierdon formation (Upper Jurassic), which rests disconformably on the Mission Canyon.

The upper part of the Mission Canyon limestone contains numerous solution cavities, some of which are lined with calcite crystals. The cavities range from small vugs to large caverns. Many of the larger cavities are partly or completely filled with marly material and in some of them this material is interstratified with thin beds of conglomerate made up of small fragments of limestone. These materials were probably introduced before deposition of the overlying Rierdon formation. In a bed exposed in a small quarry in the SE¼ sec. 21, T. 25 N., R. 24 E., in Montana Gulch near Landusky (loc. *N*, pl. 52), some of the smaller, vuglike cavities contain deposits of gilsonite—a lustrous black carbonaceous material. Near Landusky and Zortman the Mission Canyon limestone has at times been quarried and burned to produce lime for use in preparing cyanide solutions for extraction of gold from ore taken from the Little Ben, Ruby Gulch, and other mines in the Little Rocky Mountains.

The cavernous upper part of the Mission Canyon limestone contains large quantities of water under artesian pressure. At four places around the periphery of the mountainous area this water flows out at the surface as large thermal springs, which are close to the contact between the Mission Canyon and Rierdon formations. The temperature of the water ranges from about 65° to 70° F.

MESOZOIC ROCKS

Sedimentary formations of Mesozoic age with an aggregate thickness of approximately 4,000 feet crop out extensively in the foothills and in a few localities within the Little Rocky Mountains. The oldest of these is the Rierdon formation of Late Jurassic age, which rests disconformably on the Mission Canyon limestone, thereby defining a hiatus that involves much of late Paleozoic time as well as all of Triassic and Early Jurassic time. The youngest formation is the Bearpaw shale, though still younger formations of Mesozoic age—including the Fox Hills sandstone and the Hell Creek formation—are believed to have been present in early Tertiary time; if so, they have since been removed by erosion.

The rocks of Mesozoic age, which include strata representing both marine and nonmarine environments, are characterized by an overall preponderance of shale; they nevertheless include much interbedded marl and sandstone, as well as small amounts of conglomerate and limestone. Because of the comparative softness of these rocks, the areas occupied by their outcrops—including most of the foothills belt and the surrounding plains—have been subjected to rapid erosion and are relatively lower than the mountainous land, where most of the outcropping bedrock is made up of harder materials, such as limestone, dolomite, porphyry, and schist.

UPPER JURASSIC SERIES

Three formations of late Jurassic age crop out in the foothills of the Little Rocky Mountains and are logged in wells drilled in the plains on their south side. The lower two are the Rierdon formation and the overlying Swift formation, both of which are marine sedimentary formations of the Ellis group; the uppermost of the three is the Morrison formation of nonmarine origin.

RIERDON FORMATION

In the foothills of the Little Rocky Mountains the Rierdon formation is 80–150 feet thick and consists almost entirely of light- to dark-gray marly limestone that weathers to pale gray. Abundant fossils, including ammonites, nautiloids, *Belemnites*, *Gryphaea*, and *Camptonectes* are present in many beds of the Rierdon. As described by Imlay and others (1948), the lowermost 11 feet of the Rierdon at Chalk Butte dome (loc. *I*, pl. 52) in the N½ sec. 7, T. 25 N., R. 26 E. is made up of "greenish-gray fissile or papery shale that includes several thin beds of gray limestone and is overlain by 1½ feet of yellow sandy limestone that weathers reddish."

SWIFT FORMATION

The Swift formation as here exposed is 150–180 feet thick. According to Imlay and others (1948) the Swift is separated by a disconformity from the underlying Rierdon formation but underlies the Morrison formation conformably. The lower part of the Swift consists of 90–100 feet of light- and dark-gray gypsiferous shale with numerous large brown calcareous concretions. At the base of the formation is a grit layer 1½–2 inches thick, containing a few polished chert pebbles and abundant fossils. A layer of shale containing worm-bored pellets occurs 1–2 feet above the grit. Belemnites are extremely abundant in the Swift, especially in the lowermost 50 feet of beds, and small ammonites occur in the lowermost 30 feet. The upper part of the formation is made up of layers of fine-grained glauconitic sandstone, sandy mudstone, dark shale and small amounts of impure limestone. The marine origin of these layers is indicated by the presence of glauconite.

MORRISON FORMATION

The Morrison formation is 65 feet thick on the north side of Morrison Butte (loc. *S*, pl. 52) in the E½ sec. 12, T. 24 N., R. 24 E. It is 75 feet thick as measured along the road west of Stage Route Butte in the NW¼ sec. 32, T. 25 N., R. 24 E. (loc. *Q*, pl. 52) and is represented by 60 feet of rock in dry hole SZ–1. The Morrison is made up largely of light-gray mudstone and a few layers of friable glauconitic sandstone, one of which near the middle of the formation contains many black nodules of manganiferous siderite. In some exposures the uppermost bed is black carbonaceous shale; in others it is impure coal. This layer contains abundant plant remains and, at an exposure in sec. 33, T. 25 N., R. 26 E. (loc. *R*, pl. 52), south of West Coburn Butte, it has yielded specimens, which R. W. Brown (oral communication, 1953), has identified as *Podozamites* and the cycad *Zamites arcticus*, which "is abundant in the upper part of the Jurassic sequence, especially near Belt, Mont."

CRETACEOUS SYSTEM

In the immediate vicinity of the Little Rocky Mountains all the sedimentary bedrock formations that are younger than the Morrison formation belong to the Cretaceous system; the basal unit is the Kootenai formation (Lower Cretaceous). In earlier publications (Collier and Cathcart, 1922; Knechtel, 1944) all the units younger than the Kootenai were assigned to the Colorado and Montana groups (Upper Cretaceous), except the First Cat Creek sandstone of drillers; this unit was here regarded as the uppermost part of the Kootenai, notwithstanding its assignment elsewhere in Montana to the Colorado group (Fisher, 1909, p. 32; Calvert, 1909, p. 29; Barnett, 1917, p. 223; Reeves, 1924, p. 91). In recent years evidence has accumulated which indicates that not only the First Cat Creek unit but also at least a part of the overlying Thermopolis shale belongs to the Lower Cretaceous. It has even been asserted that the Mowry shale, which overlies the Thermopolis, belongs to the Lower Cretaceous (Cobban and Reeside, 1951) but the evidence for this has been questioned by Yen (1954). The uncertain stratigraphic position of the contact between the Lower and Upper Cretaceous series has resulted in confusion as to the meaning of the term Colorado group, which by definition denotes only strata of Upper Cretaceous age and is not used in this report. The term Montana group, however, is regarded as useful and is retained.

KOOTENAI FORMATION

The thickness of the Kootenai formation varies considerably from place to place in the vicinity of the Little Rocky Mountains. In the north side of Morrison Butte (loc. *S*, pl. 52) the thickness is 147 feet;

in the NW¼ sec. 7, T. 26 N., R. 25 E., west of Lodgepole subagency (loc. *A*), it is 190 feet. The logs of dry hole SZ–1 show 259 feet of rock assignable to the Kootenai. The combined thickness of the Kootenai formation and the First Cat Creek sand of drillers was reported by Collier and Cathcart (1922, p. 172) to be 700 feet, but so large a thickness for these two formations is not true of any outcrops observed by the author. The Kootenai is made up of two members, the lower of which is known to drillers as the Third Cat Creek sand; the upper is a variegated argillaceous member.

The Kootenai exposed in the Little Rocky Mountains is nearly equivalent to the Cloverly formation of central Wyoming as originally described by Darton (1904, p. 398, 399). The Third Cat Creek sand and the variegated argillaceous member are approximate equivalents, respectively, of the Lakota sandstone and the Fuson shale of the Inyan Kara group of the Black Hills region.

THIRD CAT CREEK SAND OF DRILLERS

The Third Cat Creek sand of drillers is represented in dry hole SZ–1 by 128 feet of rock. As exposed on the north side of Morrison Butte (loc. *S*, pl. 52) it is only about 60 feet thick and is made up largely of light-gray rather friable sandstone. The basal bed, however, is hard, rather coarse-grained arkosic sandstone containing a few black chalcedonic pebbles, some of which are as much as an inch in diameter. Two other sandstones beds that are almost as hard, finer grained, and less arkosic occur near the middle and near the top of the unit. In some exposures, the basal sandstone bed contains *Unio* and terrestrial plants. The uppermost 3 feet of the unit consists of light-gray dense limestone that weathers to a deep brown. This limestone contains stems of *Chara*, as well as numerous tiny irregularly shaped objects that may be coprolites; commonly it forms dip slopes strewn with angular chips of the limestone which are stained dark brown. This limestone was also noted at a depth of 3,760 feet in dry hole SZ–1.

VARIEGATED ARGILLACEOUS MEMBER

The variegated argillaceous member of the Kootenai consists of mottled maroon and gray-green clay containing a few thin beds and lenses of friable light-gray sandstone. At Morrison Butte (loc. *S*, pl. 52) the thickness of this member is 85 feet, but its thickness varies considerably from place to place in the vicinity of the Little Rocky Mountains. It is represented by 129 feet of rock in dry hole SZ–1. The variation in thickness suggests that the upper part of the member may have been subjected to erosion before the overlying beds of the First Cat Creek sand were deposited.

FIRST CAT CREEK SAND OF DRILLERS

The First Cat Creek sand is approximately equivalent to the Fall River (Dakota) sandstone, which is the uppermost formation of the Inyan Kara group of the Black Hills region, and to the uppermost beds of the Cloverly formation of outcrops near the Bighorn Mountains. As exposed in Bull Creek (loc. *P*, pl. 52), the First Cat Creek sand of drillers is reported by Reeves (1924) to be 40 feet thick; in dry hole SZ–1 the drill passed through 169 feet of beds possibly assignable to this formation. In this report, however, only the lowermost 97 feet of these beds is so classified and this figure appears to be similar to the thickness exposed on the north side of Morrison Butte (loc. *S*, pl. 52), where the formation comprises two members. The lower member is about 25 feet thick and is made up of somewhat massively bedded and arkosic coarse-grained sandstone, some of which contains numerous small clay pellets. The upper member, which is less well exposed, consists of alternating beds of dark-gray shale, siltstone, and argillaceous sandstone.

THERMOPOLIS SHALE

As described by Collier and Cathcart (1922, p. 172), the Thermopolis shale of exposures in the foothills of the Little Rocky Mountains is nearly equivalent to the unit designated as Thermopolis in recent reports on areas near the Bighorn Mountains in south-central Montana (Richards, 1955; Knechtel and Patterson, 1956).

The Thermopolis west of Lodgepole, north of locality *A* (pl. 52), is about 600 feet thick. According to Reeves (1924, p. 88) its thickness in sec. 36, T. 25 N., R. 23 E., in Bull Creek west of locality *P* is 565 feet, and the log of dry hole SZ–1 shows 624 feet of beds assignable to the Thermopolis. This formation consists chiefly of dark bluish-gray shale and includes numerous thin bentonite beds; it contains numerous small ferruginous concretions that give a somber reddish-brown cast to many large weathered exposures. Near the middle of the Thermopolis is a prominent sandy unit for which the name Cyprian sandstone member is used herein.

The Cyprian sandstone member is typically exposed in Cyprian Creek (loc. *O*, pl. 52) on the southwest side of the road that crosses the NE¼NW¼ sec. 31, T. 25 N., R. 24 E., 2 miles southwest of Landusky. Here, as in other exposures on the west side of the Little Rocky Mountains, where the Cyprian forms conspicuous ridges and cliffs, its thickness is about 25 feet. Farther east, however, the equivalent beds are shaly, and consequently the Cyprian has not been recognized in some parts of the foothills east of the mountains. As exposed on the west side of the mountains, the upper half of the member is made up of massively bedded coarse-grained sandstone, some of which contains smoothly rounded chalcedonic pebbles of various colors, shapes, and sizes. Most of these pebbles are black, but many of them are brown; others are gray and a few are green. Most of the larger pebbles are subdiscoidal and some of the flatter pebbles of this type are as much as 2 inches in their major diameters; a 43-foot succession of sandy shale beds logged in dry hole SZ-1 is correlated with this member.

The lithologic character and stratigraphic relations of the Cyprian sandstone member suggest that it may be equivalent to the Newcastle sandstone of areas in Wyoming and South Dakota on the west and north sides of the Black Hills; the shales beneath and above it may, therefore, represent the Skull Creek shale and the so-called Nefsy shale member of former usage of those areas. It is considered to be equivalent to the Viking sandstone of southern Alberta and Saskatchewan, Canada.

In earlier publications dealing with areas near the Little Rocky Mountains (Reeves, 1924, pl. 11; Knechtel, 1944) the unit herein called the Cyprian sandstone member was tentatively designated the Muddy sand.

MOWRY SHALE

The Mowry shale in the vicinity of the Little Rocky Mountains ranges in thickness from 62 to about 90 feet. Its thickness is 62 feet in the S½ sec. 33, T. 25 N., R. 26 E., a quarter of a mile south of West Coburn Butte (loc. *R*, pl. 52); it is 75 feet thick where the Mowry crosses Bull Creek, half a mile west of locality *P* in sec. 35, T. 25 N., R. 23 E., and is approximately 80 feet thick at several localities on the north side of the mountains. The log of dry hole SZ-1 shows 87 feet of rock assigned to the Mowry.

The Mowry is made up mostly of papery to slaty medium- to dark-gray shale, which is largely siliceous in composition and commonly weathers to bright, silvery gray. Some of its beds contain abundant fish scales and bones. In the Bull Creek exposure a 7-inch bed of light-bluish-gray waxy bentonite occurs 15 feet below the top of the formation.

WARM CREEK SHALE

The Warm Creek shale was named by Collier and Cathcart (1922, p. 172), who cited as typical the exposures of this unit near Big Warm Spring Creek in the NE¼ sec. 24, T. 26 N., R. 25 E. (loc. *C*, pl. 52), and Little Warm Spring Creek in sec. 28, T. 26 N., R. 26 E. (loc. *D*). The Warm Creek shale rests on the Mowry shale and is overlain by the Eagle sandstone. At Bull Creek, 1 mile west of locality *P* (pl. 52), the thickness of beds between the Mowry and

Eagle is 1,065 feet (Reeves, 1924, p. 87). The log of dry hole SZ–1 shows 983 feet of rock equivalent to the Warm Creek shale. In nearly all localities in which this formation crops out, it is divisible into three members: (a) a lower, Belle Fourche shale equivalent, (b) an intermediate, Greenhorn limestone equivalent, and (c) an unnamed upper member. The Greenhorn equivalent has not, however, been located in the exposures of the Warm Creek shale in sec. 16, T. 24 N., R. 25 E. (loc. *U*, pl. 52), in the central part of the Grouse-Alder dome.

LOWER SHALE MEMBER (BELLE FOURCHE SHALE EQUIVALENT)

The lower shale member of the Warm Creek shale (the Belle Fourche shale equivalent) consists mainly of bluish-black clay that weathers to light gray with a faint bluish cast; it includes a few thin beds of bentonite, a little sandstone, and many yellow-weathering septarian limy concretions. At Bull Creek, three-quarters of a mile west of locality *P* (pl. 52), this member is 155 feet thick (Reeves, 1924, p. 87); in dry hole SZ–1, it is logged as 248 feet of rock. The lowermost 15 feet of the member is composed largely of impure bentonitic clay containing many nodules of heavy black slightly manganiferous siderite, which are mostly 3–4 inches in diameter. According to Gries (1953, p. 102), areas on which rubble made up of these nodules is strewn are "sufficiently radioactive to affect an airborne scintillometer." At many exposures a bed of friable sandstone 2–5 feet thick that may represent the so-called Phillips sand of the Bowdoin dome occurs near the middle of the member, and the upper half of the member contains a few thin beds of bentonite and a few thin zones containing yellow calcareous concretions. The lower member of the Warm Creek shale is approximately equivalent to the Belle Fourche shale of the Black Hills region; the lowermost 15 feet, which contains black nodules and bentonitic material, resembles the interval between the Mowry and bentonite Bed *E* of the Black Hills region (Knechtel and Patterson, 1955).

MIDDLE CALCAREOUS MEMBER (GREENHORN LIMESTONE EQUIVALENT)

The middle member of the Warm Creek shale (the Greenhorn limestone equivalent) comprises: (a) a basal unit (the Mosby sandstone member) of slabby to platy sandstone that contains lenticular bodies of limestone with abundant shells of the gastropod *Pseudomelania hendricksoni* as well as other fossil forms; and (b) an upper unit consisting largely of calcareous shale that weathers light-gray. According to Gries (1953, p. 102) the uppermost few feet of the member is light- to golden-brown granular sandy limestone that contains *Inoceramus labiatus*, *Ostrea congesta*, and microfossils. The member is believed to occupy approximately the same stratigraphic interval as the Greenhorn formation of the northern part of the Black Hills bentonite mining district and as the Greenhorn calcareous member of the Cody shale in the Hardin district of south-central Montana (Knechtel and Patterson, 1956). The thickness of this member is 70 feet near the center of sec. 7, T. 24 N., R. 25 E. (loc. *T*, pl. 52); 60 feet near the center of sec. 19, T. 25 N., R. 26 E. (loc. *M*); and 60 feet in Bull Creek, a mile west of locality *P*. The logs of dry hole SZ–1 show 55 feet of rock assignable to this member.

UPPER MEMBER

The upper member of the Warm Creek shale consists mainly of bluish-gray shale that contains—especially in the lower half—many large calcareous concretions and a few beds of bentonite and sandstone. Much of the uppermost 200 feet is silty to sandy, and the top of the member contains some shaly sandstone that grades upward into the Virgelle member of the Eagle sandstone. In Bull Creek, 1 mile west of locality *P* (pl. 52) the measured thickness of the upper member is 830 feet (Reeves, 1924, p. 87). In dry hole SZ–1, 680 feet of rock is assignable to this member. The member includes rocks equivalent to the Carlile shale and probably also to the Niobrara formation of the Black Hills region. As indicated by Reeves (1924, pl. 11), the sandy beds in the uppermost part of the member may be approximately equivalent to the Telegraph Creek formation of south-central Montana.

MONTANA GROUP

In and around the foothills of the Little Rocky Mountains the Montana group, which rests upon the Warm Creek shale, is represented by four formations. In upward sequence, these are the Eagle sandstone, the Claggett shale, the Judith River formation, and the Bearpaw shale. However, the uppermost beds of the Bearpaw shale, as well as several formations younger than the Bearpaw that are believed to have been deposited here in Late Cretaceous and early Tertiary time, have been completely removed by erosion that probably began at least as early as Oligocene time.

EAGLE SANDSTONE

The Eagle sandstone, as exposed in the foothills west and north of the Little Rocky Mountains, is divisible into two members: a lower one, the Virgelle sandstone member, and an upper one, consisting chiefly of shale. The thickness of the Eagle varies from place to place. It is 263 feet thick at Bull Creek (loc. *V*, pl. 52) and 223 feet thick on the west side of Grouse-Alder dome, half a mile west of locality *U;* it is represented by about 260 feet of rock in dry hole SZ-1, in which its top is poorly defined. The Virgelle member thins eastward across the area, whereas the upper member thickens progressively in that direction. The Virgelle sandstone member accordingly forms prominent ridges and cliffs west of the Little Rocky Mountains but is much less conspicuous in the eastern foothills. Evidently the Little Rocky Mountains lie along an imaginary north-trending line east of which, according to Perry (1937, p. 10, 79), the Eagle is not easily recognized owing to the eastward decrease in its content of sandy material. According to Perry the Eagle as it occurs in the Bowdoin dome consists mostly of shale, and its sandy content is commonly ignored in well logs kept by drillers. The two members exposed in the vicinity of the Little Rocky Mountains are similar in lithology to the lower and upper members of the Milk River formation of Canada, as described by Slipper and Hunter (1931), and they are approximately equivalent to the parts of the Gammon ferruginous member of the Pierre shale of the Black Hills sequence that lies below and above the Groat sandstone bed.

Natural gas was found in the Eagle sandstone in wells drilled during the early part of the decade 1930-40 on the Guinn dome, which lies on the southwest side of the Little Rocky Mountains.

VIRGELLE SANDSTONE MEMBER

The Virgelle sandstone member is made up of yellow to buff sandstone, gray siltstone, and gray shale. Many of the sandstone beds are crossbedded, and some of them contain numerous spheroidal sandstone concretions resembling cannonballs. Where the sandstone forms nearly vertical cliffs, some of the thicker beds are honeycombed by rounded cavities, the largest of which are approximately a foot in diameter. The thickness of the Virgelle sandstone member as exposed in Bull Creek (loc. *V*, pl. 52) is 208 feet; on the west side of Grouse-Alder dome, half a mile west of locality *U*, it is 108 feet. About 130 feet of rocks in dry hole SZ-1 is tentatively assigned to this member.

UPPER MEMBER

The upper member of the Eagle is composed chiefly of gray shale with many thin beds of siltstone, sandy shale, and friable sandstone that weathers reddish tan. Many of the beds contain small ferruginous nodules. Beds of sandstone at and near the top of the formation contain many smoothly rounded chalcedonic pebbles, which are mostly black but are in part red, brown, or green, and which range in diameter from ¼ inch or less to about 1½ inches. The member weathers light gray to nearly white with a pinkish cast as seen from a distance. Its thickness is 55 feet at Bull Creek (loc. *V*, pl. 52) and 115 feet on the west side of Grouse-Alder dome, half a mile west of locality *U*. In dry hole SZ-1 it is believed to be represented by 130 feet of rocks.

CLAGGETT SHALE

The Claggett shale, which rests with apparent conformity on the Eagle sandstone, is almost wholly made up of shale and siltstone of marine origin. Fresh surfaces of these materials are dark gray, but upon exposure to weathering they commonly acquire a distinctive brownish cast by which the Claggett is readily recognized. The Claggett on the west side of Grouse-Alder dome, three quarters of a mile west of locality *U* (pl. 52), is 516 feet thick; it is represented by 508 feet of rock in dry hole SZ-1. The basal part of the formation contains numerous highly polished chalcedonic pebbles averaging about a quarter of an inch in diameter. In most exposures these pebbles occur in sandy shale, from which they are readily weathered out to lie scattered on the ground close to the outcrop. A unit about 25 feet thick, its base about 27 feet above the Eagle sandstone, is made up of dark bentonitic shale with a number of intercalated layers, each less than 1 foot thick, of mealy bentonite that range in color from bright yellow to orange. Another thin bentonite bed occurs about 130 feet below the top of the formation. Interspersed among the beds of the Claggett at intervals ranging from 6 to 47 feet are beds 6 inches to 4 feet thick containing large calcareous septarian concretions and aggregates of aragonitic cone-in-cone material. The weathered concretions are boulderlike, commonly 1 foot or more in diameter; their brownish-yellow color distinguishes them from the concretions in the Bearpaw shale and in the shales of the Colorado group.

JUDITH RIVER FORMATION

The Judith River formation averages about 380 feet in thickness in the vicinity of the Little Rocky Mountains, where it forms many cliffs and ridges. It is composed largely of light-gray to buff shale, sandy shale, and sandstone; locally it includes a few thin coal beds. The sandstone is fine grained and mostly soft, but it includes a few hard layers and some layers containing numerous brown concretions; much of it is strongly crossbedded. The shale, some of which is sandy, contains many calcareous concretions and aggregates of aragonite showing cone-in-cone structure.

The individual beds of the Judith River are extremely irregular in thickness, and the proportion of sandstone to shale in the formation generally varies greatly from place to place. The formation was deposited largely in fresh and brackish water as indicated by fossil molluscan shells, plants, and bones and teeth of vertebrates, including fresh-water fishes, terrestrial dinosaurs, and other reptiles.

BEARPAW SHALE

The Bearpaw shale, which is the youngest Mesozoic formation exposed in the vicinity of the Little Rocky Mountains, rests conformably on the Judith River formation. In dry hole SZ–1, in which drilling began at an unknown distance below the top of the Bearpaw, the depth to its contact with the Judith River formation is logged as 691 feet. The Bearpaw consists mainly of dark-gray marine shale, which weathers to light gray; it also contains a few beds of bentonite and of sandstone, many thin beds and lenses of cherty material, and aggregates of aragonite showing cone-in-cone structure. A zone about 20 feet thick, its base about 120 feet above the Judith River formation, includes several beds of bentonite. This zone is believed to be approximately equivalent to the Monument Hill bentonitic member of the Pierre shale of the Black Hills region (Rubey, 1930, p. 3) and to a highly bentonitic part of the Bearpaw that is extensively exposed in Rosebud and Treasure Counties, Mont.

CENOZOIC ROCKS

TERTIARY SYSTEM

In the Little Rocky Mountains large bodies of syenite porphyry of early Tertiary origin have been mapped in contact with the Warm Creek shale and most of the formations older than the Warm Creek. These bodies of igneous rock represent alkalic magmas that invaded the Precambrian rocks—and possibly also the Cambrian rocks of some localities—but are believed to have solidified in part before coming into contact with post-Cambrian units. Most, if not all, of the contacts between the porphyry and the post-Cambrian rocks are accordingly believed to be fault surfaces.

The large bodies of syenite porphyry are cut in some places by dikes of syenite porphyry, monzonite porphyry, and trachyte porphyry; some of the trachyte porphyry has a high aegerine content. These dikes appear to have undergone little, if any, alteration.

Much of the older porphyry of the larger bodies, however, is greatly shattered, and much of it is impregnated with silica that was evidently introduced—at the time of shattering or not long afterward—by circulating aqueous solutions, which are believed also to have deposited the gold-silver ores of various mines and prospects in and around the Little Rocky Mountains (Emmons, 1908; Dyson, 1939). The sedimentary rocks are also silicified at some places along and near their contacts with the porphyry. For example, conspicuous chimney rocks in the SE¼ sec. 10, T. 25 N., R. 24 E. (loc. *K*, pl. 52), on the east side of the Landusky-Hays road about half a mile north of the Little Ben mine, are composed almost entirely of fossiliferous jasperoid, representing silicification of beds of Lodgepole limestone probably by aqueous solutions that ascended along nearby faults during the early Tertiary igneous activity. The bulk of the Cambrian and younger rocks exposed in the Little Rocky Mountains and the foothills are nevertheless essentially unaltered, and their porosity and permeability do not appear to have been impaired appreciably by any effects of the igneous activity.

In many places the porphyry contains numerous vugs. In a small prospect pit about 150 feet north of the portal of the Goldbug mine in the NW¼NE¼ sec. 22, T. 25 N., R. 24 E. (loc. *L*, pl. 52), many of the vugs are partly filled with gilsonite, believed to represent hydrocarbonaceous material that migrated into the porphyry from nearby sedimentary rocks at some time after the igneous activity ceased.

Small dikes and bosses of lamprophyre occur at several places in the foothills of the Little Rocky Mountains, cutting rocks of the Mesozoic sequence as young as the Eagle sandstone, as for example in the NE¼ sec. 7, T. 24 N., R. 24 E. (loc. *V*, pl. 52). These dikes and bosses are believed to have formed at some time during the Tertiary period and are similar to dikes cropping out in many other parts of the Montana plains, as those near Jordan, Garfield County, which have intruded rocks of the Fort Union formation of Paleocene age.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT DEPOSITS

Extensive surficial deposits that have accumulated in the Little Rocky Mountains and the surrounding foothills are principally alluvium, glacial debris, and soil. The alluvial deposits, consisting of gravel, sand, and silt, lie partly on dissected pediments that slope away in all directions from the base of the Little Rocky Mountains (Alden, 1932, p. 45) and partly on the flood plains of several intermittent streams issuing radially from the mountains. These deposits contain fragments, as much as 1 foot in diameter, of materials derived from the bedrock units that crop out in and around the mountainous area. A large proportion of them are subangular fragments of porphyry that are intermixed with boulders and cobbles of quartzite, schist, limestone, dolomite, sandstone, and other rocks. The deposits on the pediments are tentatively assigned an early Pleistocene age, though they may have begun accumulating in late Tertiary time. Those on the flood plains are of Recent origin.

The glacial deposits, which include rock materials transported in Pleistocene time from the Canadian shield and from the Great Plains (Knechtel, 1942, p. 922–923), occur in the northern, eastern, and southeastern parts of the foothills.

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