Geology of the Lloyd 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 mineral resources of the area

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

By Robert George Schmidt, W. T. Pecora, Bruce Bryant, and W. G. Ernst

ABSTRACT

The Lloyd quadrangle has an area of about 200 square miles and includes part of the northeastern Bearpaw Mountains and part of the bordering plains. About 25 percent of the quadrangle is underlain by sedimentary rocks of Middle Jurassic to Recent age, 15 percent by intrusive and extrusive igneous rocks of middle Eocene age, and 60 percent by surficial deposits of late Pliocene(?), Pleistocene, and Recent ages.

The sedimentary rocks are subdivided into 19 formations, which have a total stratigraphic thickness in the Bearpaw Mountains region of about 8,000 feet. However, in the Lloyd quadrangle the exposed sedimentary section is about 5,000 feet thick. The surficial deposits include pediment and terrace gravels of Pliocene(?) and Pleistocene ages, glacial deposits of late Pleistocene age, and alluvium of Recent age. The aggregate thickness of these deposits is about 150 feet.

The igneous rocks of the Lloyd quadrangle range in composition from subsilicic-alkalic to silicic-alkalic and represent the shonkinite-syenite and monzonite families. The intrusive varieties occur as stocks, plugs, dikes, and sills. The extrusive varieties are part of a volcanic pile that consists predominantly of interlayered flows of mafic and felsic lava and beds of mafic and felsic pyroclastic rocks. Analcime trachyte flows and breccias are interlayered with the mafic and felsic flows in the youngest part of the volcanic pile. As mapped, the flow rock units include some irregular pluglike bodies of intrusive rock that are indistinguishable from and merge with the flows. The estimated maximum stratigraphic thickness of the layered volcanic sequence is about 15,000 feet. Within the area mafic lava flows exceed felsic lava flows in areal distribution by a ratio of about 3 to 2. However, porphyritic latite, the intrusive equivalent of the felsic flow rocks, is more abundant than the shonkinitic rocks, the intrusive equivalent of the mafic flow rocks.

The principal structural feature of the area is the Bearpaw Mountains structural arch, an eastward-trending belt of uplifted and deformed sedimentary rocks that has been extensively intruded by a great variety of igneous rocks. The arch is bounded by a northern and southern volcanic field, each of which covers an area of about 300 square miles. Part of the northern limb of the Bearpaw Mountains structural arch and the eastern part of the northern volcanic field lie in this quadrangle. Although there are many exceptions, the

layered units in the northern volcanic field have a general eastward strike and dip south toward the arch at angles of 10° to 50°. In the Lloyd quadrangle the northern volcanic field is essentially a monoclinal structure dipping southward about 30° toward the arch. However, in the western part of the quadrangle the volcanic rocks are faulted down against older sedimentary rocks, and the general strike of the volcanic rocks in this area is erratic.

The plains area north of the volcanic field is characterized by a series of fault blocks in which Tertiary and younger Cretaceous rocks have been faulted down against older Cretaceous rocks. Part of a broad structural dome—the Bowes dome—lies within the plains area in the extreme northeastern corner of the quadrangle. This dome is the site of the Bowes oil and gas field.

Deformation and volcanism occurred in this region in the Eocene epoch. Faulted rocks in and adjacent to the volcanic fields demonstrate that deformation occurred before, during, and after volcanism. The boundary between the northern volcanic field and the Bearpaw Mountains arch is a major unconformity. However, it cannot be determined in this quadrangle if disruption of initial layering in the volcanic field is more likely the result of successive collapse and tilting along high-angle normal faults or of landsliding toward the plains, as suggested by Reeves.

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

INTRODUCTION AND ACKNOWLEDGMENTS

The Lloyd quadrangle is one of eight 15-minute quadrangles (fig. 13) that encompass the Bearpaw Mountains uplift. The geologic map (pl. 6) is the sixth quadrangle map of the group to be published and the second to be issued on a topographic base. A map of the Maddux quadrangle, also compiled on a topographic base, has been published as Bulletin 1081–C of the U.S. Geological Survey (Bryant and others, 1960). The four western quadrangles, the Laredo, Centennial Mountain, Shambo, and Warrick quadrangles, 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 and others), I–236 (Kerr and others), and I–237 (Pecora and others). Geologic maps of the Cleveland and Rattlesnake quadrangles were in preparation at the time of publication of this report.

The Lloyd quadrangle was mapped in the summer seasons of 1954, 1956, and 1957. Schmidt contributed to the map in 1956 and 1957, Bryant in 1954 and 1956, and Ernst in 1956. R. D. Bentley, W. B. Bryan, Jr., R. L. Borst, J. E. Cotton, E. J. Olsen, and D. J. Milton each participated part of one season. W. T. Pecora supervised the separate mapping parties. Except for 30 square miles in the southern part of the quadrangle, mapped on aerial photographs in 1954, the geology was plotted on topographic field sheets at a scale of 1:15,840.

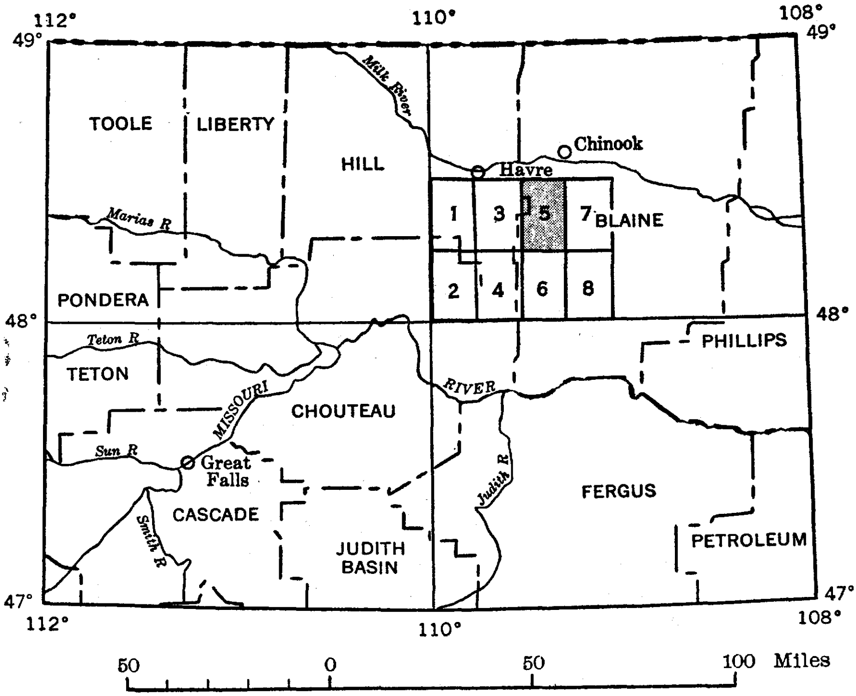

FIGURE 13.—Index map of north-central Montana showing location of Lloyd and adjoining quadrangles. 1, Laredo quadrangle, I–234; 2, Centennial Mountain quadrangle, I–235; 3, Shambo quadrangle, I–236; 4, Warrick quadrangle, I–237; 5, Lloyd quadrangle (shaded), this report; 6, Maddux quadrangle, Bulletin 1081–C; 7, Cleveland quadrangle, in preparation; 8, Rattlesnake quadrangle, in preparation.

Generous cooperation was extended members of the field staff by residents of the area, who provided lodging accommodations and many other courtesies, including access to their properties and information concerning accessibility. The authors are particularly indebted to the members of the board of School District No. 67, Blaine County, for permission to use the Peoples Creek schoolhouse as an office and living quarters during the mapping 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. The authors also had access to an unpublished map of the northeastern Bearpaw Mountains, prepared by Bernard Fisher.[1] Fisher's rock specimens and thin sections were also made available for reference. Published reports dealing with the geology of the Bearpaw Mountains region are included in the references listed at the end of this report.

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

GEOGRAPHY

The Lloyd quadrangle has an area of about 200 square miles and includes part of the northeastern Bearpaw Mountains and part of the bordering plains. The principal livelihood of the inhabitants is cattle and sheep ranching and wheat farming. The resident population is less than 100. Chinook, the nearest town, is located 7½ miles to the north of the quadrangle area (fig. 13).

The highest point in the quadrangle, 5,600 feet above sea level, is in the southwestern part. Maximum topographic relief is about 2,900 feet. The southern part of the quadrangle is mountainous but generally less rugged than other parts of the Bearpaw Mountains to the west. The plains area in the northern part of the quadrangle is characterized by a bench-and-tableland topography whose relief has been greatly subdued by a mantle of glacial deposits. Streams in the quadrangle flow to the north and empty into the Milk River; Clear Creek, Bean Creek, and Snake Creek are the only perennial streams. The climate is semiarid and the annual precipitation normally is between 10 and 15 inches. Trees are sparse and most of the country is grassland.

GEOLOGIC HISTORY

Regional sedimentation in north-central Montana in Paleozoic and Mesozoic times was principally marine in character, but in Cenozoic time it was entirely nonmarine. A broad regional uplift, probably in Early Jurassic time, resulted in a well-marked unconformity between the Mississippian and Middle Jurassic rocks. Transgressive and regressive sedimentation occurred in Cretaceous time and the sea permanently receded from this part of the Great Plains region by Paleocene time. Regional sedimentation ceased in early Eocene time with the deposition of beds of channel boulders, composed of material derived from the Rocky Mountain region to the west and southwest.

The long interval of sedimentation was followed by uplift and by the irruption of magma in middle and late Eocene time. The first major structural feature to form was the Bearpaw Mountains structural arch, and its uplift was accompanied by magmatic activity. The arch and its bordering areas were intruded by dikes, sills, plugs, and stocks, culminating in volcanic eruptions which covered the arch and the bordering plains area with lava flows and pyroclastic rocks. The complex doming and folding of the arch occurred during this period of magmatic activity, and apparently the arch was an active structural element throughout middle Eocene time. Collapse faulting in the sedimentary floor beneath and along the margin of the volcanic fields, and in the adjacent plains area, began sometime before the period of volcanism and continued into late Eocene time, after volcanism had ceased. The general monoclinal dip of the volcanic rocks toward the arch was probably established during the period of collapse faulting in late Eocene time.

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

A continental ice sheet advanced southeastward across the northern half of the quadrangle in late Pleistocene time, abutted against the high terrain of the northern volcanic field, filled the existing stream valleys with till, and covered with drift and outwash sediment all the interstream areas below an elevation of about 4,200 feet. After retreat of the ice sheet, a system of consequent drainage developed on the ground moraine, and locally, as along Clear Creek, parts of the preglacial valleys have been resurrected.

SEDIMENTARY ROCKS

GENERAL FEATURES

The stratigraphic section resting on Precambrian basement rocks in the Bearpaw Mountains region has a thickness of about 10,000 feet, distributed as follows:

Age of formations	*Thickness (feet)*
Tertiary	2, 150
Cretaceous	5, 400
Jurassic	450
Unconformity.	
Paleozoic	2, 000 (?)
Total	10, 000

In the Lloyd quadrangle about 50 square miles, or 25 percent of the quadrangle area, is underlain by sedimentary rocks of Jurassic, Cretaceous, and Tertiary age. Locally, in the southern part of the quadrangle, adjacent to igneous intrusions, rocks of Jurassic and Cretaceous age have undergone thermal metamorphism, which has converted sandstones to quartzite, shales to hornfels, and impure limestones to marble and calc-silicate rock. Rocks of Tertiary age are exposed at only a few places in the northern part of the quadrangle where they lie within fault blocks adjacent to rocks of Late Cretaceous age.

A brief description of the exposed rock units is given in the explanation of the geologic map (pl. 6); a summary of their ages and approximate maximum thicknesses in this region is given below:

Age and stratigraphic unit	*Maximum thickness (feet)*
Tertiary:	
Eocene:	
Wasatch formation equivalent	650
Paleocene:	
Fort Union formation	1,500
Cretaceous:	
Late Cretaceous:	
Hell Creek formation	425
Fox Hills sandstone	60
Montana group:	
Bearpaw shale	1,200
Judith River formation	650
Claggett shale	500
Eagle sandstone	275
Colorado shale:	
Telegraph Creek formation equivalent	300
Niobrara and Carlile shale equivalents	850
Greenhorn limestone equivalent	40
Belle Fourche shale equivalent	200
Early Cretaceous:	
Colorado shale:	
Mowry shale equivalent	100
Newcastle sandstone and Skull Creek shale equivalents	250
Fall River sandstone equivalent	275
Kootenai formation	275
Jurassic:	
Late Jurassic:	
Ellis group:	
Swift formation	160
Rierdon formation	200
Middle Jurassic:	
Ellis group:	
Sawtooth formation	100

Stratigraphic descriptions of these formations are found in reports by Pepperberg (1909, 1912), Stebinger (1914, 1916), Bowen (1914), Reeves (1924a), Pierce and Hunt (1937), Cobban (1945, 1951), Brown and Pecora (1949), and Hunt (1956).

JURASSIC SYSTEM

In mapping the rocks of Jurassic age in the Bearpaw Mountains, the U.S. Geological Survey has followed the nomenclature of Cobban (1945) in naming the three formations of the Ellis group. From oldest to youngest, these are the Sawtooth, Rierdon, and Swift formations. These formations are exposed in the southern part of the Lloyd quadrangle, along the southeastern margin of Barber Butte, but the rocks there are altered by thermal metamorphism. The Sawtooth formation (Middle Jurassic) is probably equivalent to upper part of the Piper formation of Imlay and others (1948). The name

"Piper formation" is preferred by petroleum geologists in recent publications on this region (Hunt, 1956).

About 60 feet of the Sawtooth (Piper) formation is exposed at Barber Butte. The lower part, which elsewhere consists of a gray to white, massive to porous petroliferous limestone, is here metamorphosed to a dense rock. The upper part contains thin beds of fine-grained brownish-yellow sandstone alternating with thin laminae of medium-gray limestone. Wavy bedding and crossbedding are characteristic of this upper sequence. The Sawtooth (Piper) formation is exposed at several other localities in the Bearpaw Mountains and is the producing formation in the Bowes oil field. It also has yielded a substantial amount of oil in the Williston basin, some 200 miles east of the Bearpaw Mountains. Recent stratigraphic correlations and descriptions of the Sawtooth (Piper) are given by Hunt (1956), McKee and others (1956), Francis (1956), Rayl (1956), Nordquist (1955), and Hadley and Milner (1953).

The Rierdon formation (Late Jurassic) overlies the Sawtooth formation with apparent conformity and is about 200 feet thick. At Barber Butte the lower part is principally light-gray, brownish-gray, and bluish-gray dense calcareous shale. The upper part is characterized by about 10 feet of thin-bedded brownish-gray argillaceous limestone. The Swift formation (Late Jurassic) overlies the Rierdon formation conformably, is about 160 feet thick, and consists predominantly of brown to brownish-gray thin-bedded sandstone and dark-gray to greenish-gray shale and siltstone, containing thin conglomerate beds composed of fossil fragments, principally of belemnites.

The Morrison formation (Late Jurassic) has not been identified with any degree of certainty in the Bearpaw Mountains. A sequence of 25 to 50 feet of olive-drab to brownish-gray mudstone, claystone, siltstone, and carbonaceous shale that forms a transition between the Swift formation and the overlying Kootenai formation may possibly be equivalent to Morrison beds elsewhere in Montana.

CRETACEOUS SYSTEM

The Cretaceous system includes the Kootenai formation, Colorado shale, Montana group, Fox Hills sandstone, and Hell Creek formation, in ascending order. Elsewhere in Montana the boundary between the Lower and Upper Cretaceous is drawn at the top of the Mowry shale, and this division has been followed in the explanation on the geologic map (pl. 6). A special effort has been made in the Bearpaw Mountains to subdivide the Colorado shale into several formations in order to define the structure of the mountains in detail. These formations are correlated with equivalent units of the Black Hills region of South Dakota and Wyoming according to the usage of Rubey (1930) and Cobban (1951). The Colorado shale of north-central Montana, however, includes a unit (Telegraph Creek formation equivalent) that is stratigraphically higher than the uppermost unit in the Black Hills section. Characteristic stratigraphic features of the Cretaceous section in the Bearpaw Mountains that have served as guides in the recognition of formations are summarized below.

The base of the Kootenai formation is placed at the first appearance, above the Swift sequence, of conspicuous gray to white quartz-chert sandstone. Within the Colorado shale, the thin-bedded Mowry shale equivalent is easily recognized by a characteristic bluish-white weathering and by abundant fish-scale markings. The conspicuous bentonite zone known as the Clay Spur bentonite bed, which occurs in the uppermost part of the Mowry shale in other regions (Rubey, 1930, p. 4; Knechtel and Patterson, 1956, p. 10), is present in the Bearpaw Mountains but not in the Lloyd quadrangle. The Greenhorn limestone equivalent is the most readily identifiable unit in the Colorado shale and has proved to be the most valuable marker bed for determining structural relationships in areas where the rocks are highly deformed or metamorphosed.

Bentonite beds and marine calcareous concretions, the latter commonly septarian and containing fossil invertebrates, are abundant in the upper part of the Colorado shale and in the Claggett and Bearpaw shales of the Montana group. Lignite and carbonaceous-shale beds are most abundant in the Judith River formation, particularly at the top of the formation, where they are overlain locally by beds rich in oyster shells. Lignite in thin beds also occurs in the upper part of the Eagle sandstone and in the lower part of the Hell Creek formation. Beds of carbonaceous bentonitic clay in the upper parts of the Eagle sandstone and Judith River formation are light gray to dark gray, but those in the lower part of the Hell Creek formation are conspicuously dark gray to black.

Grains of chert are most abundant in the quartz sandstone of the Kootenai formation. Sandstone beds rich in black chert pebbles occur abundantly in the Fall River sandstone equivalent near the base of the Colorado shale, are rare in a gritty to muddy sandstone member in the lower part of the Belle Fourche shale equivalent, and are common at the top of the Eagle sandstone of the Montana group. The purest quartz sandstone of the Cretaceous section is the Virgelle sandstone member (not separately mapped) at the base of the Eagle sandstone. Large calcareous-sandstone concretions occur in the Eagle sandstone, Judith River formation, and Fox Hills sandstone. Limy concretionary nubbles characterize slopes underlain by the upper part of the Hell Creek formation. Sandstone in the lower part of the Hell Creek formation locally contains abundant muscovite. Sandstones of Tertiary age characteristically contain pink to rose quartzite grains not observed in rocks of earlier age.

The identification of formations for mapping purposes was done largely on a lithologic basis, although fossils, where diagnostic, have proved most helpful in areas of poor exposure. Transition zones between sandstone formations and overlying marine shale formations are commonly 25 feet or less in thickness, but transition zones between marine shale formations and overlying sandstone formations are much thicker. It is everywhere difficult to recognize the contact between the Niobrara shale equivalent and the Telegraph Creek formation equivalent, and the contact is placed arbitrarily at the base of the first appearance upward of massive sandstone beds. The contact between the Fox Hills sandstone and the overlying Hell Creek formation is placed at the first appearance upward of carbonaceous shale. Conglomerate observed elsewhere (Jensen, 1951) at the base of the Hell Creek formation is not found in this quadrangle.

The sandy beds forming a transition zone between the Bearpaw shale and the overlying Fox Hills sandstone are well exposed in the northwestern part of the Lloyd quadrangle along Little Box Elder Creek and are about 170 feet thick. This is the maximum thickness of the zone in the Bearpaw Mountains region. Normally the zone is between 25 and 50 feet thick. The section along Little Box Elder Creek is given below.

Section of Fox Hills sandstone and the transition zone at the top of the Bearpaw shale along Little Box Elder Creek in sec. 1, T. 31 N., R. 17 E., Lloyd quadrangle

[Measured by Robert D. Bentley and R. G. Schmidt with tape and compass, September 15, 1956]

	Feet
Hell Creek formation, basal bed:	
Shale, reddish-brown to black, thinly bedded, carbonaceous and lignitic	1.5
Fox Hills sandstone:	
Sandstone, gray, fine-grained, thick-bedded, noncohesive	5
Sandstone, light-gray, fine-grained, thick-bedded, noncohesive; weathers golden yellow and yellowish orange; large brown disclike sandstone concretions as much as 4 ft in diameter, common	42
Sandstone, yellowish-brown to buff, fine-grained, thinly bedded; alternates with thin partings of light-gray shale and thin beds of golden-yellow sandstone; at base is 2½ ft of light-gray, thinly bedded sandstone containing disclike sandstone concretions as much as 4 ft in diameter	11
Total thickness, Fox Hills sandstone	58
Bearpaw shale transition zone:	
Shale, light-gray; thin beds alternating with 1- to 3-in beds of tan to golden-yellow sandstone	11
Sandstone, brownish-gray, fine-grained, thick-bedded	2
Shale, grayish-buff, moderately sandy; alternates with several 1- to 6-in beds of brown sandstone	18
Shale, dark-gray, fissile	2

Bearpaw shale transition zone—Continued	*Feet*
Shale, grayish-buff to brownish-gray, moderately to highly sandy; alternates with 1- to 6-in beds of golden-yellow, brown, and light-brown sandstone; small dark-brown limestone concretions near middle	104
Sandstone, light brownish-gray to buff, fine-grained, thinly bedded, and papery; alternates with 1- to 3-in beds of light-gray and light brownish-gray sandy shale; flat, disclike yellowish-brown and golden-yellow sandstone concretions abundant at base and near top	9
Siltstone and shale, light-brown and dark brownish-gray; alternates with 1- to 3-in beds of compact brown sandstone; flat, disclike yellowish-brown sandy limestone concretions, 6 in to 1 ft in diameter, common	22
Total thickness, Bearpaw shale transition zone	168

Bearpaw shale, upper part: Shale, weathers brown to reddish-brown; dark-gray to black fissile shale with brown, iron-stained limestone concretions.

TERTIARY SYSTEM

In the Bearpaw Mountains region the Tertiary system is represented by the Fort Union formation of Paleocene age and the Wasatch formation of early Eocene age. These formations are incompletely exposed in several small outcrops in the northwestern and northeastern parts of the Lloyd quadrangle. The location, outcrop area, and general lithology of these occurrences are tabulated below.

Formation	Locality			Outcrop area (acres)	Lithology
	Section	Town-ship (North)	Range (East)		
Fort Union	13, 14	31	17	160	Light-green, yellowish-green and gray claystone and siltstone; carbonaceous shale; massive concretionary sandstone.
Do	28, 29, 30	31	19	50	Light yellowish-brown sandstone, buff claystone, and dark purplish-gray bentonitic clay; claystone contains fossil plants of Paleocene age.
Wasatch	7	30	18	.1	Gray to dark-gray and pinkish mudstone; conglomerate with fractured pebbles of quartzite and volcanic rock.
Do	29	31	19	.1	Yellowish-green and gray claystone; purplish-gray sandstone.

Elsewhere in the Bearpaw Mountains, particularly in the Rattlesnake, Maddux, Warrick, and Centennial Mountain quadrangles, the Tertiary formations crop out over much larger areas, and at several localities complete sections of these formations are exposed. As observed, the boundary between the Cretaceous and Tertiary systems is marked by a transition from marly beds of the Hell Creek formation to a basal thick-bedded sandstone of the Fort Union formation which contains many thin beds of carbonaceous shale. Where exposure permits, this boundary may be located within 10 feet.

The Fort Union formation is characterized by several massive, thick-bedded sandstone units in which there are thin beds and lenses of clay-gall conglomerate. The Wasatch formation is generally characterized by variegated beds of siltstone, mudstone, and sandstone; carbonaceous shale is rare in the basal part. Channel-conglomerate lenses are abundant in the upper part of the Wasatch formation and the stones are fractured, crushed, and recemented. A discussion of the composition, fracturing, and source area of these stones has been given in reports by Pecora (1949) and Bryant and others (1960). The two formations are separated on the basis of first appearance of the variegated siltstone beds that occur at the base of the Wasatch formation.

The sandstones of the Tertiary formations have one lithologic feature that readily distinguishes them from sandstones of older formations. In the Bearpaw Mountains, pink and rose grains in the matrix of the Tertiary sandstones are readily observable by hand lens. Such grains are sparse in the lowest beds of the Fort Union formation, are more abundant upward in the stratigraphic section, and are conspicuous in the younger beds of the Wasatch formation. They are not found in the sandstones of Mesozoic age in the Bearpaw Mountains region. Most probably they are grains of colored quartzite derived from the Belt series in the Rocky Mountain region to the west.

The identification of the Fort Union and Wasatch formations in the Bearpaw Mountains (Bowen, 1914; Brown and Pecora, 1949) indicates that early Tertiary sedimentation in this region was much more extensive than had been recognized earlier. Other exposures of the Fort Union formation are more than 90 miles distant to the southeast and the nearest Wasatch beds are more than 250 miles away to the southeast along the Montana-Wyoming border.

SURFICIAL DEPOSITS

Gravel of local origin lies on at least four separate erosion surfaces that stand above the present streams. The highest of these surfaces marks a pediment that is probably coextensive with the Flaxville plain of Collier and Thom (1918) and the No. 1 Bench of Alden (1932, p. 14–20). If this premise is correct, the pediment gravels are then of late Tertiary age. Remnants of this pediment occur in the mountainous terrane in the southern part of the quadrangle, notably around Barber Butte, but the most extensive remnant is the prominent bench in the central part of the quadrangle known as Tiger Ridge. The northern portion of Tiger Ridge is overlain by glacial deposits, and here the pediment gravels crop out only along the western and northern margins of the escarpment beneath a cover of till. Along Wind Creek, Clear Creek, and Snake Creek, gravels are locally preserved on at least three lower terraces at elevations of roughly 100, 50, and 20 feet above the present flood plains. These three terraces were formed in pre-Wisconsin time, for gravel on the lowest terrace along Clear Creek is overlain by glacial drift.

Deposits of glacial origin cover more than 50 percent of the northern part of the quadrangle. They were deposited in late Pleistocene time by a continental ice sheet that advanced southeastward across the northern half of the quadrangle and abutted against the high terrain of the northern volcanic field. The ice sheet filled the existing stream valleys with till, covered all the pediment and terrace surfaces and interstream areas below an elevation of about 4,200 feet with drift and outwash sediment, and advanced well into the mountains along the valleys of Clear Creek on the west and Snake Creek on the east. The glacial deposits have been subdivided into two units: ground moraine, consisting predominantly of yellowish-gray to light-gray, clay-rich to sandy or pebbly till; and glaciofluvial deposits, consisting of gravel, sand, silt, and clay, and representing outwash sediment deposited along the margins of the wasting ice sheet. The glaciofluvial deposits are locally varved and thinly laminated and grade laterally and vertically into ground moraine.

The western margin of a prominent boulder train occurs in the east-central part of the quadrangle in secs. 15, 21, and 22, T. 30 N., R. 19 E. and is shown on the geologic map (pl. 6). The train is formed of large angular blocks of nepheline shonkinite derived from the prominent sill along Bean Creek about 5 miles to the north.

Alluvium of local origin is distributed along most of the watercourses, but is mapped only along the lower portions of the major streams or within closed depressions. In the northeastern corner of the quadrangle, alluvium in several of the valleys draining northward off the Bowes dome has been deeply incised and stands as much as 20 feet above the bottom of the stream channels. The jaws of a modern horse were covered from this alluvium 5 feet below the surface and attest to the Recent age of the deposits. The cutting is presumably the result of a recent change in base level at some point north of the quadrangle boundary.

IGNEOUS ROCKS

GENERAL FEATURES

More than half of the Lloyd quadrangle is underlain by intrusive and extrusive rocks, but because the northern part of the quadrangle is mostly covered by surficial deposits they are exposed over an area of only about 30 square miles. The intrusive rocks form stocks, dikes, plugs, and sills and are mostly confined to the southern part of the quadrangle, which encompasses part of the Bearpaw Mountains structural arch. The extrusive rocks consist of mafic and felsic lava flows and pyroclastic rocks, although, as mapped, they also include some irregular pluglike and sill-like bodies of intrusive rocks that are indistinguishable from and merge with the flows. The extrusive rocks extend across the central part of the quadrangle and form the eastern part of the northern volcanic field of the Bearpaw Mountains. On the basis of plant fossils that occur at several horizons within the volcanic fields in other parts of the Bearpaw Mountains, the igneous rocks have been dated as middle and late Eocene in age.

Within the Lloyd quadrangle, mafic flow rocks exceed felsic flow rocks in areal extent by a ratio of about 3 to 2. Both types were erupted concurrently during the period of magmatic activity and are represented throughout the sequence of volcanic rocks. Among the intrusive rocks, felsic varieties exceed mafic varieties in areal extent.

The igneous rocks range in composition from subsilicic-alkalic to silicic-alkalic. The subsilicic-alkalic varieties are mostly mafic and the silicic-alkalic varieties are mostly felsic. Nomenclature of these rocks follows that established in earlier reports on the Bearpaw Mountains and is based on the kind and amount of light- and dark-colored minerals in the rocks. The rocks belong to two major families; shonkinite-syenite and monzonite. Intrusive varieties of the shonkinite-syenite family include shonkinite, nepheline shonkinite, syenite, and porphyritic potassic syenite; extrusive varieties are mafic phonolite, mafic analcime phonolite, trachyte, and analcime trachyte. The shonkinites (mafic phonolites) have a color index greater than 40; the syenites (trachytes) less. Intrusive and extrusive varieties of the monzonite family are felsic, porphyritic, and fine-grained and include porphyritic latite and porphyritic quartz latite. Rocks of the shonkinite-syenite family have one essential feldspar (sanidine) and rocks of the monzonite family have two (plagioclase and sanidine).

About 60 rocks specimens, representing the varieties that occur in the quadrangle, were studied in thin section. Their color indices range from about 10 to 65. Among the light minerals, potassic feldspar is present in all the specimens; others are plagioclase, quartz, nepheline, pseudoleucite, and primary(?) analcime. Leucite has not been identified in any of the specimens, although it occurs in rocks elsewhere in the mountains. Among the dark minerals, augite is present in all specimens; others are biotite, olivine, aegirite, and hornblende. Accessory minerals are magnetite, apatite, sphene, melanite, and zircon. Alteration minerals include a ferromagnesian group (serpentine, chlorite, iddingsite) derived from the dark minerals; zeolites (principally natrolite and analcime), calcite, and sericite.

Chemical analyses, norms, and modes of 5 igneous rocks from the Lloyd quadrangle are given in table 1. The data are taken from Fisher. (See footnote 1.) The rocks on which Fisher based his study were loaned to the U.S. Geological Survey for reference. Comparable analyses of rocks from other parts of the Bearpaw Mountains are included in earlier reports on the Laredo, Centennial Mountain, Shambo, and Warrick quadrangles.

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

[Data from Bernard Fisher, 1946, Igneous rocks of the northeastern Bearpaw Mountains, Mont.: Doctoral dissertation, Harvard University, 127 p. Modes of the rocks in columns 2 and 3 have been recalculated by the present authors. All analyses by F. A. Gonyer. P, mineral is present; A, absent.]

	1	2	3	4	5
Analyses					
SiO_2	50.34	50.38	58.22	59.80	67.32
TiO_2	.76	.58	.72	.47	.24
Al_2O_3	10.32	10.20	15.40	15.63	14.72
Fe_2O_3	3.04	1.90	3.26	3.10	.96
FeO	5.90	6.28	3.36	1.50	.86
MnO	.09	.09	.09	.08	.09
MgO	12.58	14.78	3.30	3.28	1.11
CaO	7.40	7.28	4.82	4.76	1.86
Na_2O	2.16	2.20	3.92	3.76	4.70
K_2O	4.47	4.57	5.26	4.92	3.26
H_2O-					
H_2O+	1.85	.93	.28	1.72	4.16
CO_2	.07			.29	
P_2O_5	.78	.61	.72	.16	.08
SO_3			.04		.03
BaO			.33	.32	.36
Total	99.76	99.80	99.72	99.79	99.75
Norms					
Q			3.18	7.20	21.54
or	26.69	27.24	31.14	28.91	19.46
ab	16.24	9.43	33.01	31.96	39.82
an	5.56	4.45	8.90	11.12	9.17
ne	.57	4.83			
nc	.21				
di	20.29	22.33	8.64	7.99	
hy			6.42	4.50	3.20
ol	20.60	25.32			
mt	4.41	2.78	4.87	3.48	1.39
il	1.52	1.22	1.37	.91	.46
hm					
ap	2.02	1.34	1.68	.34	.34
Modes					
Quartz			3	Trace	Trace
Sanidine	P	36		4	4
Microperthite			63		
Plagioclase	A		9	19	10
Nepheline	A	8			
Thompsonite	A	3			
Analcime	P				
Augite	19	29	P	11	P
Aegerine-augite	A	A	15	A	A
Augite and hypersthene	A	A	A	A	1
Olivine	15	18		2	
Biotite	2	5	7	Trace	Trace
Magnetite	P	1	3	P	P
Apatite	Trace	Trace	Trace	(?)	(?)
Groundmass	64			66	85

NOTE: Source of samples:

1. Mafic analcime phonolite; flow or plug, west flank of Sayer Butte, northeast-central part of quadrangle, sec. 5, T. 30 N., R. 19 E. Specimen EB-1.
2. Olivine-augite-nepheline shonkinite; sill along Bean Creek, northeast-central part of quadrangle, sec. 27, T. 31 N., R. 19 E. Specimen EB-26.
3. Augite-biotite syenite; stock west of Barber Butte, southwest part of quadrangle, sec. 18, T. 29 N., R. 18 E. Specimen EB-211.
4. Augite-biotite latite; flow, about 100 yards east of Clear Creek, southwest part of quadrangle, sec. 26, T. 30 N., R. 17 E. Specimen EB-314.
5. Quartz latite vitrophyre; base of flow, about 450 yards east of Clear Creek, southwest part of quadrangle, sec. 26, T. 30 N., R. 17 E. Specimen EB-254.

INTRUSIVE ROCKS

Intrusive igneous rocks underlie about 10 square miles of the Lloyd quadrangle, principally in its southern part. However, large areas of rock in the volcanic field are believed to be of intrusive origin, but because these rocks cannot be classed as intrusive by reason of their texture and contact relationships they are included within the flow-rock units. Most of these rocks are of felsic composition. For purposes of mapping, the intrusive rocks are subdivided into four principal units: shonkinite, syenite, porphyritic latite, and porphyritic potassic syenite.

SHONKINITIC ROCKS

Shonkinitic rocks underlie about 2½ square miles of the Lloyd quadrangle and occur in small stocks, dikes, plugs, and sills. In texture these rocks range from very fine grained to coarse grained; as mapped, they include mafic syenitic varieties. The essential minerals are sanidine, analcime, pseudoleucite, nepheline, augite, biotite, and olivine. The common accessory minerals are magnetite, apatite, and sphene. Minor amounts of plagioclase (andesine) and quartz occur in some of the feldspathoid-free shonkinite. The dark minerals commonly make up about 50 percent by volume of this group of rocks, but the extreme range is from about 35 to 65 percent. In general, the shonkinitic rocks of stocks and sills in the Bearpaw Mountains are coarse grained, whereas that of dikes and plugs in the volcanic field is fine grained.

The large body of shonkinitic rock in the southwestern corner of the quadrangle is part of a composite stock composed of several varieties of shonkinite, syenite, and porphyritic latite. The oldest variety is a coarse-grained, biotite-rich potassic shonkinite that is cut by many bodies of nepheline shonkinite (and related syenite) that contains less than 10 percent of plagioclase (andesine). Dikelike bodies of porphyritic latite and quartz latite are abundant and cut the other rocks.

The prominent exposures of shonkinite along Bean Creek at the east-central margin of the quadrangle (secs. 27 and 28, T. 31 N., R. 19 E.) are part of a thick sill that probably intrudes sandstone of the Judith River formation. The rock is gray to dark gray and medium grained. The essential minerals are augite, olivine, biotite, sanidine, and nepheline. The nepheline is partly altered to an intergrowth resembling pseudoleucite. Accessory minerals are apatite, magnetite, and thomsonite. An analysis, norm, and mode of a typical rock specimen (EB–26) from this sill are given in table 1, column 2.

Most of the smaller bodies mapped as shonkinite in the southern part of the quadrangle are shonkinite, but some are mafic augite-biotite syenite; they are devoid of feldspathoids and olivine. These rocks generally have a porphyritic and trachytic texture, and their essential minerals are potassic feldspar (sanidine or microperthite), augite, and biotite. Accessory minerals are magnetite, apatite, and, rarely, small amounts of plagioclase and quartz. Their color index ranges from about 35 to 60 percent. Some contain small inclusions of biotite pyroxenite derived from the basement complex.

As a group, the shonkinitic rocks vary considerably in their content of dark and light minerals; all contain potassic feldspar, many contain a substantial proportion of feldspathoids, and some contain a minor amount of plagioclase and, rarely, quartz. Within the larger composite bodies of shonkinite, where differentiation has resulted in mafic and felsic syenite, the essential light-colored minerals in the rocks are the same as in the genetically related shonkinite. Quartz is present in shonkinite containing foreign inclusions, but nepheline is not.

SYENITE

The rocks mapped as syenite have an areal extent of about 1¼ square miles and occur in 4 small stocks in the southern part of the quadrangle. They are distinguished from shonkinite by their distinctly lighter color and from porphyritic latite by an absence of plagioclase phenocrysts.

The largest stock of syenite is exposed at Barber Butte in secs. 8 and 17, T. 29 N., R. 18 E. This stock has a narrow margin of dark-gray, fine-grained mafic augite-biotite syenite grading into a large central body of light-gray, coarse-grained plagioclase syenite. The essential minerals of the syenite are microperthite, in large euhedral crystals; oligoclase; augite, with rims of aegirine-augite, and biotite. Accessory minerals are quartz, magnetite, and apatite. The microperthite crystals are elongate and tabular and form a meshed fabric enclosing the other mineral grains. The mode of the rock (specimen EB–303) as determined by point count is as follows:

	Volume (percent)		*Volume (percent)*
Microperthite	70	Quartz	3
Plagioclase (oligoclase)	12	Magnetite	2
Augite and aegirine-augite	8	Apatite	Trace
Biotite	5		
			100

West of Barber Butte is a small stock composed of light-gray, medium-grained syenite similar to the syenite of Barber Butte but containing a larger proportion of augite. Oligoclase forms the cores of many of the larger microperthite crystals. An analysis, norm, and mode of this rock (specimen EB–211) are given in table 1, column 3.

A syenite of slightly different composition occurs in the small stock in secs. 17 and 18, T. 29 N., R. 19 E., in the southeastern part of the quadrangle. This rock is light greenish gray, of seriate-porphyritic texture, and contains abundant small inclusions of biotite pyroxenite. Its minerals are augite, biotite, microperthite, oligoclase, and minor quartz. The oligoclase forms the cores of many of the larger microperthite crystals.

The syenites are chemically equivalent to augite trachyte of the felsic flow-rock unit.

PORPHYRITIC LATITE

The rocks mapped as porphyritic latite are the most widespread of all the intrusive rocks in the Lloyd quadrangle and have an areal extent of about 5 square miles. They form small stocks, dikes, plugs, and sills intruding both sedimentary and volcanic rocks; because of their resistant nature these rocks form conspicuous topographic features. The name "porphyritic latite" is used in preference to the name "monzonite", because the rocks are universally porphyritic and have a very fine grained groundmass. In texture and composition varieties of intrusive porphyritic latite are identical to varieties of felsic extrusive rocks.

The porphyritic latites are light to dark gray, greenish or brownish gray, or light brown to tan. Essential minerals are potassic feldspar, plagioclase (oligoclase to andesine), quartz, augite, and biotite. Aegirine-augite forms rims around augite in some rocks, and hornblende is a common constituent in others. The principal accessory minerals are magnetite and apatite. The color index of the group ranges from about 10 to 35 percent; and in most varieties it averages about 20 percent. Quartz is present as small anhedral to euhedral phenocrysts and in small grains and granular aggregates in the groundmass of many specimens of the latite. Quartz latite is the most abundant variety.

Many of the porphyritic latite intrusions are characterized by a wide variety of inclusions of Precambrian basement rocks. The commonest are biotite pyroxenite, gabbro, hornblendite, garnet gneiss, mica schist, anorthosite, and granite.

Chemical analyses of rocks representatives of the porphyritic latite unit in the Lloyd quadrangle were not available at the time this report was prepared. However, their chemical composition is similar to latite of the felsic flow rock unit as given in table 1, columns 4 and 5.

Fresh specimens of the felsic flow rocks are light gray, light greenish gray, brownish gray, or tan; fine grained, porphyritic and massive. The most common petrographic type is quartz latite; less abundant types are latite and augite trachyte. Principal minerals of the rocks include sanidine, plagioclase (oligoclase to andesine), quartz, augite, biotite, and hornblende. The common accessory minerals are magnetite, apatite, rare zircon, rare melanite, and thomsonite. Alteration minerals include chalcedony, calcite, sericite, and, locally, blue-green celadonite. The rocks are characterized by small phenocrysts of feldspar, augite, and biotite enclosed in a fine-grained to glassy groundmass. The proportion of plagioclase to sanidine is widely variable in the latites but plagioclase is absent in the augite trachytes. Quartz is common in the ground mass of quartz latites but is rare as phenocrysts. Biotite is abundant in some varieties of latite. The color index of the felsic flow rocks ranges from 5 to 40 but is generally between 10 and 20. An analysis, norm, and mode of typical augite-biotite latite (specimen EB–314) and of glassy quartz latite (specimen EB–254) are given in table 1, columns 4 and 5.

The felsic flows and flow-breccias are characterized by a wide variety of inclusions of Precambrian rock. The most common of these are biotite pyroxenite, gabbro, hornblendite, anorthosite, gneiss, schist, and granite.

PORPHYRITIC POTASSIC SYENITE

Porphyritic potassic syenites are equivalent to the tinguaites described by Weed and Pirsson (1896). They are the least abundant type of intrusive rock and have a total areal extent in the Lloyd quadrangle of less than a square mile. The rocks occur as dikes and small pluglike bodies in the Bearpaw Mountains arch and in the volcanic field in the west-central part of the quadrangle. Intrusive relationships indicate that they are the youngest of all the intrusive rocks. Most of the dikes are a few feet wide and several hundred feet long, but the largest dike is 400 feet wide and more than half a mile long (secs. 19 and 20, T. 29 N., R. 19 E). Because of their massive and extremely resistant nature, the dikes commonly form prominent wall-like ridges standing above the surrounding terrain.

The porphyritic potassic syenites are light gray, light greenish gray, and light green. Commonly they are coarsely porphyritic and massive and contain large tabular phenocrysts of sanidine as much as 2 centimeters long arranged in planar fabric. Their essential minerals are sanidine, augite, aegirine-augite, aegirine, and biotite; their common accessory minerals are magnetite, apatite, and zircon. In some rocks the large sanidine phenocrysts constitute as much as 60 percent of the rock, but more commonly they make up 20 to 30 percent. The groundmass is ordinarily very fine grained and is composed essentially of sanidine and aegirine. Some varieties have subordinate nepheline, pseudoleucite, and sodalite; others have analcime; and a few contain minor amounts of plagioclase and quartz. Disseminated sulfides occur in many of the dikes, and Pecora (1956) believes that the porphyritic potassic syenites are genetically related to sulfide mineral deposits in the Bearpaw Mountains. Zircon from a potassic syenite body in the Warrick quadrangle was dated as 40 to 50 million years old by the lead-alpha method.

EXTRUSIVE ROCKS

Extrusive rocks extend from east to west across the central part of the quadrangle and rest unconformably on sedimentary rocks of Late Cretaceous and early Tertiary age. They form the eastern part of the northern volcanic field of the Bearpaw Mountains and crop out over an area of about 20 square miles, or 10 percent of the quadrangle. Because most of the northern part of the quadrangle is covered by glacial deposits, the exact extent of the volcanic rocks is not known, but it is estimated to be about 60 square miles. For the most part, the extrusive rocks form a thick pile of interlayered lava flows and pyroclastic beds, but locally they include irregular pluglike and still-like bodies of intrusive rock that are similar to and indistinguishable from the flows.

Along the western border of the quadrangle the extrusive rocks are faulted down against older sedimentary rocks, and in places they strike northward. In general, however, the layered units of the northern volcanic field strike eastward and dip south toward the Bearpaw Mountains arch at angles of 10° to 50°, the average being about 30°. They are thought to be arranged in a shinglelike manner within a broad lenslike volcanic pile that as a whole dips gently, and the aggregate stratigraphic thickness of the rocks is about 15,000 feet. A similar and even more pronounced structural arrangement exists in the southern volcanic field (Bryant, Schmidt, and Pecora, 1960), where the aggregate stratigraphic thickness of the rocks is about 30,000 feet.

Because the volcanic rocks were erupted during a very short interval of time and show repetitive lithology and no faunal changes, it has not been possible to subdivide them into major stratigraphic units that have any significance for correlation. Consequently, for mapping purposes, they have been separated on a strictly compositional basis into 5 major lithologic units: mafic flow rocks, mafic pyroclastic rocks, felsic flow rocks, felsic pyroclastic rocks, and analcime trachyte.

MAFIC FLOW ROCKS

Mafic flow rocks, the most widespread of all the volcanic-rock units, are exposed over an area of about 12 square miles and occur throughout the volcanic field, interlayered with mafic pyroclastic rocks and felsic flow rocks. Their aggregate stratigraphic thickness probably exceeds 10,000 feet.

The unit consists principally of lava flows but probably includes a number of small sills, plugs, and small 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, highly altered and oxidized, rubbly, vesicular rock, alternating with layers of dark-gray to black, fine-grained, massive rock. They are irregular to tabular in form and commonly of wide areal extent. Because many have a composite layered structure, it is difficult to estimate the thickness of individual flows. Some flows, built of alternating rubbly and massive layers, are probably as much as 100 feet or more in thickness. Other flows are massive and only a few feet thick. Banding on a large scale is common in many flows. Soil zones are absent.

Fresh specimens of the mafic flow rocks are dark gray to dark brown or black, fine grained, poryphyritic, and massive. The unit is predominantly composed of mafic phonolite, with or without feldspathoids, and probably includes minor amounts of mafic trachyte and mafic latite. The principal minerals in the mafic phonolites are sanidine, analcime, pseudoleucite, augite, olivine, and biotite, and the common accessory minerals are magnetite and apatite. The principal alteration minerals are calcite, fibrous natrolite, clear analcime, thomsonite, and other zeolites. Mafic analcime phonolite, the most abundant type of rock in the unit, is devoid of plagioclase and quartz, is locally rich in olivine, and commonly contains light-gray, greenish-gray, or reddish-gray euhedra of analcime and pseudoleucite. The analcime crystals have the same form and habit as those of leucite, and it is not known whether some or all of the analcime is primary in origin or whether it is mostly a late magmatic alteration of original leucite. Fresh leucite has not been identified in any of the rocks from the Lloyd quadrangle. A chemical analysis, norm, and mode of typical mafic analcime phonolite (specimen EB–1) are given in table 1, column 1. The color index of the mafic flow rocks ranges from 40 to 70 percent.

The generally tabular form and wide areal extent of the mafic flows indicate that they were erupted in relatively quiet fashion as fairly fluid lavas from many different vents during several episodes of volcanic activity.

MAFIC PYROCLASTIC ROCKS

Mafic pyroclastic rocks crop out over an area of less than a square mile but are probably more extensive in the drift-covered area of the quadrangle.

The unit consists of interbedded light- to dark-gray, dark-green, black, and red to purplish variegated breccia, tuff-breccia, and tuff. Most of the unit is tuff-breccia in which large angular to subrounded blocks as much as 3 feet in diameter and smaller fragments of mafic rock are enclosed in a coarse tuffaceous matrix. Fine to coarse-grained tuff and lapilli tuff are rare. The character of the rocks indicates that they were produced by explosive volcanic eruptions.

The rock fragments in the pyroclastic deposits are chiefly mafic phonolite but some are mafic trachyte and mafic latite. Locally, the deposits contain accessory fragments of felsic rocks, such as latite and quartz latite, and a great variety of inclusions of Precambrian rocks.

A typical occurrence of the mafic pyroclastic rocks is along the southern margin of the volcanic field in sec. 34, T. 30 N., R. 18 E., where they rest unconformably on Upper Cretaceous sedimentary rocks. The thickness of this sequence is about 200 feet.

FELSIC FLOW ROCKS

Felsic flow rocks occur throughout the volcanic field and are interlayered with mafic flow rocks and felsic pyroclastic rocks. They are less widespread than the mafic flow rocks and are exposed over an area of about 6 square miles. Their aggregate stratigraphic thickness probably exceeds 5,000 feet.

The unit consists principally of lava flows and flow-breccias but includes a number of sills, plugs, and irregular intrusive bodies that are indistinguishable from and merge with the flows. The flows are light gray, yellowish gray, brownish gray, purplish gray, and tan, fine grained, and massive. Some flows are conspicuously banded, others are vesicular, and a few are glassy. Many of the thicker felsic flows are composite, in that the basal and marginal parts are rubbly and the upper part massive and banded. The felsic flows are highly irregular in form and vary greatly in thickness along strike. In contrast to the mafic phonolite flows, the felsic flows tend to be massive and uniform, and a gross layered structure is absent in most of them. The maximum thickness of individual flows is as much as 200 feet.

The irregular form and thickness of the flows and their small lateral extent indicate that the lavas which gave rise to these rocks were relatively viscous and were erupted as small, thick flows from many different vents during several episodes of volcanic activity.

FELSIC PYROCLASTIC ROCKS

Felsic pyroclastic rocks are more limited in their occurrence than mafic pyroclastic rocks and crop out over an area of less than half a square mile. Their aggregate stratigraphic thickness is probably not more than 200 or 300 feet.

The unit consists of interbedded light-gray, brownish-gray, yellowish-brown, greenish-gray, and variegated breccia, tuff-breccia, and tuff. The predominant rock is tuff-breccia, which contains blocks as much as 4 feet in diameter. Tuff is not abundant. The fragmental nature of the rocks indicates they are the product of explosive volcanic activity.

The felsic pyroclastic rocks are composed chiefly of angular to subrounded blocks and smaller fragments of quartz latite, latite, and perhaps trachyte, but they also include accessory fragments of mafic phonolite. Like the felsic flow rocks, they are characterized by abundant inclusions of Precambrian basement rocks.

ANALCIME TRACHYTE

Analcime trachyte occurs along the western margin of the quadrangle. It is exposed over an area of less than a square mile, and has an aggregate statigraphic thickness of probably less than 300 feet. The unit includes lava flows and beds of coarse breccia that are interlayered with mafic and felsic flow rocks in the youngest part of the volcanic field.

The flows of analcime trachyte are light greenish gray, fine grained, porphyritic, and massive. The breccia beds are composed of blocks and smaller fragments of similar rock, but they also include large blocks of porphyritic quartz latite, some of which are as much as 3 feet in diameter. The flows are variable in thickness; as nearly as can be determined, individual flows are thin and range from a few feet to perhaps 20 or 30 feet in thickness. They appear to be continuous only for short distances.

The groundmass of the rock has a pronounced trachytic texture. Principal minerals include sanidine, analcime, and augite with rims of aegirine-augite. Sanidine forms elongate to tabular euhedral phenocrysts as much as 4 millimeters in length, as well as smaller crystals and microlites in the groundmass. The analcime occurs in small euhedral crystals and also in irregular forms molding between sanidine and augite grains. The accessory minerals are magnetite and apatite.

The analcime trachyte was erupted late in the period of volcanism. The irregular shape and thickness of the flows, their small lateral extent, and the presence of coarse breccia in the unit indicate that the rocks are the result of explosive volcanic activity. The pluglike body of porphyritic potassic syenite associated with these rocks may represent the vent from which they were erupted.

STRUCTURAL GEOLOGY

REGIONAL RELATIONS

The Bearpaw Mountains are one of several isolated mountain uplifts of Tertiary age in the northern Great Plains region of Montana. These uplifts lie to the east of the Rocky Mountain cordillera, and their position and structural setting is shown on the Montana State geologic map (Ross and others, 1955) and on the structure contour map of the Montana plains prepared by Dobbin and Erdmann (1955). The Bearpaw Mountains consist essentially 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. The 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 Lloyd quadrangle includes part of the Bearpaw Mountains structural arch, the eastern part of the northern volcanic field, and a large area of the bordering plains.

In general, the sedimentary rocks of the plains area, to the north of the Bearpaw Mountains, are gently tilted and have a regional north dip, but in places they are deformed into broad folds or are broken by high-angle normal faults. These faults have produced a series of grabens in which rocks of Tertiary and Late Cretaceous age have been faulted down against older formations. The faults belong to a system that extends around the Bearpaw Mountains, and they define a zone of collapse peripheral to the main uplift.

BEARPAW MOUNTAINS STRUCTURAL ARCH

In the Lloyd quadrangle, the most prominent structural features of the arch are small domes, some nearly symmetrical and as much as 2 miles in diameter. They are the result of arching of the sedimentary rocks over and around nearly concordant stocklike bodies of igneous rock which are exposed in the central part of some of the domes. Other stocks and smaller pluglike bodies of igneous rock, some of highly irregular shape, bear a discordant relation to the sedimentary rocks and in places have produced tight folds in the adjacent sedimentary rocks. Tectonic thickening and thinning of shaly formations is common in areas of intense deformation.

The prominent dome formed by the intrusion of the syenite stock at Barber Butte is an excellent example of a so-called trapdoor faulted dome, a type of structure common in the Bearpaw, Little Rocky, and Judith Mountains. At Barber Butte a wedge or trapdoor of sedimentary rocks on the southeast side of the dome has been raised upward between bounding faults, and subsequent erosion has exposed rocks of Jurassic age along the inner margin of the trapdoor adjacent to the intrusion. The trapdoor was formed with the development of a curved fracture or fault in the sedimentary roof above the intruding magma, which then worked its way upward to lift the roof in a hingelike manner on the concave side of the fault. The intrusive contact along the northwest side of the stock is approximately continuous with the faults that bound the trapdoor and perhaps is the trace of the curved fault. A cross section of the Barber Butte dome is shown in plate 6 (section *A–A′*). A dome of this type in an incomplete stage of development is situated in the Maddux quadrangle about 4 miles south of Barber Butte (Bryant, Schmidt, and Pecora, 1960, pl. 3).

A narrow syncline extends along the western side of the Barber Butte dome and plunges to the north, transverse to the main trend of the arch. East of the dome a second prominent northward-trending synclinal structure of highly irregular shape is also transverse to the main trend of the arch. This structure extends for some distance south into the Maddux quadrangle and has preserved beds of the Judith River formation (Late Cretaceous) at the same general elevation as Jurassic and Lower Cretaceous rocks to the west and east. The western limb of a narrow anticline, also of northward trend and transverse to the arch, is exposed along the southeastern margin of the quadrangle.

Faults of the arch area are of high angle and most are found on the flanks of domes. The largest fault has a maximum displacement of about 500 feet.

Dikes are not as numerous in the arch in the Lloyd quadrangle as they are elsewhere in the Bearpaw Mountains. Their greatest concentration is in the vicinity of the large stock of shonkinite in the southwestern part of the quadrangle.

NORTHERN VOLCANIC FIELD

Rocks of the northern volcanic field, including those covered by glacial deposits, underlie about 60 square miles in the Lloyd quadrangle and form an irregular mass mainly composed of interlayered lava flows. The flows generally dip southward at angles of 10° to 50°, and the volcanic pile as a whole appears to represent a monoclinal structure dipping toward the Bearpaw Mountains arch. The attitude of the flows is not that of initial deposition, for stratified volcanic sandstones and siltstones in the adjoining quadrangles are interlayered with steeply inclined flows, and the sediments when deposited must have been in a horizontal or nearly horizontal attitude. Although the structure is not well understood, the available evidence indicates that some kind of large-scale deformation has affected the volcanic pile.

Reeves (1924a, 1924b, 1925, 1946) has suggested that the inward dip of the volcanic rocks toward the arch is the result of wholesale landsliding of the volcanic pile and underlying sedimentary rocks toward the plains, probably along bentonite beds in the upper part of the Colorado shale. However, in the Lloyd quadrangle, at the few places where the contact is exposed, the volcanic rocks rest unconformably on the underlying sedimentary rocks. On the other hand, it cannot be determined from field evidence whether the monoclinal structure of the volcanic pile is due to collapse and tilting along high-angle normal faults, whether it was formed in a single episode or in successive stages as volcanism occurred, or whether it is the result of landsliding toward the plains as suggested by Reeves. The absence of reliable and extensive marker beds in the volcanic pile, and the extensive cover of glacial deposits over most of the volcanic field, hinder the inquiry into the nature of this deformation.

At the western boundary of the quadrangle, part of the volcanic field is faulted down against Upper Cretaceous sedimentary rocks along a north-trending high-angle fault concealed beneath a cover of glacial deposits. The trace of the fault runs generally parallel to the valley of Clear Creek and continues into the adjoining Shambo quadrangle to the south (Kerr and others, 1957). Although the evidence is not conclusive, it is possible that this fault may continue northward, roughly parallel to the quadrangle boundary, and offset the entire volcanic field. The maximum vertical displacement along this fault is probably on the order of a few thousand feet.

The northern boundary of the volcanic field is not exposed. The area of volcanic rocks in the vicinity of Sayer Butte may be an outlier of the main volcanic field that is faulted down against beds of the Judith River formation.

PLAINS AREA

The plains area north of the volcanic field occupies almost half the area of the quadrangle, and the greater part is covered by glacial deposits. The underlying bedrock consists largely of sedimentary rocks of Late Cretaceous age but includes some Tertiary sedimentary rocks and extrusive and intrusive rocks. Bedrock is mainly exposed along stream courses and bench escarpments, and the total area of sedimentary-rock outcrop is less than 10 square miles. Over most of the plains area the sedimentary rocks are gently tilted or are flat-lying, but in places they are folded and faulted and have steep attitudes.

The western part of a broad, low, irregular dome—the Bowes dome— is situated in the northeastern corner of the quadrangle. This dome is the site of the Bowes oil and gas field. The dome is 7 to 8 miles in diameter, covers an area of about 40 square miles, and its center lies to the east in the Cleveland quadrangle. The outward regional dips on the flanks of the structure are generally low and range from 1° to 10°. The expression of the dome at the ground surface is largely masked by prominent subsidiary folds, by a graben, and by high-angle normal faults which have produced steep and erratic dips in the surface formations at many places.

A broad anticline, on which the majority of the producing gas wells in the Bowes field are located, is situated on the southwest part of the Bowes dome. The anticline has an areal extent of about 6 square miles, is doubly plunging, and the dips on its flanks are low and range from 2° to 20°. The axis trends northeast. The structural summit of the anticline is located about a third of a mile southwest of the Cole school near the center of sec. 9, T. 31 N., R. 19 E. To the south the anticline terminates against a northwest-trending fault; northward it extends beneath a cover of glacial deposits and probably dies out against a north-trending graben in the Cleveland quadrangle.

North of the main gas anticline, along the eastern border of the quadrangle, an east-trending anticline is developed in the Judith River formation. This structure is abruptly terminated against the north-trending graben in the Cleveland 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 structure in the adjoining Cleveland quadrangle.

The Bowes dome, and the subsidiary northeast-trending gas anticline, are abruptly terminated and displaced upward against a high-angle normal fault at their southwest margin. This fault brings the middle part of the Judith River formation in contact with the Bearpaw shale, and the maximum displacement is between 250 and 300 feet. South of this fault a pattern of three major normal faults form a large graben in which the Fox Hills sandstone and beds of the Hell Creek formation are faulted down against the Bearpaw shale. The eastern and western faults bounding this structure each have a maximum displacement of about 1,200 feet.

South of the Fox Hills—Hell Creek graben, in the vicinity of Grasshopper reservoir, beds of the Fort Union formation (Paleocene), Wasatch formation (Eocene), and mafic pyroclastic rocks (middle Eocene) are faulted down against the Bearpaw shale in a large triangular-shaped block that extends southeastward to the large outlier of the northern volcanic field in the vicinity of Sayer Butte. The east-trending fault forming the northern boundary of this block has a vertical displacement of about 2,000 feet. It represents one of the largest faults in the zone of collapse at the margins of the Bearpaw Mountains. The fault runs eastward, probably along the south side of the Bean Creek sill, and dies out in beds of the Judith River formation in the adjoining Cleveland quadrangle. To the west the fault is terminated against a large wedge-shaped block in which the Fox Hills sandstone and beds of the Hell Creek formation are faulted down against the Bearpaw shale.

Several high-angle normal faults of northward trend have dislocated beds of the Judith River formation and Bearpaw shale along the southern margin of the Bowes dome in secs. 16, 21, and 22, T. 31 N., R. 19 E., and along its northwestern margin in sec. 31, T. 32 N., R. 19 E. The displacement on these faults is small and ranges from about 20 to 200 feet.

Along the western side of Tiger Ridge, in the north-central part of the quadrangle, there is an east-trending horst in which beds of the Judith River formation are faulted up against the Bearpaw shale. The faults bounding this block have a maximum displacement of about 500 feet. To the east this structure disappears beneath a cover of pediment gravel and glacial till; to the west it is terminated against a north-trending fault that has a displacement of several hundred feet. A small area of Claggett shale is brought up on the west side of this fault, and beds of the Judith River formation here have steep dips and are tightly folded.

In the northwest corner of the quadrangle, a pattern of high-angle normal faults form a small and complex graben in which the Fox Hills sandstone and beds of the Hell Creek formation are faulted down and preserved against the Bearpaw shale. South of this structure is another graben block, of triangular shape, in which beds of the Fort Union formation (Paleocene) and Hell Creek formation are faulted down against the Bearpaw shale. The faults bounding this structure have maximum vertical displacements of more than 500 feet.

A small area of Fox Hills sandstone and beds of the Hell Creek formation is present beneath a cover of glacial deposits in the north-central part of the quadrangle in secs. 4 and 9, T. 31 N., R. 18 E. These beds are either preserved in a shallow structural basin, as shown on the geologic map (pl. 6), or are faulted down against the Bearpaw shale in a graben structure similar to those that occur elsewhere in the plains area.

ECONOMIC GEOLOGY

The Bowes dome, part of which lies in the northeastern corner of the Lloyd quadrangle, is the site of the Bowes oil and gas field. An account of this field, with emphasis on subsurface stratigraphy, structure, and reservoir characteristics, has been given by Hunt (1956). The first well in the field was drilled in 1924, but the principal development was during the period 1926–1935, when 9 gas wells were completed and a pipe line was laid to Chinook and Havre. The field has produced gas continuously since that time and is presently maintained and operated by the Montana Power Company. Currently there are 20 producing gas wells in the Bowes field; eleven are in the Lloyd quadrangle. The gas occurs in the upper part of the Eagle sandstone at depths ranging from 653 to 1,078 feet (Hunt, 1956, p. 190).

Oil was discovered in the eastern part of the Bowes dome in 1949. In 1959 there were 88 producing oil wells in the field, all of which are in the adjoining Cleveland quadrangle. Operations are maintained principally by the Texas Company and to a lesser extent by the Trigood Oil Company. The producing zone is the Sawtooth (Piper) formation of Middle Jurassic age.

Early homesteaders in the area obtained lignite and low-rank coal for the local use from the upper part of the Judith River formation and the lower part of the Hell Creek formation. Their excavations are now largely caved and abandoned. The best grade of coal occurs in the upper part of the Judith River formation along Black Coulee and its tributaries in the northeastern part of the quadrangle, where the coal is locally of subbituminous rank and the main seam is as much as 6 feet thick. The principal coal workings are shown on the geologic map (pl. 6).

Sand and gravel of glaciofluvial origin are abundant in many parts of the quadrangle and locally provide material for construction purposes and road surfacing. The best grade of sand was observed along the western border of the quadrangle in sec. 34, T. 30 N., R. 17 E. Vesicular mafic phonolite in the volcanic field constitutes an excellent material for surfacing roads and is especially well suited for terrain underlain by shale or till. Massive bodies of intrusive rock in the quadrangle form a potential source for riprap and road metal.

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

Water of the best quality issues from springs in the lower part of the Eagle sandstone and from permeable zones in the volcanic rocks. Wells dug or drilled in surficial deposits, though shallow, are productive.

Small metalliferous veins occur at many places in the Bearpaw Mountains arch, and several prospect pits have been excavated to explore their economic potentialities. The principal prospects in the quadrangle are shown on the geologic map (pl. 6). The veins are chiefly found in or near intrusive masses of porphyritic latite and dikes of porphyritic potassic syenite. The principal vein minerals are argentiferous galena, pyrite, pyrrhotite, and chalcopyrite. Sphalerite and molybdenite are rare. Gangue minerals include quartz, calcite, and barite. The veins are rarely more than an inch wide, and they occur in discontinuous brecciated zones rather than in persistent fractures. The largest of these deposits, known as the O'Hanlon mine prospect, is located near the southern border of the quadrangle in the NE¼ sec. 19, T. 29 N., R. 19 E. It was discovered in 1888 and development work has been carried on intermittently to the present time. The principal ore mineral is argentiferous galena. A few tons of hand-picked ore were shipped from this deposit between the years 1888 and 1892 (Pepperberg, 1909, p. 141), but no other metal production is known from the Lloyd quadrangle. The O'Hanlon prospect and several other small prospects in the southwest corner of the Lloyd quadrangle and the northwest corner of the Maddux quadrangle have been described by Pepperberg (1909). Placer gold was found a few decades ago a few miles east of Lloyd Butte, according to residents of the area.

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