Geology of the Cleveland Quadrangle Bearpaw Mountains Blaine County, Montana

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CONTRIBUTIONS TO GENERAL GEOLOGY

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A description of the geologic features and economic resources of the area

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GEOLOGY OF THE CLEVELAND QUADRANGLE, BEARPAW MOUNTAINS, BLAINE COUNTY, MONTANA

By Robert George Schmidt, W. T. Pecora, and B. C. Hearn, Jr.

ABSTRACT

The Cleveland 15-minute quadrangle includes part of the northeastern Bearpaw Mountains and part of the bordering plains. About 15 percent of the quadrangle is underlain by sedimentary rocks of Middle Jurassic to early Tertiary age, 6 percent by instrusive and extrusive rocks of middle Eocene age, and nearly 80 percent by surficial deposits of late Pliocene(?), Pleistocene, and Recent age.

The sedimentary rocks in this region have a total stratigraphic thickness of about 10,000 feet, although only about 4,000 feet of this section is exposed in the Cleveland quadrangle. Surficial deposits include pediment and terrace gravels, glacial deposits, and alluvium; these deposits have an aggregate thickness of about 150 feet.

The igneous rocks of the Cleveland quadrangle are Eocene in age; they range in composition from subsilicic-alkalic to silicic-alkalic and represent the shonkinite-syenite and monzonite families. The intrusive igneous rocks occur as stocks, laccoliths, plugs, dikes, and sills. The extrusive rocks form the eastern part of the northern volcanic field of the Bearpaw Mountains and occur as lava flows and pyroclastic rocks.

The principal structural feature of the Bearpaw Mountains is an eastward-trending arch of uplifted and deformed sedimentary rocks that has been extensively intruded by a variety of igneous rocks. The northeastern part of the arch lies in the southern part of the Cleveland quadrangle. At the western boundary of the quadrangle, the eastern end of the northern volcanic field of the Bearpaw Mountains is faulted down against Cretaceous rocks. The plains area, to the north of the mountain front, is mostly underlain by rocks of Late Cretaceous age. These rocks are gently folded and locally faulted. Part of the Bowes dome, which is the site of a producing oil and gas field, lies within the plains area in the northwestern part of the quadrangle.

Mineral resources include oil and natural gas in the Bowes dome and minor amounts of bentonite, lignite, and low-rank coal. Vesicular mafic phonolite flows provide a potential source for road metal, and many masses of intrusive rock are a source for riprap. Gravel and sand suitable for construction purposes are locally abundant.

INTRODUCTION AND ACKNOWLEDGMENTS

Geologic quadrangle mapping of the Bearpaw Mountains uplift was begun by the U.S. Geological Survey in 1949 under the direction of W. T. Pecora as a resumption of his earlier studies (Pecora, 1940,[1] 1941; Pecora and Fisher, 1947). The uplift is contained within eight 15-minute quadrangles (fig. 1). The geologic map of the Cleveland quadrangle accompanying this report (pl. 1) is the seventh of the series published and the third issued on a topographic base. Geologic maps of the Maddux and Lloyd quadrangles, also issued on a topographic base, have been published in the Bulletin series of the U.S. Geological Survey (Bryant, Schmidt, and Pecora, 1960; Schmidt, Pecora, Bryant, and Ernst, 1961). Preliminary geologic maps with texts of the four western quadrangles (Laredo, Centennial Mountain, Shambo, and Warrick) were issued on a planimetric base and published in the Miscellaneous Geologic Investigations series of the U.S. Geological Survey in 1957 as maps numbered I–234 (Pecora, Witkind, and Stewart), I–235 (Stewart, Pecora, Engstrom, and Dixon), I–236 (Kerr, Pecora, Stewart, and Dixon), and I–237 (Pecora and others).

The Cleveland quadrangle was mapped during the summers of 1957 and 1958 under the field party leadership of R. G. Schmidt and general supervision of W. T. Pecora. B. C. Hearn, Jr., mapped the southeastern part of the quadrangle; W. B. Bryant, Jr., mapped part of the Bowes dome; and W. G. Ernst mapped the area near Timber Butte. W C Swadley, T. L. Wright, J. E. Cotton, and R. L. Borst served as field assistants, each for one season. Swadley made modal analyses of five of the analyzed rocks from the Cleveland quadrangle given in table 1 and assisted the authors in map compilation. The geology was recorded on preliminary topographic field sheets at a scale of 1:15,840.

Many courtesies were extended to members of the field staff by the residents of the area. We are particularly indebted to the members of the boards of school districts 14 and 67, Blaine County, for permission to use the Cleveland school and the Peoples Creek school as field offices and to the Post Office Department for space in the Havre Post Office Building during the project seasons.

An unpublished reconnaissance geologic map of the Bearpaw Mountains prepared in 1924 by Frank Reeves and W. S. Burbank of the U.S. Geological Survey proved to be a most helpful reference throughout these investigations. In addition to Pecora's earlier maps, the

[1] Pecora, W. T., 1940, Petrology and mineralogy of the western Bearpaw Mountains, Montana: Doctoral dissertation, Harvard Univ., 290 p.

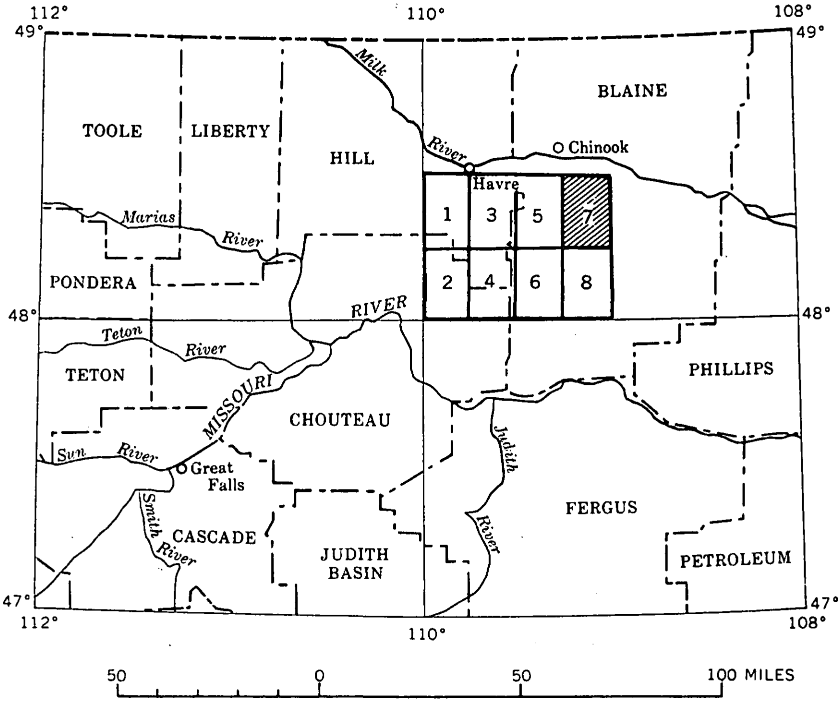

FIGURE 1.—Index map of north-central Montana showing map area and nearby quadrangles: 1, Laredo quadrangle, I–234; 2, Centennial Mountain quadrangle, I–235; 3, Shambo quadrangle, I–236; 4, Warrick quadrangle, I–237; 5, Lloyd quadrangle, Schmidt and others (1961); 6, Maddux quadrangle, Bryant and others (1960); 7, Cleveland quadrangle (shaded), this report; 8, Rattlesnake quadrangle, report in preparation.

authors also had access to an unpublished reconnaissance geologic map of the northeastern Bearpaw Mountains, prepared by Bernard Fisher.[2]

GEOGRAPHY

The Cleveland quadrangle has an area of about 200 square miles. Part of the northeastern Bearpaw Mountains extends across the extreme southern part of the quadrangle. The principal livelihood of the inhabitants is the raising of cattle and sheep and dry-land wheat farming. Resident population is about 100. Chinook, the nearest town, is 7½ miles north of the quadrangle boundary on U.S. Highway 2 and the Great Northern Railway. The Cleveland Bar in the southern part of the quadrangle is the only commercial establishment. The climate of the area is semiarid and the annual precipitation normally

[2] Bernard Fisher, 1946, Igneous rocks of the northeastern Bearpaw Mountains, Montana: Doctoral dissertation, Harvard Univ. 127 p.

is between 10 and 15 inches. Vegetation is sparse and most of the country is grassland.

The highest elevation in the quadrangle is 5,446 feet at the summit of Timber Butte in the southwestern corner of the quadrangle. Maximum topographic relief is about 2,950 feet. The southern part of the quadrangle is mountainous, though less rugged than other parts of the Bearpaw Mountains to the south and west. In general, the principal peaks in the quadrangle have a smooth, rounded, or conical outline and are composed of igneous rocks stripped of their cover of sedimentary rock. Excellent examples of such topographic forms are McCann Butte, Miles Butte, Iron Butte, Timber Butte, and Crown Butte.

The northern part of the quadrangle lies within the plains area and is generally characterized by bench topography. Over much of this area the relief has been greatly subdued by a cover of glacial deposits that have produced a gently rolling and locally bouldery surface of low hills and closed depressions in the interstream areas. These deposits were laid down in late Pleistocene time by a continental ice sheet which advanced southeastward across the plains and abutted against the lower slopes of the mountains.

Within the Cleveland quadrangle, as elsewhere in the Bearpaw Mountains region, remnants of at least four separate erosion surfaces stand above the present streams. The highest of these surfaces is about 250 feet above the major streams and marks an extensively developed pediment along the border of the mountains that is probably coextensive with the Flaxville plain of Collier and Thom (1918) and the No. 1 bench of Alden (1932, p. 14–20). Remnants of this surface are well preserved west and north of Cleveland in the southern part of the quadrangle. Along Peoples Creek and its tributaries at least three successively lower terrace surfaces are preserved at elevations of roughly 120, 60, and 20 feet above the streams. All three terraces were formed prior to continental glaciation in this area, for gravel of the lowest (youngest) terrace in this region is overlain by glacial deposits.

Present drainage in the quadrangle flows to the north and east and empties into the Milk River. In the southeastern part of the quadrangle (T. 30 N., R. 20 and 21 E.), well-defined channels as much as 150 feet deep and 1,600 feet wide were cut through the high pediment surface and its cover of till. These are melt-water channels produced by streams that originated from the wasting Pleistocene ice sheet. The valleys of Peoples Creek, Snake Creek, Bean Creek, and Box Elder Coulee were also modified by melt-water streams.

SEDIMENTARY ROCKS

Sedimentary rocks of Jurassic, Cretaceous, and Tertiary age are exposed over an area of about 30 square miles or 15 percent of the Cleveland quadrangle and comprise 16 stratigraphic units. Surficial deposits of Pliocene(?), Pleistocene, and Recent age are exposed over an area of about 158 square miles, or nearly 80 percent of the quadrangle, and comprise 5 stratigraphic units. The sedimentary units exposed in the Cleveland quadrangle and their geologic age and maximum thickness, are given as follows.

Age and stratigraphic unit	*Maximum thickness (feet)*
Quaternary:	
Recent:	
Alluvium	15
Pleistocene:	
Glaciofluvial deposits	30
Ground moraine	100
Terrace gravel	15
Tertiary:	
Pliocene(?):	
Pediment gravel	20
Eocene:	
Wasatch Formation	650
Cretaceous:	
Upper Cretaceous:	
Montana Group:	
Bearpaw Shale	1,200
Judith River Formation	650
Claggett Shale	650
Eagle Sandstone	275
Colorado Shale:	
Telegraph Creek Member	300
Niobrara Shale and Carlile Shale Members	850
Greenhorn Limestone Member	40
Belle Fourche Shale Member	300
Lower Cretaceous:	
Colorado Shale:	
Mowry Shale Member	100
Newcastle Sandstone and Skull Creek Shale Members	360
Fall River Sandstone Member	285
Kootenai Formation	275
Jurassic:	
Upper Jurassic:	
Ellis Group:	
Swift Formation	225
Rierdon Formation	210
Middle Jurassic:	
Ellis Group:	
Sawtooth Formation	220

Only a summary description of these rock units is given in this report. A more nearly complete treatment is given in many other publications, including Pepperberg (1909; 1912), Stebinger (1914; 1916), Bowen (1914a; 1914b), Reeves (1924), Pierce and Hunt (1937), Cobban (1945; 1951), Brown and Pecora (1949), Hunt (1956), Bryant and others (1960), and Schmidt and others (1961).

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JURASSIC SYSTEM

The Jurassic System in the Bearpaw Mountains is represented by the Ellis Group, which is made up of the Sawtooth, Rierdon, and Swift Formations, following the nomenclature of Cobban (1945). In the Cleveland quadrangle, these formations are exposed only in the central part of a symmetrical dome in the southwestern part of the quadrangle. Here their total area of outcrop is slightly less than 1 square mile, and they have been modified by thermal metamorphism.

SAWTOOTH FORMATION

The thickness of the Sawtooth Formation, which is fully exposed elsewhere in the Bearpaw Mountains, is about 100 feet, but only the upper 72 feet of the formation is exposed in the Cleveland quadrangle. The lower 48 feet of this section consists of massive cliff-forming blue-gray fetid limestone that is locally fossiliferous. The upper 24 feet of the formation consists of yellowish-gray to light-gray arenaceous limestone that contains thin beds in which small abraded fossil fragments are abundant. Crossbedding and thin intraformational conglomerate beds are present in the upper 24 feet of the formation. The top of the formation is marked by an 8- to 10-inch thick massive to platy dark bluish-gray banded algal limestone. Rocks of Sawtooth age penetrated by drill holes in the Bowes oil and gas field in the northwestern part of the quadrangle are correlated with the Piper Formation (Imlay and others, 1948). The Piper Formation at Bowes is about 220 feet thick and is subdivided, from the base upward, into the Tampico Shale, Firemoon Limestone, and Bowes Members (Hunt, 1956, p. 187–189). The Tampico Shale Member is apparently absent in the Bearpaw Mountains. The Firemoon Limestone Member is probably equivalent to the lower part and the Bowes Member to the upper part of the Sawtooth Formation of the Bearpaw Mountains. Both the Firemoon Limestone and Bowes Members yield oil in the Bowes dome.

RIERDON FORMATION

The Rierdon Formation consists mostly of light-gray, yellowish-gray, greenish, and bluish-gray thick-bedded calcareous shale and argillaceous limestone. A conspicuous zone of *Gryphaea* occurs 23 feet above the base. The top of the formation is marked by a massive light-gray ledge-forming limestone that is between 20 and 30 feet thick. The Rierdon Formation is approximately 160 feet thick in the Cleveland quadrangle, but maximum thickness of 210 feet is recorded in other parts of the Bearpaw Mountains.

SWIFT FORMATION

The lower part of the Swift Formation consists of grayish-brown, dark-gray, and greenish-gray shale and siltstone and lenses of argillaceous limestone. Thin conglomerate beds composed of abraded fossil fragments, principally *Belemnites*, occur near the base of the formation. Above this lower sequence are alternating beds of yellowish-brown to gray-ribboned sandstone and shale. The top of the formation is marked by a 25- to 30-foot sequence of olive-drab to brownish-gray sandstone, siltstone, mudstone, and claystone that may possibly be correlated with beds of the Morrison Formation elsewhere in Montana. On the northeastern flank of the dome in the southwestern part of the quadrangle, the Swift Formation is 160 feet thick. The maximum thickness of the formation in the Bearpaw Mountains region is about 225 feet.

CRETACEOUS SYSTEM

Within the Cleveland quadrangle, the Cretaceous System is represented by the Kootenai Formation, the Colorado Shale, and the Montana Group. The Fox Hills Formation and Hell Creek Formation, which occur at the top of the Cretaceous System in other parts of the Bearpaw Mountains region to the south and west, are not exposed in the Cleveland quadrangle. The Cretaceous formations are exposed in the mountainous area in the southern part of the quadrangle, where they are commonly modified by thermal metamorphism, and in scattered outcrops over the plains area to the north. Their total mapped area of outcrop is about 30 square miles.

KOOTENAI FORMATION

The Kootenai Formation is exposed in or near the central part of four domes in the southern part of the quadrangle, and the uppermost part of the formation is probably also present beneath a cover of alluvium in the prominent dome midway between Cleveland and McCann Butte. The Kootenai consists of a sequence of alternating beds of red, tan, green, and purplish claystone and siltstone and white to buff sandstone. Reddish siltstone is characteristic of the formation and thin beds of black massive limestone, which weather bluish gray, occur at several horizons. At the base is a white thin-bedded sandstone which weathers yellowish brown. The basal sandstone is as much as 50 feet thick and at places contains conglomeratic lenses made up of smooth rounded pebbles and cobbles of chert, probably of Paleozoic age, and quartzite and quartz of unknown age. The maximum thickness of the formation in the Bearpaw Mountains region is about 275 feet. On the north flank of the dome about 1 mile south of Cleveland the upper 180 feet of the formation is well exposed.

COLORADO SHALE

The Colorado Shale is subdivided into seven map units, all of which were deposited in a marine environment. From oldest to youngest these are the Fall River Sandstone Member, Newcastle Sandstone and Skull Creek Shale Members, Mowry Shale Member, Belle Fourche Shale Member, Greenhorn Limestone Member, Niobrara Shale and Carlile Shale Members, and Telegraph Creek Member. The names of these map units follow the nomenclature of Rubey (1930) and Cobban (1951). The boundary between the Lower and Upper Cretaceous lies at or near the top of the Mowry Shale Member.

FALL RIVER SANDSTONE MEMBER

The lower part of the Fall River Sandstone Member consists of a sequence of alternating beds of dark-gray to black fissile shale and thin beds and lenses of gray argillaceous sandstone and mudstone. Phosphatic concretions are present in the lower 25 feet of this sequence. Worm trails and ripple marks are common in the sandstone beds; impressions of *Inoceramus bellevuensis* Reeside are rare. At the top of the member is a gray to greenish-gray pure to impure sandstone, as much as 30 feet thick, that contains thin lenses of conglomerate composed of green, red, and black chert pebbles having a maximum diameter of about 1 inch. The maximum thickness of the Fall River in the Bearpaw Mountains region is about 285 feet.

NEWCASTLE SANDSTONE AND SKULL CREEK SHALE MEMBERS

The upper 200 to 260 feet of this unit is the Newcastle Sandstone Member. It consists of black to gray fissile shale and mudstone and thin beds of gray and greenish-gray fine-grained glauconitic sandstone. The sandstone weathers yellowish brown and has a platy structure; outcrops of this sequence are generally strewn with flat chips or plates of the weathered sandstone. The lower part of the unit, the Skull Creek Shale Member, is 50 to 100 feet thick and consists of black hard silty and sandy shale. The unit has a maximum thickness of about 360 feet in the Bearpaw Mountains region.

MOWRY SHALE MEMBER

The Mowry Shale Member consists of about 75 feet of hard thin-bedded, papery siliceous shale, siltstone, and very fine grained siliceous sandstone. The shale is dark gray in fresh outcrop but weathers light gray to bluish gray, and outcrops are generally strewn with silvery-gray chips. Fossil fish scales, as much as 3 inches across, are abundant in the member. Other fossils are sparse. The maximum thickness of this member in the Bearpaw Mountains region is about 100 feet.

BELLE FOURCHE SHALE MEMBER

The Belle Fourche Shale Member consists of dark-gray to black shale, thin sandstone and bentonite beds, and limestone concretions. The basal 40 feet of the member contains numerous ovoid clay-ironstone concretions that weather dark reddish brown. About 50 feet above the base is a 5- to 10-foot thick sequence composed locally of arkosic grit, mudstone, and coarse greenish-gray sandstone containing small rounded chert pebbles. The upper part contains calcareous concretions. Fossils are rare. This member has a maximum thickness of about 300 feet in the Bearpaw Mountains region.

GREENHORN LIMESTONE MEMBER

The Greenhorn Limestone Member is about 40 feet thick; it is composed of blue-gray thin-bedded silty and sandy limestone and gray to black calcareous and noncalcareous shale. The limestone occurs principally in the upper and lower parts of the unit and characteristically breaks into flat plates or slabs. The upper limestone is more thinly bedded and more silty than the lower limestone. When broken, the more massive limestone has a pronounced fetid odor. Fossils are abundant, particularly *Inoceramus labiatus* (Schlotheim) and fish scales.

NIOBRARA SHALE AND CARLILE SHALE MEMBERS

The upper 480 to 600 feet of this unit, the Niobrara Shale Member, consists mostly of dark-gray papery marine shale. Thin beds of bentonite, as much as 18 inches thick, and thin sandstone and limestone beds make up a subordinate part of this sequence. Massive to septarian light-gray and light-yellow discoid limestone concretions occur in the shale, and some contain abundant invertebrate fossils. The lower 200 to 250 feet of the unit, the Carlile Shale Member, consists of black silty to sandy nonfossiliferous shale. Near the base of the black shale are numerous ovoid clay-ironstone concretions that are dark gray on fresh fracture but which weather reddish brown. Weathered fragments characterize the zones of concretions in outcrop and this feature has given rise to the term "red chip zone" (Reeves, 1924).

TELEGRAPH CREEK MEMBER

The Telegraph Creek Member forms a transition between the Niobrara Shale and the overlying Eagle Sandstone of the Montana Group. It consists of a lower sequence of dark-gray to black shale and blue-black mudstone, which contains thin lenses of concretionary limestone and beds of sandstone, and an upper sequence of light-gray to buff silty sandstone beds separated by thin partings of dark-gray shale and mudstone. In the Cleveland quadrangle the thickness of the Telegraph

Creek Member is between about 150 and 180 feet; the maximum thickness in the Bearpaw Mountains region is nearly 300 feet.

MONTANA GROUP

The Montana Group consists of four formations. From oldest to youngest these are the Eagle Sandstone, Claggett Shale, Judith River Formation, and Bearpaw Shale.

EAGLE SANDSTONE

The lower part of the Eagle Sandstone unit is the Virgelle Sandstone Member. It consists of about 80 feet of massive bluff-forming sandstone containing large rounded rusty-brown sandstone concretions as much as 10 feet in diameter. The Virgelle Sandstone Member is an excellent aquifer throughout the region, and the upper part of the formation yields natural gas. Above the Virgelle is an interbedded sequence of light-gray thick- and thin-bedded sandstone, thin-bedded shale and siltstone, and carbonaceous mudstone. In places, one or more beds of conglomerate composed of small smoothly polished black chert pebbles occur near the top of the formation. A section of the Eagle Sandstone exposed south of McCann Butte is about 200 feet thick; the maximum thickness of the formation is about 275 feet in other parts of the Bearpaw Mountains.

CLAGGETT SHALE

The Claggett Shale is a dark-gray to black, brownish-weathering fissile marine shale that contains numerous yellow-brown ovoid septarian limestone concretions. The basal part of the formation is characterized by many thin beds of bentonite; the upper part, by thin beds of sandstone and siltstone that represent a transition from marine shale to overlying sandstone of the Judith River Formation. *Baculites* occur in some limestone concretions in the upper part of the formation but are rare in the lower part. The thickness of the Claggett Shale in the Bearpaw Mountains region is about 450 to 650 feet.

JUDITH RIVER FORMATION

The Judith River Formation consists of a sequence of light-gray and buff sandstone, dark-brown concretionary sandstone, light-gray and light-green siltstone and gypsiferous claystone, and thin beds of reddish-brown lignite and carbonaceous shale. A massive, thick-bedded ledge-forming sandstone unit, as much as 60 feet thick, occurs at the base of the formation and forms one of the aquifers of the region. Several thin beds of carbonaceous shale and lignite and one or more thin beds composed largely of oyster shells occur at the top of the formation. Large ovoid sandstone concretions that weather orange brown and that are as much as 8 feet across are a characteristic feature of the formation. The thickness of the Judith River ranges from about 500 feet to 650 feet in the Bearpaw Mountains region.

BEARPAW SHALE

Only the lower few hundred feet of the Bearpaw Shale is exposed in the Cleveland quadrangle. This part of the formation is mostly dark-gray fissile marine shale containing numerous ovoid massive and septarian limestone concretions that weather dark gray, reddish brown, and yellowish brown. In places the concretions contain abundant fossils, principally species of *Baculites*, *Inoceramus*, and *Placenticeras*. Numerous thin beds of bentonite and light-gray gypsiferous clay are present in the formation. The maximum thickness of the Bearpaw Shale in the Bearpaw Mountains region is about 1,200 feet.

TERTIARY SYSTEM

The Tertiary System in the Cleveland quadrangle is represented by beds equivalent to the Wasatch Formation of Eocene age and by pediment gravel of Pliocene(?) age. The Fort Union Formation of Paleocene age, which lies at the base of the Tertiary System, is not exposed in the Cleveland quadrangle but occurs in other parts of the region to the south and west.

WASATCH FORMATION

Gray to buff medium-grained sandstone and pink and gray siltstone and claystone beds of the Wasatch Formation are exposed in several small isolated outcrops in the canyon formed by Snake Creek in sec. 26, T. 29 N., R. 19 E. The outcrops are less than 1 acre in extent and probably represent less than 50 feet of the formation, which has a maximum thickness of about 650 feet in the Bearpaw Mountains region. In some of these outcrops the exposed beds of the Wasatch Formation are overlain unconformably by mafic tuff-breccia of the volcanic series; in other outcrops they are faulted against the volcanic rocks, and at two localities small blocks of sediments of the Wasatch are included within pyroclastic breccias.

Sandstone and variegated claystone of the Wasatch Formation beneath a cover of glacial drift make up part of the cuttings of a seismic shothole north of Snake Creek Canyon in sec. 23, T. 30 N., R. 19 E., and the formation probably extends beneath and along the margin of the volcanic field in the Cleveland quadrangle.

PEDIMENT GRAVEL

Gravel deposits occur on mesalike remnants of the highest bench surface in this quadrangle, principally along the northern front of the mountains. In the area north of Peoples Creek, the bench gravel is overlain by glacial deposits; there the gravel crops out almost continuously along the margins of the bench escarpment. Small exposures of the gravel are also found in the central part of the quadrangle west of the South Fairview School and in the northwestern part of the quadrangle south of the Bowes oil field. The gravel is poorly sorted and consists of boulders, cobbles, and pebbles of rocks that are exposed in the mountains. The chief rock types are porphyritic potassic syenite, latite, quartz latite, fine-grained shonkinite, hornfels, quartzite, and mafic and felsic volcanic rocks. Near the mountain front, boulders of porphyritic syenite are as much as 3 feet long. The maximum thickness of the gravel is about 20 feet. The pediment surface capped by this gravel is probably late Tertiary in age and equivalent to the Flaxville plain of Collier and Thom (1918).

QUATERNARY SYSTEM

The Quaternary System in the Cleveland quadrangle is represented by terrace gravel of Pleistocene age, glacial deposits of late Pleistocene age, and alluvium of Recent age. The glacial deposits have been subdivided into two units—ground moraine and glaciofluvial deposits. The deposits of Quaternary age cover approximately 158 square miles of the quadrangle and lie chiefly north of the mountain front.

TERRACE GRAVEL

The terrace gravel occurs on three successively lower terrace surfaces lying roughly at elevations of 120, 60, and 20 feet above the major streams. The terraces are mainly along Peoples Creek and its tributaries in the southern part of the quadrangle, but small remnants are present at several places in the northern part of the quadrangle. The deposits consist of poorly sorted gravel of local origin and are lithologically similar to the pediment gravel described previously. Glacial drift overlies the gravel on the lowest terrace in the Lloyd quadrangle and shows that all these deposits are of preglacial age. The maximum thickness of the gravel on any individual terrace surface is about 15 feet. The higher terrace may possibly be late Tertiary in age.

GROUND MORAINE

Ground Moraine is the most extensive surficial deposit and covers most of the quadrangle north of the mountain front. It consists of yellowish-gray to light-gray clay-rich to sandy and pebbly till containing scattered glacial erratics as much as 10 feet in diameter. The erratics include a great variety of angular to rounded stones transported from the Precambrian shield area of Canada, well-rounded stones of quartzite from the high gravel plains in Alberta, and rocks of local origin. The maximum thickness of the glacial drift is more than 100 feet where the deposits fill preglacial stream valleys.

A fan-shaped boulder train, which was mapped as part of the ground moraine unit, occurs along the west-central boundary of the quadrangle and is shown on the geologic map (pl. 1). The boulder train consists of large angular blocks of nepheline shonkinite, which were derived from the prominent sill along Bean Creek, and extends southeastward from the sill.

GLACIOFLUVIAL DEPOSITS

Glaciofluvial deposits occur at many places in the quadrangle where they grade laterally and vertically into glacial till of the ground moraine unit. They consist of gravel, sand, silt, and clay and represent outwash sediments deposited along the margins of the wasting Pleistocene ice sheet. The deposits are ordinarily laminated, and clay of this unit is locally varved. The maximum thickness of the deposits is more than 30 feet.

ALLUVIUM

The alluvium includes gravel, sand, silt, and clay deposited in stream valleys and in closed undrained depressions by slope runoff. The unit is not mapped along minor tributaries. The maximum thickness of the deposit is about 15 feet. Recent dissection of alluvial flood plains has taken place in the upper reaches of most tributaries.

METAMORPHISM

In the southern part of the quadrangle the sedimentary rocks of Jurassic and Cretaceous age have locally been thermally metamorphosed along the margins of igneous intrusions. Shale has been converted to hornfels, sandstone to quartzite, and impure limestone to lime-silicate rock. This thermal metamorphism is most widespread in the mountainous area near Crown Butte and south of Miles Butte. The sedimentary rocks adjacent to most of the igneous intrusions have been metamorphosed in narrow zones a few inches to a few score feet wide.

The metamorphism of marine shales and siltstones has produced massive dense silicified black hornfels that weathers tan, very light tan, and light gray. In places, gray to black spotty discolorations, as much as 5 mm in diameter, are developed in the light-colored hornfels; these discolorations appear to be restricted to areas of more intense metamorphism. Under the microscope the small spots are seen to consist of concentrations of an indeterminate fine-grained opaque material, and some contain a pale yellowish-brown micaceous mineral.

The metamorphism of normally gray to greenish-gray sandstone has produced tan, yellowish, and white massive quartzite. Original textures and fossils are destroyed in the process of metamorphism and, in those areas where the metamorphism is widespread, it is difficult to assign the rocks to their proper formational units. Pyrite is common in hornfels.

Near the center of the dome in the southwestern part of the quadrangle, limestone of the Rierdon Formation has been converted to marble, and thin beds of calcareous siltstone within the rock now consist of a greenish, finely crystalline mixture of grossularite, vesuvianite, and calcite. Some of the former siltstone beds are composed entirely of small dodecahedra of grossularite as much as 1 mm in diameter.

IGNEOUS ROCKS

Intrusive and extrusive igneous rocks are exposed over an area of about 12 square miles in the Cleveland quadrangle. The intrusive rocks form stocks, laccoliths, dikes, plugs, and sills. They occur mostly in the southern part of the quadrangle. The extrusive rocks consist of mafic and felsic lava flows and pyroclastic rocks and occur mostly in a small area in the west-central part of the quadrangle along Snake Creek. These volcanic rocks represent the eastern end of the northern volcanic field of the Bearpaw Mountains, which extends westward for some 30 miles through the Lloyd, Shambo, and Laredo quadrangles (fig. 1). The plant fossils that occur within the volcanic sequence in other parts of the Bearpaw Mountains (Pecora and others, 1957) indicate that the igneous rocks are of middle Eocene age.

The igneous rocks of the Cleveland quardangle are similar to those in other parts of the Bearpaw Mountains, although all the petrographic types are not represented in this quadrangle. Chemically the rocks range from subsilicic-alkalic to silicic-alkalic. The extrusive rocks are similar in composition to the intrusive rocks, and these two groups are represented by rock types of nearly identical mineral composition and texture. However, the intrusive rocks are generally coarser grained or more coarsely porphyritic than their extrusive equivalents. Nomenclature of the igneous rocks follows that established in the earlier published maps of the Laredo, Centennial Mountain, Shambo, and Warrick quadrangles and the U.S. Geological Survey Bulletin reports on the Maddux and Lloyd quadrangles.

Thirty-five specimens of igneous rock, representative of the varieties occurring in the quadrangle, were studied in thin section. Their color index ranges from about 7 to 65. The principal felsic minerals in the suite are sanidine, plagioclase, quartz, nepheline, pseudoleucite, and analcime. Leucite has not been identified in any rocks of the suite. The principal mafic minerals are augite, olivine, biotite, hornblende, aegirine-augite, and aegirite. Accessory minerals are magnetite, apatite, sphene, melanite, and zircon. The principal alteration minerals are serpentine, chlorite, iddingsite, celadonite, zeolites, calcite, and sericite.

Chemical analyses, norms, and modes of six igneous rocks from the Cleveland quadrangle are presented in table 1. All the analyses are new except for that in column 5, which is taken from Weed and Pirsson (1896, p. 295). Comparable analyses of igneous rocks from other parts of the Bearpaw Mountains are to be found in the texts accompanying the earlier published quadrangles.

INTRUSIVE ROCKS

Intrusive igneous rocks underlie about 10 square miles of the Cleveland quadrangle. For purposes of mapping, they have been separated into four units: shonkinitic rocks, syenite, porphyritic latite, and porphyritic syenite.

TABLE 1.—*Chemical analyses, norms, and modes of igneous rocks from the Cleveland quadrangle*

[Analysis by U.S. Geological Survey: Analyses 1, 2, 3, 4, and 6 by P. L. D. Elmore, I. H. Barlow, S. D Botts, and M. D. Mack by rapid rock analysis methods; analysis 5 by H. N. Stokes (Weed and Pirsson, 1896)]

	1	2	3	4	5	6
Analyses (weight percent)						
SiO_2	53.5	57.4	61.0	66.1	66.22	66.5
TiO_2	.73	.66	.39	.25	.22	.32
Al_2O_3	12.6	15.1	15.0	15.6	16.22	15.5
Fe_2O_3	2.1	4.2	2.7	1.4	1.98	1.8
FeO	6.4	2.9	1.8	1.6	.16	1.6
MnO	.19	.16	.09	.08	Tr.	.10
MgO	7.3	3.7	3.4	1.9	.77	2.0
CaO	8.8	5.9	3.8	2.0	1.32	2.2
Na_2O	2.6	4.2	5.0	4.9	6.49	4.5
K_2O	5.1	4.4	5.2	4.1	5.76	4.1
H_2O	.42	.77	.71	1.1	.32	.87
P_2O_5	.53	.57	.31	.18	.10	.15
CO_2	.12	.13	.07	.31	------	.12
SO_3	------	------	------	------	.02	------
BaO	------	------	------	------	.29	------
SrO	------	------	------	------	.06	------
Li_2O	------	------	------	------	Tr.	------
Fl	------	------	------	------	Tr.	------
Cl	------	------	------	------	.04	------
Total	100	100	99	100	99.97	100

TABLE 1.—*Chemical analyses, norms, and modes of igneous rocks from the Cleveland quadrangle*—Continued

	1	2	3	4	5	6
CIPW norms (weight percent)						
Quartz	----	2.7	2.5	15.2	4.7	17.0
Orthoclase	30.0	26.1	30.6	24.5	34.5	24.5
Albite	17.3	35.6	42.4	41.4	50.8	38.3
Anorthite	7.8	9.2	3.1	7.2	----	9.2
Corundum	----	----	----	.4	----	.2
Nepheline	2.6	----	----	----	----	----
Acmite	----	----	----	----	3.7	----
Diopside:						
Wollastonite	13.2	6.5	5.7	----	2.2	----
Enstatite	8.2	5.2	4.7	----	1.9	----
Ferrosilite	4.1	.5	.3	----	----	----
Hypersthene:						
Enstatite		4.1	3.8	4.8	----	5.0
Ferrosilite	----	.4	.3	1.5	----	.9
Olivine:						
Forsterite	7.1	----	----	----	----	----
Fayalite	3.9	----	----	----	----	----
Wollastonite	----	----	----	----	.2	----
Magnetite	3.0	6.0	3.9	2.1	----	2.6
Ilmenite	1.4	1.4	.8	.5	.3	.6
Titanite	----	----	----	----	.2	----
Apatite	1.3	1.3	.7	.3	.3	.3
Hematite	----	----	----	----	.8	----
Total	99.9	99.0	98.8	97.9	99.6	98.6
Modes (volume percent)						
Felsic minerals:						
Phenocrysts:						
Potassium feldspar	0	0	4	3	----	7.5
Plagioclase	0	0	0	7	----	9.5
Groundmass:						
Quartz	0	.5	.5	3	----	5.5
Sanidine	44	} 70.5	72.5	74	{ ---- }	61.5
Plagioclase	0					
Mafic minerals:						
Phenocrysts and groundmass:						
Olivine	7.5	0	0	0	----	0
Augite	33	19.5	12	.5	----	Tr.
Hornblende	0	.5	0	7	----	9
Biotite	8.5	4.5	8.5	3.5	----	5
Magnetite	5.5	4	1.5	} 2	{ ----	1.5
Others	1.5	.5	1			.5
Total	100	100	100	100	----	100

1. Olivine-augite shonkinite; plug, summit of Crown Butte, in SE¼ sec. 10, T. 29 N., R. 19 E. Specimen P58–1.
2. Hornblende-augite-biotite latite; stock, summit of McCann Butte in SW¼ sec. 6, T. 29 N., R. 21 E. Specimen P58–31.
3. Augite syenite; stock, west side of Miles Butte, northeast corner sec. 24, T. 29 N., R. 20 E. Specimen P58–20C.
4. Hornblende-biotite latite; sill, south of Lloyd-Cleveland road in NE¼ sec. 1, T. 29 N., R. 19 E. Specimen P57–103.
5. Porphyritic syenite; stock, Iron Butte, sec. 24, T. 29 N., R. 20 E. (Weed and Pirsson, 1896, p. 295).
6. Hornblende-biotite latite; dike, summit of Crown Butte, in SE¼ sec. 10, T. 29 N., R. 19 E. Specimen P58–3.

SHONKINITIC ROCKS

Shonkinitic rocks occur mainly in numerous sills, some of which are at least 30 feet thick, but they are also found as plugs, dikes, and small intrusive bodies of irregular shape. The rocks range in texture from very fine grained in dikes and plugs to coarse grained in the sills and irregular intrusions. The most abundant type of shonkinitic rock has sanidine, augite, and biotite as its principal minerals. However, as a group, the shonkinitic rocks vary considerably in their content of light and dark minerals. All contain sanidine, augite, and biotite; some contain analcime, pseudoleucite, nepheline, and olivine; a few contain a minor amount of plagioclase and quartz. The common accessory minerals are magnetite, apatite, and sphene. The color index ranges from about 35 to 65; in most varieties it is about 50.

An analysis, a norm, and a mode of a specimen of olivine shonkinite from the pluglike body at Crown Butte are given in column 1 of table 1. The rock is dark gray, massive, and porphyritic. Small phenocrysts of augite and olivine are enclosed in a fine-grained groundmass consisting of sanidine, augite, olivine, biotite, and accessory magnetite and apatite. Biotite forms small flakes at the margins of olivine and magnetite grains.

Several of the larger shonkinitic sills in the quadrangle contain numerous inclusions of Precambrian basement rocks as much as 2 feet in diameter. The chief rock types represented among the inclusions are biotite pyroxenite, gabbro, garnet gneiss, mica schist, anorthosite, and granite. Quartz is present in shonkinite from some of these normally subsilicic intrusions, the excess silica most likely being due to contamination.

SYENITE

A large stock of fine-grained light greenish-gray augite-biotite syenite exposed at Miles Butte is the only body mapped as syenite in the Cleveland quadrangle. The rock is composed of sanidine as elongated crystals, microperthite as large equidimensional crystals, augite, aegirine-augite, biotite, and minor amounts of quartz and plagioclase. The principal accessories are magnetite and apatite. Quartz, which is present as small irregular interstitial fillings between sanidine grains, forms as much as 2 percent of the rock and is evidently a product of late crystallization. The texture of the rock is trachytic. There is considerable variation in mineral composition within the Miles Butte stock. A border phase of the stock, near the base of the butte, has a color index of about 30; at the top of the butte, the rock is much more leucocratic and has a color index of about 15.

A chemical analysis, a norm, and a mode of the mafic syenite at Miles Butte, representing the darker border phase of the stock, are given in column 3 of table 1. The rock is essentially saturated in silica.

PORPHYRITIC LATITE

The rocks mapped as porphyritic latite crop out over an area of about 6 square miles and mainly occur as plugs, small stocks, laccoliths, dikes, and sills. The most prominent bodies of porphyritic latite are the laccolith at Timber Butte (pl. 1, section *A–A′*) and the plug at McCann Butte (pl. 1, section *B–B′*). The unit includes quartz latite and subordinate amounts of latite. In general these rocks are light to dark gray, greenish gray, brownish gray, light brown to tan, fine to medium grained, and porphyritic. All the rocks contain sanidine, oligoclase or andesine, and augite, and some have quartz, biotite, and hornblende. The color index of the suite ranges from 10 to 35 and in most varieties is about 20.

The porphyritic latite is characterized by abundant inclusions of Precambrian basement rocks, such as biotite pyroxenite, gabbro, hornblendite, anorthosite, garnet gneiss, schist, and granite.

Chemical analyses, norms, and modes of three specimens of intrusive latite from the Cleveland quadrangle are given in columns 2, 4, and 6 of table 1.

PORPHYRITIC SYENITE

The porphyritic syenite is related to the tinguaites of Weed and Pirsson (1896, p. 189). Within the Bearpaw Mountains, tinguaite, porphyritic potassic syenite, and porphyritic syenite occur as dikes, plugs, and stocks. They are the least abundant of all the rock types, and their intrusive relationships indicate that they are among the youngest of all the igneous rocks.

In the Cleveland quadrangle, porphyritic syenite occurs in two stocks, one at Iron Butte and the other immediately southwest of Iron Butte. In both of these stocks the rock is light greenish gray and coarsely porphyritic; large stout sanidine phenocrysts, as much as 1 cm long, constitute from about 25 to 55 percent of the rock. The principal minerals are sanidine, augite, aegirine-augite, and aegirite. The common accessory minerals are magnetite, biotite, apatite, and sphene. The groundmass is fine grained and composed of sanidine, aegirite, minor plagioclase, and a small amount of quartz.

A chemical analysis of a specimen of porphyritic syenite from the Iron Butte stock, published by Weed and Pirsson (1896, p. 295), is given in column 5 of table 1. A modal analysis, in percent, of a specimen of rock collected in 1958 from Iron Butte is: quartz, 4; sanidine, 48.5; plagioclase within sanidine phenocrysts, 7; pyroxene, 7.5; and groundmass, 33.

EXTRUSIVE ROCKS

Extrusive rocks are exposed over an area of about 2 square miles at the west border of the quadrangle, mainly north and west of Snake Creek. A small patch of volcanic rocks occurs east of the Red Rock school in the west-central part of the quadrangle. The extrusive rocks consist of a thick accumulation of interlayered lava flows and pyroclastic deposits. Where Snake Creek has cut a canyon through the extrusive rocks, they rest unconformably upon and are faulted against beds of the Wasatch Formation. This entire block of volcanic rocks and underlying Tertiary sedimentary rocks in the Cleveland quadrangle is faulted down against Cretaceous rocks (pl. 1).

For mapping purposes, the extrusive rocks are subdivided into four lithologic units: (1) mafic flow rocks, (2) mafic pyroclastic rocks, (3) felsic flow rocks, and (4) felsic pyroclastic rocks.

MAFIC FLOW ROCKS

Mafic flow rocks are made up principally of lava flows, but they probably include a number of small sills and irregular intrusive bodies that cannot be distinguished from the flows. The flows consist largely of thick layers of reddish-gray, purplish-red, and dark-gray rubbly vesicular rock and thin irregular layers of dark-gray to black massive rock. They are tabular in form and commonly of wide areal extent. Their thickness ranges from a few feet for individual flows to perhaps 100 feet in composite flows built of alternating massive and rubbly layers.

Fresh specimens of the mafic flow rocks are dark gray to dark brown and black, fine grained, porphyritic, and massive. The common rock types are mafic varieties of phonolite, all of which contain sanidine, augite, and biotite, and some of which also contain analcime and olivine. The mafic flow rocks are chemically equivalent to the shonkinitic rocks.

MAFIC PYROCLASTIC ROCKS

Mafic pyroclastic rocks form a significant part of the volcanic sequence in the Cleveland quadrangle and are interbedded with mafic and felsic flow rocks and felsic pyroclastic rocks. The mafic pyroclastic rocks consist of light- to dark-gray, dark-green, black, and red to purplish breccia, tuff-breccia, and coarse crystal-lithic tuff. The predominant type of rock is tuff-breccia in which large angular to rounded blocks are enclosed in coarse tuff. In agglomeratic facies, the included blocks are as much as 3 feet in diameter. Most of the blocks and smaller fragments are varieties of mafic phonolite. Locally the deposits contain accessory fragments of latite, quartz latite, and Precambrian basement rocks.

FELSIC FLOW ROCKS

Felsic flow rocks form a significant part of the area of volcanic outcrop and are interlayered with other units of the volcanic sequence. The unit consists principally of massive flows and brecciated flows, but it probably also includes several small sills and irregular intrusive bodies that are indistinguishable from the flows. The felsic flows are light gray, light greenish gray, yellowish gray, brownish gray, and tan, fine grained, and massive. Some are conspicuously flow banded and a few are vesicular. The flow breccias are composed of similar rock, and, where exposures are poor, it is generally impossible to distinguish these rocks from massive flows. The felsic flows and flow breccias are highly irregular in form; they vary in thickness along strike and are continuous only over short distances. In contrast to the mafic flow rocks, the felsic flows tend to be massive, uniform, and devoid of layered structure. The thickness of individual felsic flows and flow breccias is variable and ranges from a few feet to 50 feet or more.

The felsic flow rocks are composed of quartz latite and subordinate porphyritic latite. They are similar in chemical and mineralogical composition to intrusive porphyritic latite, and all contain sanidine, oligoclase or andesine, and augite; some also contain biotite and hornblende. Like the intrusive porphyritic latite, the felsic flows generally contain a variety of inclusions of Precambrian basement rocks.

FELSIC PYROCLASTIC ROCKS

The felsic pyroclastic unit consists of interbedded light-gray, brownish-gray, yellowish-brown, and greenish-gray agglomeratic breccia, tuff-breccia, tuff, and water-laid deposits. The predominant type of deposit is tuff breccia. The blocks and smaller fragments are composed chiefly of quartz latite and latite and minor amounts of trachyte. Accessory fragments of mafic phonolite and inclusions of Precambrian basement rocks are also present in the deposits.

STRUCTURE

The Bearpaw Mountains uplift is one of several isolated mountain uplifts of early Tertiary age in the northern Great Plains region of Montana. It consists of a northern and a southern volcanic field separated by a central strip of deformed sedimentary rocks and intrusive igneous rocks known as the "Bearpaw Mountains structural arch." This arch extends for some 40 miles in an easterly direction, and the northern and southern volcanic fields each cover an area of about 300 square miles along its flanks. The Cleveland quadrangle encompasses the northeastern part of the arch, the easternmost part of the northern volcanic field, and the bordering plains.

BEARPAW MOUNTAINS STRUCTURAL ARCH

The eastern part of the arch is expressed as a composite dome, some 12 miles in diameter. The northern part of this dome lies in the Cleveland quadrangle. The average vertical stratigraphic displacement in the dome, with respect to the plains area, is about 5,000 feet. Several subsidiary domes are contained within the composite dome, as shown in the geologic map (pl. 1). Some of the small domes are nearly symmetrical and as much as 2 miles in diameter. The domes are the result of arching of the sedimentary rocks over and around nearly concordant stocklike and laccolithic bodies of igneous rock. Between domes, the sedimentary rocks have been folded into anticlines and synclines. The principal folds of this type are north and east of Crown Butte, northwest of Iron Butte, and along the southwest boundary of the quadrangle.

In the southeastern part of the quadrangle, near McCann Butte and to the east and southeast of Miles Butte, beds of the Judith River Formation, Claggett Shale, Eagle Sandstone, and Telegraph Creek Member of the Colorado shale have been faulted down against older rocks; they form a series of small grabens. The largest of these grabens is to the east of McCann Butte, where the maximum displacement is about 2,000 feet. Other faults within the arch are of smaller displacement and occur mostly on the flanks of domes.

NORTHERN VOLCANIC FIELD

The small area of volcanic rocks at the western boundary of the quadrangle and the underlying beds of the Wasatch Formation are faulted down against Cretaceous rocks along two high-angle faults. The maximum throw on the northeastward-trending fault, along the south boundary of the volcanic area, is about 4,000 feet. This fault probably extends westward into the Lloyd quadrangle. Within the volcanic field, the rocks are tilted and folded irregularly. Their present attitudes are not initial, because bedded sedimentary volcanic rocks occur in the tilted sections. In accordance with evidence from other parts of the mountains, prevolcanic deformation produced normal faults that were sites of recurrent dislocation during and following volcanism.

PLAINS AREA

In general, the sedimentary rocks of the plains area, to the north of the mountain front, are gently deformed into broad folds. In places they are faulted and have steep attitudes. A broad anticlinal fold occurs in beds of the Judith River Formation in the north-central part of the quadrangle in secs. 28, 29, 32, and 33, T. 31 N., R. 20 E.

At the southwest margin of this structure, the Bearpaw Shale in fault contact with beds of the Judith River Formation is exposed in a graben; to the south of the graben, the Claggett Shale is faulted up against beds of the Judith River Formation. Over most of the northeastern part of the quadrangle, beds of the Judith River Formation are flat lying or dip at angles less than 5°.

The eastern part of a broad, low irregular dome, 7 to 8 miles in diameter and covering an area of about 30 square miles, is in the northwestern part of the quadrangle. This structural feature, known as the Bowes dome, is the site of the Bowes oil and gas field. The center of the dome is near the NW¼ of sec. 2, T. 31 N., R. 19 E.; outward dips on its flanks are generally low and range from 1° to 10°. The expression of the dome at the surface is largely masked by subsidiary folds, by a graben, by high-angle normal faults that have produced steep and erratic dips in the exposed formations at many places, and by surficial deposits.

A syncline extends northeastward through the main area of producing oil wells near the center of the dome. The Bearpaw Shale is preserved along the axis of the syncline, and inward dips along its flanks range from 4° to 40°. At its northern limit the syncline flares out abruptly; its south end is concealed beneath a cover of glacial deposits. The central and northeast margins of the syncline are broken by high-angle normal faults of small displacement that have dislocated beds of the Judith River Formation and the Bearpaw Shale. The largest of these faults is in the southeast corner of sec. 2, T. 31 N., R. 19 E.; it has a throw of about 100 feet.

North of the main syncline, in secs. 26, 27, 34, and 35, T. 32 N., R. 19 E., is a north-trending graben in which the basal part of the Bearpaw Shale is faulted down against beds of the Judith River Formation. The graben extends for a short distance beyond the mapped area to the north; at the south it is concealed by a cover of glacial deposits. At the north and south ends of the graben the contact of the Bearpaw Shale and Judith River Formation is inclined toward the center of the graben, which appears to be bow-shaped and synclinal. The major faults bounding the graben dip inward toward the axis of the structure at an angle of about 70°, and the maximum displacement along these faults is estimated to be about 300 feet. Drag folding along the fault planes is pronounced. The western margin of the graben is a single fault. The eastern margin is a single fault in the Cleveland quadrangle and a complex of small normal faults north of the quadrangle boundary.

To the west of the graben an eastward-trending anticline occurs in the Judith River Formation. This structure is abruptly terminated eastward against the graben and extends westward for a distance of more than a mile into the adjoining Lloyd quadrangle. Outward dips on the flanks of the anticline range from 3° to 12°. Two producing gas wells are located on the eastern part of this anticline in the Cleveland quadrangle.

Several high-angle normal faults that trend northward have dislocated beds of the Judith River Formation and Bearpaw Shale along the south margin of the Bowes dome in secs. 22 and 23, T. 31 N., R. 19 E. The displacement on these faults is small, ranging from about 20 to 100 feet. Because the eastern part of the Bowes dome is mostly covered with glacial deposits, the surface structure is not well known; the beds probably dip gently to the northeast, east, and southeast.

Drilling information indicates that the faults in the Bowes dome are shallow features; only a few extend deep enough to intersect the Sawtooth Formation.

GEOLOGIC HISTORY

Sedimentation in this area in Paleozoic and Mesozoic time was principally marine. A broad regional uplift in Early Jurassic time resulted in a well-marked hiatus between beds of Mississippian and Middle Jurassic age. Transgressive and regressive sedimentation occurred in Late Cretaceous time, and the sea permanently receded from this region near the close of the Cretaceous. In Paleocene and early Eocene time sedimentation was entirely nonmarine and the sedimentary material was derived from the Rocky Mountain region to the west and southwest.

The long interval of sedimentation ceased in middle Eocene time because of uplift and igneous activity. The first major structural feature to form was the Bearpaw Mountains structural arch. During this deformation the arch and its bordering areas were intruded by dikes, sills, plugs, laccoliths, and stocks. The igneous activity culminated in volcanic eruptions that covered the arch and the bordering plains area with lava flows and pyroclastic deposits. Complex doming and folding of the arch occurred during this period of magmatic activity, and the arch was an active structural element throughout middle Eocene time. Collapse faulting began prior to the volcanism and continued after the cessation of volcanism in late Eocene time.

Erosion during the remaining part of the Tertiary period and during the early part of the Quaternary period produced the present topography and established a drainage pattern that was adjusted to the late Tertiary ancestral Missouri River system. Several erosion surfaces were formed around the Bearpaw Mountains at this time.

A continental ice sheet advanced southeastward across the region in late Pleistocene time, abutted against the mountainous terrain in the southern part of the quadrangle, filled the existing stream valleys with till, and covered all the interstream areas below an elevation of about 3,800 feet with till and outwash sediment. After the retreat of the ice sheet, a system of consequent drainage developed on the ground moraine, and locally, as along Snake Creek, parts of the preglacial valleys have been resurrected.

ECONOMIC GEOLOGY

The Bowes oil field lies in the northwest corner of the quadrangle. Oil was discovered in this field in 1949, and by 1959 88 wells were in production. Operations are maintained principally by the Texas Co. and to a lesser extent by the Trigood Oil Co. Production is from the Piper Formation of Middle Jurassic age. An account of the Bowes oil field, which emphasizes, the subsurface stratigraphy, structure, and reservoir characteristics, has been given by Hunt (1956).

Gas is produced from nine wells in the Cleveland quadrangle. Most of these wells are along the western margin of the oil field, and, together with 11 gas wells in the adjoining Lloyd quadrangle and a single well north of the Cleveland quadrangle, they constitute the producing Bowes gas field. The first gas well in this field was drilled in 1924, but the principal development was during the period 1926–35 when nine successful wells were completed and a pipe line was laid to Chinook and Havre. The field has produced gas continuously since that time; it is presently operated by the Montana Power Co. Several of the gas wells in the Cleveland quadrangle are operated by the Texas Co. for local use. The gas occurs in the upper part of the Eagle Sandstone at well depths ranging from 653 to 1,078 feet (Hunt, 1956, p. 190).

Early homesteaders in the area obtained lignite and low-rank coal from the upper part of the Judith River Formation. Their excavations are now largely caved and abandoned. The best grade of coal is in the upper part of the Judith River Formation in the northeastern part of the quadrangle. The principal coal workings are shown on the geologic map (pl. 1).

Sand and gravel of glaciofluvial origin are abundant in many parts of the quadrangle and locally provide material for construction and road surfacing. The best grade of sand observed is in the northwestern part of the quadrangle in sec. 19, T. 31 N., R. 20 E. and in the southwestern part in sec. 36, T. 30 N., R. 19 E. and sec. 31, T. 30 N., R. 20 E. Massive bodies of intrusive rock in the quadrangle are a potential source for riprap and road metal.

Bentonite beds are abundant in the marine shale formations, but they rarely are more than a foot thick. Multiple beds of bentonite occur in a zone at the base of the Claggett Shale and in some parts of the Niobrara Shale Member of the Colorado Shale. Earthen dams of bentonitic shale, constructed to retain surface runoff, generally experience less leakage than those built of other materials. However, clay-rich glacial till of the ground moraine unit has also proved to be a satisfactory material for dam construction.

Several small prospect pits that expose metalliferous deposits have been excavated in the southern part of the quadrangle. Galena, pyrite, and chalcopyrite are the principal ore minerals. The veins, however, are rarely more than an inch wide and occur in discontinuous fracture zones, rather than in persistent fractures. No metals have been produced from this quadrangle.

The best quality of water occurs in the lower part of the Eagle Sandstone. This sand and a 50-foot bed of sandstone at the base of the Judith River Formation are the best aquifers in the region.

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