Geology of the Maddux Quadrangle Bearpaw Mountains Blaine County, Montana

By BRUCE BRYANT, ROBERT GEORGE SCHMIDT, *and* W. T. PECORA

CONTRIBUTIONS TO GENERAL GEOLOGY

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

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

ABSTRACT

The Maddux quadrangle which has an area of about 200 square miles, is in the southeastern part of the Bearpaw Mountains. About 20 percent of the quadrangle is underlain by sedimentary rocks of Late Jurassic to Recent age and 80 percent by intrusive and extrusive igneous rocks of middle Eocene age.

The consolidated sedimentary rocks are subdivided into 18 formations, which have a total stratigraphic thickness of about 7,900 feet. The surficial deposits include pediment and terrace gravels of Pliocene(?) and Pleistocene age and alluvium of Recent age. The maximum stratigraphic thickness of these deposits is about 100 feet.

The intrusive igneous rocks of the Maddux quadrangle occur as simple and composite stocks, dikes, plugs, and sills. The extrusive rocks form an interlayered pile of mafic and felsic lava flows, pyroclastic deposits, and volcanic sediments. The mapped flow units also include some irregular pluglike bodies of intrusive rock that are indistinguishable from and merge with the flows. The maximum stratigraphic thickness of the sequence of layered volcanic rocks is about 30,000 feet.

The igneous rocks range in composition from subsilicic-alkalic to silicic-alkalic and include representatives of the shonkinitic, syenitic, and quartz monzonitic families. Within the quadrangle, mafic-lava flows exceed felsic-lava flows in areal distribution by a ratio of about 2 to 1. However, intrusive porphyritic latite is about as abundant as intrusive shonkinitic rock.

The principal structural feature of the Bearpaw Mountains uplift is the Bearpaw Mountains structural arch, an eastward-trending belt of uplifted and deformed sedimentary rocks that has been extensively intruded by many types of igneous rocks. Part of the southern limb of this arch lies in the northern part of the quadrangle, and the arch is bordered on the south by the eastern portion of the southern volcanic field—a wide expanse of volcanic rocks that forms the south flank of the Bearpaw Mountains. In general, the layered units in this part of the southern volcanic field have a northeastward strike and dip northwest toward the Bearpaw Mountains structural arch at angles of 10°–65°. Considered as a single mass, the southern volcanic field is a monoclinal structure dipping about 30° NW. toward the arch.

Deformation and volcanism occurred in this region in the Eocene epoch. Faulted rocks in and adjacent to the volcanic field demonstrate deformation

before, during, and after volcanism. In this quadrangle it cannot be determined whether disruption of the initial layering of the volcanic rocks is more likely the result of successive collapse or of plainsward landsliding as suggested by Reeves (1946).

Mineral resources include minor amounts of bentonite, lignite and low-rank coal, and sparse deposits of galena, pyrite, and chalcopyrite. Vesicular mafic phonolite flows provide a source for road-surfacing material, and many masses of intrusive rock are a potential source of riprap.

INTRODUCTION AND ACKNOWLEDGMENTS

The Maddux 15-minute quadrangle, Blaine County, north-central Montana, is one of eight quadrangles that encompass the Bearpaw Mountains uplift. The geologic map (pl. 3) is the fifth quadrangle map of the group to be published but the first to be issued on a topographic base. The first four maps were published on a planimetric base and were issued in the Miscellaneous Geologic Investigations series of the U.S. Geological Survey in 1957 as maps numbered I–234 (Pecora and others), I–235 (Stewart and others), I–236 (Kerr and others), and I–237 (Pecora and others). (See fig. 10.) The other quadrangles were being mapped at the time of preparation of this report.

Detailed geological mapping of the Bearpaw Mountains uplift was begun in 1949 as a continuation of earlier field investigations by W. T. Pecora. The Maddux quadrangle was mapped in the summer seasons of 1954 and 1955. Bryant was a member of the party during both seasons and each of the following participated one season: R. G. Schmidt, W. G. Ernst, B. C. Hearn, Jr., J. E. Case, E. J. Olsen, D. J. Milton, and K. E. Books. The geology was plotted on aerial photographs at a scale of 1:20,000 and was later transcribed to the topographic base, when it became available. W. T. Pecora supervised the mapping in both seasons.

Generous cooperation was extended members of the Geological Survey field staff by many residents of the area who provided lodging accommodations and many other courtesies, including access to their properties, information concerning accessibility, and help in location of section corners. The authors are particularly indebted to the members of the Blaine County school boards for permission to use the Peoples Creek and Golden Valley schoolhouses as field offices and living quarters.

An unpublished reconnaissance geologic map of the Bearpaw Mountains, prepared in 1924 by Frank Reeves and W. S. Burbank of the

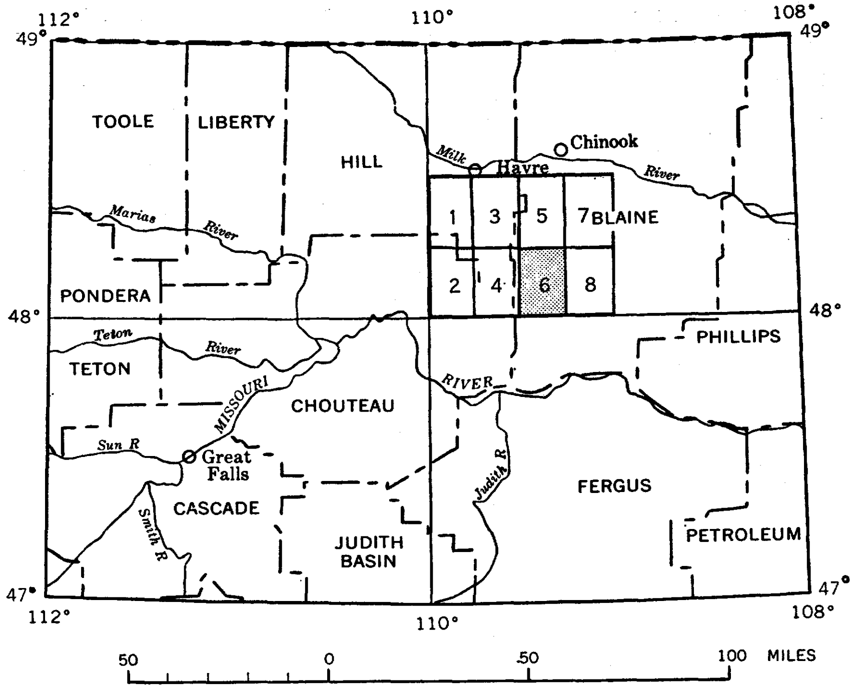

FIGURE 10.—Index map of north-central Montana showing map area and adjoining quadrangles: 1, Laredo quadrangle, I–234; 2, Centennial Mountain quadrangle, I–235; 3, Shambo quadrangle, I–236; 4, Warrick quadrangle, I–237; 5, Lloyd quadrangle (Schmidt and others, 1960); 6, Maddux quadrangle, (shaded), this report; 7, Cleveland quadrangle, report in preparation; 8, Rattlesnake quadrangle, report in preparation.

U.S. Geological Survey, proved to be a most helpful reference throughout these investigations. The authors also had access to an unpublished map accompanying a doctoral dissertation prepared in 1941 by Bernard Fisher and submitted to Harvard University. Published reports dealing with geologic problems in this region are included in the references listed at the end of this report and cited elsewhere in the report.

GEOGRAPHY

The Maddux quadrangle has an area of about 200 square miles and is in the southeastern part of the Bearpaw Mountains. In the area there are about two dozen ranches where cattle and sheep are raised. The resident population is less than 100. Chinook, the nearest town, is 30 miles to the north of the quadrangle area and is on U.S. Highway 2 and the Great Northern Railway (fig. 10).

The watershed between the Milk River and the Missouri River drainage areas lies in the central part of the quadrangle, along the extension of the ridge that includes Corrigan Mountain and Bentel Divide. The highest point in the quadrangle, nearly 6,000 feet above sea level, is on the ridge north of Peoples Creek. Maximum topographic relief is about 2,500 feet. The topography of most of the quadrangle is mountainous but generally less rugged than that in other parts of the Bearpaw Mountains to the west. Clear Creek, Peoples Creek, and Cow Creek are the principal perennial streams draining this part of the mountains. Benches and badlands characterize the southeastern part of the area. The climate is semiarid and annual precipitation ranges normally between 10 and 15 inches.

GEOLOGIC HISTORY

Regional sedimentation in north-central Montana in Paleozoic and Mesozoic times was principally marine in character but was entirely nonmarine in Cenozoic time. A broad regional uplift in the Jurassic period resulted in a well-marked unconformity between Mississippian and Middle Jurassic rocks and minor disconformities in the Middle and Upper Jurassic formations. Transgressive and regressive sedimentation occurred in Late Cretaceous time and the sea permanently receded from this region by Paleocene time. Sedimentation ceased in the early Eocene epoch with deposition of beds of channel boulders derived from the Rocky Mountain region to the west and southwest and was followed by deformation and by irruption of a great variety of intrusive and extrusive igneous rocks in middle and late Eocene time.

Faulting occurred throughout the period of igneous activity. Erosion during the rest of the Tertiary period sculptured the present mountainous terrain and provided sediments of late Tertiary age deposited to the east. Successive establishment of base levels of erosion locally produced around the Bearpaw Mountains and neighboring mountains a series of pediments and benches that mark the topography of central Montana.

In late Pleistocene time a continental ice sheet advanced southeastward, abutted against the high terrain of the Bearpaw Mountains, and deposited ground moraine and outwash sediment on the western, northern, and eastern slopes of the range. The Maddux quadrangle, however, lies within an unglaciated area.

SEDIMENTARY ROCKS

GENERAL FEATURES

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

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

In the Maddux quadrangle about 40 square miles, or 20 percent of the quadrangle area, is underlain by consolidated sedimentary rocks ranging in age from Late Jurassic (Rierdon formation) to Early Eocene (Wasatch formation). In the northern part of the quadrangle the sedimentary rocks are pre-Tertiary in age and locally have undergone thermal metamorphism. Rocks of Tertiary age are exposed within fault blocks adjacent to rocks of Late Cretaceous age along the eastern and southern borders of the quadrangle.

A brief description of the exposed rock units in the Maddux quadrangle is given in the explanation of the geologic map (pl. 3), and a summary of their age and approximate maximum thicknesses in this area is given below:

Age and stratigraphic unit	*Maximum thickness (ft)*
Tertiary:	
Eocene:	
Wasatch formation	650
Paleocene:	
Fort Union formation	1,500
Cretaceous:	
Upper Cretaceous:	
Hell Creek formation	425
Fox Hills sandstone	70
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

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Age and stratigraphic unit	*Maximum thickness (ft)*
Cretaceous—Continued	
Lower Cretaceous:	
Colorado shale:	
Mowry shale equivalent	100
Newcastle sandstone and Skull Creek shale equivalents	250
Fall River sandstone equivalent	275
Kootenai formation	275
Jurassic:	
Upper Jurassic:	
Ellis group:	
Swift formation	160
Rierdon formation	200

Stratigraphic descriptions of most of the formations occurring in this region and listed above may be found in reports of Bowen (1914), Reeves (1924a), Cobban (1951), Brown and Pecora (1949), Stebinger (1914, 1916), Pierce and Hunt (1937), and Pepperberg (1909, 1912).

JURASSIC SYSTEM

Since 1947, U.S. Geological Survey parties in the Bearpaw Mountains have followed Cobban's (1945) nomenclature in mapping the Jurassic rocks of the Ellis group, which includes the Sawtooth, Rierdon, and Swift formations. The Sawtooth formation (Middle Jurassic) is equivalent to the Piper formation of Imlay and others (1948). The name Piper formation is preferred by petroleum geologists in recent publications on this region.

The Sawtooth (Piper) formation does not crop out in the Maddux quadrangle but is exposed elsewhere in the Bearpaw Mountains. It is the principal producing zone for petroleum in the Bowes dome, located 20 miles north of the Maddux quadrangle, and also is a substantial producer in the Williston basin, some 200 miles east of the Bearpaw Mountains. Recent stratigraphic correlations of the Sawtooth are given by Hunt (1956), Nordquist (1955), Francis (1956), Rayl (1956), Hadley and Milner (1953), and McKee and others (1956).

The Rierdon formation of Late Jurassic age is incompletely exposed in the dome located north of Peoples Creek in secs. 28, 29, 32, 33, T. 29 N., R. 18 E. About 80 feet of the formation is exposed in a total outcrop area of about 100 acres. The lower part is principally calcareous shale that weathers brown to yellowish brown. The upper part is characterized by about 10 feet of thin-bedded argillaceous limestone. The Swift formation, like the Rierdon, is exposed only in the dome north of Peoples Creek where it is composed essentially of sandstone and shale.

The Morrison formation has not been identified with any degree of certainty in the Bearpaw Mountains. A sequence of 25 to 50 feet of brown siltstone, sandstone, and carbonaceous shale representing a zone of transition from the Swift formation and to the overlying Kootenai formation may possibly be correlated with the Morrision elsewhere in Montana.

CRETACEOUS SYSTEM

The Cretaceous system includes, from oldest to youngest, the Kootenai formation, Colorado shale, Montana group, Fox Hills sandstone, and Hell Creek formation. No attempt was made to determine the position of the boundary between the Upper and Lower Cretaceous, although it lies within the Colorado shale. In other areas it is drawn at the contact between the Mowry and Belle Fourche shales and is so indicated on the geologic map (pl. 3). In the present investigations, the Colorado shale has been subdivided into several mappable units in order to define the structure of the mountains in more detail. In an attempt to show correlation with rocks of the Black Hills region, the nomenclature of Cobban (1951) has been followed. The Colorado shale of north-central Montana, however, includes units that are stratigraphically higher than the Colorado group of the Black Hills.

The base of the Kootenai formation is placed at the first appearance of conspicuous gray to white quartz-chert arkosic sandstone. Within the Colorado shale, the Greenhorn limestone equivalent is the most readily identifiable unit and has proved to be the most helpful in determining structural relationships in areas of highly deformed and metamorphosed formations. The thin-bedded Mowry shale equivalent is easily recognized by the characteristic blue-white weathering of its loose chips and by abundant fish-scale markings; but it is difficult to determine the top and bottom of this formation with any degree of assurance.

Bentonite beds and marine limestone concretions, commonly septarian and fossiliferous, are abundant in the upper part of the Colorado shale and in the Claggett and Bearpaw shales of the Montana group. The conspicuous Clay Spur bentonite bed, which is in the uppermost part of the Mowry formation in other regions (Knechtel and Patterson, 1956, p. 10), occurs only locally in the Bearpaw Mountains and has not been observed in the Maddux quadrangle.

Lignite and carbonaceous-shale beds are most abundant in the Judith River formation of the Montana group, particularly in a zone at the top of the formation, where they are overlain locally by beds rich in oyster shells. In places this zone has been mined for coal.

Lignite in thin beds also occurs in the upper part of the Eagle sandstone of the Montana group and in the lower part of the Hell Creek formation. Beds of carbonaceous bentonitic clay that occur in the upper parts of the Eagle sandstone and Judith River formation are light to dark gray; those in the lower part of the Hell Creek formation are dark gray to black.

Grains of chert are most abundant in the quartz sandstone of the Kootenai formation. Sandstone beds locally rich in black chert pebbles are present in the Fall River sandstone equivalent near the base of the Colorado shale, are rare in a gritty or muddy sandstone member in the lower part of the Belle Fourche shale equivalent, and are common at the top of the Eagle sandstone. Calcareous-sandstone concretions are abundant in the Judith River formation and Fox Hills sandstone. Limy concretionary nubbins characterize slopes underlain by the upper part of the Hell Creek formation. The sandstone in the lower part of the Hell Creek formation has abundant muscovite.

The recognition of one formation from another for mapping purposes was done largely on a lithologic basis. Transitions from sandstone units to overlying units of marine shale are well defined within a few feet, however, the transition from units of shale to overlying units of sandstone ranges from 10 to 50 feet stratigraphically. It is most difficult to determine the contact between the Niobrara and Telegraph Creek equivalents, but the contact is placed arbitrarily at the base of the first group of sandstone beds. The contact between the Fox Hills sandstone and the overlying Hell Creek formation is placed at the first appearance of carbonaceous shale. Fossils, where diagnostic, have proved most helpful in areas of poor exposure.

TERTIARY SYSTEM

The boundary between the Cretaceous and Tertiary systems is marked by a zone of transition from marly beds of the Hell Creek formation to a thick-bedded sandstone sequence of the Fort Union formation containing many carbonaceous-shale beds that range in thickness from a fraction of an inch to several inches. Where the zone is exposed the contact between these formations may be placed with assurance within 5–10 feet. The two formations of Tertiary age, the Fort Union (Paleocene) and the Wasatch (early Eocene), are separated on the basis of first appearance of variegated siltstone beds, which occur at the base of the Wasatch formation. The top of the Wasatch formation is characterized by stream-channel conglomerate that is overlain with angular unconformity by volcanic rocks of local origin. Both formations are lithologically similar to rocks bearing the same formation names in other regions.

The sandstone of the Tertiary formations has one lithologic feature that readily distinguishes it from the sandstone of older formations. In this quadrangle, as in other parts of the Bearpaw Mountains, pink and rose grains in the matrix of the Tertiary rocks can be identified by hand lens. Such grains occur sparingly in the lowest beds of the Fort Union formation, become more abundant upward in the stratigraphic section, and are conspicuous in the upper beds of the Wasatch formation. They are absent in the sandstones of Mesozoic age in the area. Most probably they represent lithic grains of colored quartzite derived from the Precambrian Belt series and mark some rapid uplift occurring in the Rocky Mountain region to the west.

The Fort Union formation is important in eastern and southern Montana for its minable coal beds. The coal is of higher rank than that in the Judith River formation in this region. The formation contains several massive, thick-bedded sandstone units and prominent lenses of clay-gall conglomerate.

Carbonaceous shale is rare in the basal part of the Wasatch formation; and beds of variegated siltstone and claystone in hues of purple, pink, red, and green are characteristic. Channel-conglomerate lenses are abundant in the upper part of the formation and the stones are normally of pebble and cobble sizes. Rarely are they of boulder size in this quadrangle, although boulders are abundant in the western part of the mountains. Most of the stones are of quartzite derived from the Precambrian Belt series. Many are of volcanic rock, foreign to the Bearpaw Mountains area, and Pecora (1949) has tentatively correlated these with quartz-latite flows and welded tuffs of Late Cretaceous age that occur to the west in the Rocky Mountains. A few stones are of sedimentary rocks identical to the Flathead quartzite of Cambrian age and limestone and dolomite of other Paleozoic formations. The source area must be at least 150 miles distant to the southwest. Locally some of the pebbles and cobbles are fractured and recemented.

The occurrence of the Fort Union and Wasatch formations in the Bearpaw Mountains region (Bowen, 1914; Brown and Pecora, 1949) indicates that early Tertiary sedimentation was much more extensive than had been believed earlier; other exposures of the Fort Union 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 and alluvium of local origin are distributed along most of the watercourses and on the surfaces of three successively higher terraces that stand above the present streams. Inasmuch as the streams are sharply incised into the lowest terrace, the alluvium is meager locally and rarely exceeds 5 feet in thickness. On the terraces, however, the gravel ranges in thickness from a mere veneer to as much as 30 feet.

The surface of the highest terrace, herein called the No. 1 pediment surface, has the thinnest gravel cap and 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 assumption is correct, this terrace, or pediment, is then late Tertiary in age. Gravels of all three terraces are most likely pre-Wisconsin in age, for along the southwestern and western margins of the mountains three terrace levels also exist, and the highest was dissected before the incursion of the Wisconsin ice sheet and deposition of till. Correlation and dating of the gravel-capped terrace levels in the till-covered and the unglaciated areas in north-central Montana can be made with assurance only by detailed investigations made with the aid of topographic base maps.

IGNEOUS ROCKS

GENERAL FEATURES

Intrusive and extrusive igneous rocks of middle and late Eocene age are widely distributed within the area of the eight 15-minute quadrangles shown in figure 10. The intrusive rocks occur as simple and composite stocks and as dikes, plugs, and sills. The extrusive rocks comprise two principal volcanic fields, a northern and a southern field, separated by the Bearpaw Mountains structural arch, a strip of deformed and locally metamorphosed sedimentary rocks extensively intruded by igneous rocks (Reeves, 1925). In the Maddux quadrangle about 160 square miles, or about 80 percent of the quadrangle area, is underlain by igneous rocks.

Many varieties of the intrusive and extrusive igneous rocks in the quadrangle are of nearly identical chemical composition, but the intrusive rocks are commonly coarser grained or more coarsely porphyritic than their extrusive equivalents. In chemical composition the igneous rocks range from subsilicic-alkalic to silicic-alkalic varieties. The subsilicic-alkalic varieties are mostly mafic in character and the silicic-alkalic varieties are felsic. Mafic flows occupy at least twice as much area as felsic flows. Both kinds were erupted continually during the period of volcanism and occur throughout the sequence of volcanic rocks. Among the intrusive rocks, coarse-grained mafic varieties have a much greater areal extent than coarse-grained felsic varieties, whereas the fine-grained mafic and felsic varieties are about equal in areal extent.

Nomenclature of the igneous rocks follows that established in recently published geologic maps on this region. Essential criteria for nomenclature are kind and relative proportion of light-colored minerals, kind and relative proportion of dark-colored minerals, and relative proportion of dark- and light-colored minerals (color index). The light-colored minerals include sanidine, plagioclase, nepheline, pseudoleucite, leucite(?), primary(?) analcime, and quartz. Sanidine is present in all the rocks. The dark-colored minerals include augite, biotite, olivine, and hornblende. Augite is present in all the rocks. Quartz and hornblende are normally found only in those felsic rocks that contain plagioclase but are not found in those that contain feldspathoids. The groundmass of most of the porphyritic rocks is glassy to very fine grained.

On the basis of relative proportion of light- and dark-colored minerals (color index) and kind of light-colored minerals, the igneous rocks of the Maddux quadrangle are placed in two main families: Shonkinitic (sanidine, with or without feldspathoids) and monzonitic (sanidine and plagioclase, with or without quartz). In forming rock names different prefixes are used to indicate varieties; for example: mafic syenite, porphyritic potassic syenite, nepheline shonkinite, mafic analcime phonolite. Terms such as monzoshonkinite and shonkimonzonite are thus avoided.

A suite of 75 rocks, representative of the varieties occurring in the quadrangle, was studied in thin section. Their color index, based on the summation of the volume percent of all the dark minerals and their alteration products, ranges from 5 to 70 percent. Augite or aegirine-augite is the most abundant dark mineral, ranging, in most specimens, from 10 to 45 percent; in very few specimens is there less than 5 percent. The content of olivine, including its alteration products, is rarely more than 10 percent though it ranges from 0 to 30 percent. The content of biotite in rarely more than 10 percent, but ranges from 0 to 25 percent. Hornblende occurs in very few specimens; if present the amount is less than 5 percent. Opaque minerals, mostly magnetite, make up 1 to 15 percent of these rocks, but commonly less than 5 percent.

Among the light-colored minerals, potassic feldspar (sanidine and some microperthite) is most abundant and makes up 5 to 90 percent of the rocks. Plagioclase, with a composition of An_{10} to An_{60}, makes up 0 to 45 percent of the rocks. In most of the rocks containing both of these minerals, sanidine is the more abundant and its proportion to plagioclase ranges from about 1:1 to 15:1. In many of the porphyritic latites, plagioclase is the more abundant as phenocrysts. In a few porphyritic trachytes, phenocrysts of sanidine are partly altered to sodic plagioclase. In most of the felsic rocks the phenocrysts are altered. Quartz as phenocrysts is rare in these rocks but is probably abundant in the very fine grained matrix of the porphyritic latites.

The feldspathoids identified in the rocks include nepheline, pseudoleucite, and euhedral (primary?) analcime. The total feldspathoid content ranges from 0 to 45 percent. Nepheline commonly makes up less than 10 percent of those rocks in which it occurs. Fresh leucite has not been identified in any of the rocks. Euhedral analcime is common in the mafic extrusive rocks and on the basis of its form, internal zoning, and oriented mineral inclusions, it may possibly be of magmatic origin rather than the result of the alteration of leucite.

Alteration minerals include a ferromagnesian group derived from olivine and biotite, zeolites (principally fibrous natrolite and clear analcime), calcite, and sericite. Many rocks are vuggy and some of the alteration minerals are abundant on the walls of cavities. In a few rocks as much as 60 percent of the rock is altered; but in most the alteration minerals make up less than 10 percent.

Chemical analyses of rocks from the Maddux quadrangle were not available at the time the report was prepared. For comparison, however, the published analyses of similar rocks in the other quadrangles can serve to show the chemical variations to be expected.

INTRUSIVE ROCKS

Intrusive igneous rocks underlie at least 20 square miles, or 10 percent, of the Maddux quadrangle. In many places rocks in the volcanic field could not be classed as intrusive or extrusive because of a lack of distinguishing characteristics, such as texture or contact relationships, and these rocks were mapped as part of the volcanic-flow units.

For mapping purposes the intrusive rocks have been separated into four major units: shonkinitic rocks; syenite; porphyritic latite; and porphyritic potassic syenite.

SHONKINITIC ROCKS

The unit of shonkinitic rock, as mapped, includes some mafic syenite and underlies about 10 square miles. These are the most abundant of the igneous rocks intrusive into the sedimentary rocks. In texture they range from very fine grained to coarse grained. Biotite, augite, and olivine occur as coarser grains in the rock. The dark minerals make up about 50 percent by volume of the unit, although the range is between 30 and 70 percent. In the Bearpaw Mountains arch the shonkinitic rocks are commonly coarse grained. Fine-grained varieties, equivalents of some of the volcanic rocks, occur as dikes and plugs in the volcanic field.

The large composite stock located north of Greenough Coulee, in the northwestern corner of the quadrangle, is composed essentially of coarse-grained, biotite-rich shonkinite intruded by less coarse grained to medium-grained shonkinitic and mafic syenitic rocks and still younger varieties of monzonitic rocks. Less than 10 percent of the shonkinite of this stock is nepheline and plagioclase (andesine).

The shonkinite sill exposed in the canyon of Peoples Creek in sec. 3, T. 28 N., R. 19 E. is also a composite intrusion and contains irregular bodies of mafic syenite and syenite. It has many inclusions derived from the Precambrian basement complex, principally gneiss, granite, and gabbro. Thin sections show that the rock contains sanidine, is free of nepheline and plagioclase, and locally contains quartz with a myrmekitic pattern that is most likely the result of contamination of the magma by the inclusions.

Intrusive bodies of nepheline shonkinite in volcanic rocks near Black Coulee in the southwestern part of the quadrangle in secs. 4 and 5, T. 26 N., R. 18 E. are massive, well-jointed rock containing relatively unaltered nepheline in addition to sanidine. The prominent volcanic plug named Blue Stone Peak in sec. 25, T. 27 N., R. 17 E. is a dense, very fine grained, dark-gray rock whose light-colored minerals include both sanidine and euhedral cloudy analcime that is probably primary in origin. In many of the shonkinitic dikes, the analcime grains are a conspicuous feature of the rock's texture.

Zeolitic alteration is common in the coarse-grained shonkinitic rocks. Clear analcime, natrolite, and calcite are the principal alteration products of the rock. Resorbed and altered olivine grains are another characteristic feature.

In general, the shonkinitic rocks in this quadrangle differ considerably in their proportion of dark to light minerals. In addition to sanidine some contain a substantial amount of feldspathoids and others a subordinate amount of plagioclase. Within an intrusive body of shonkinite where differentiation has produced mafic and felsic syenite, the essential light minerals are the same. If the shonkinite contains or is devoid of nepheline or plagioclase, so are the syenitic varieties. These shonkinitic rocks have chemical equivalents among the mafic volcanic rocks.

SYENITE

The syenites have a distinctively higher content of light-colored minerals than the shonkinites. With the exception of a small dikelike body along the northern border of the quadrangle, they are intrusive into volcanic rocks and are probably the intrusive equivalents of trachytic extrusive rocks.

Of the four bodies of syenite in the quadrangle, the largest is along the county road in secs. 23, 24, 25, and 26, T. 27 N., R. 18 E. This syenite is probably the most intensively altered of all the intrusive rocks in the quadrangle. Essentially composed of sanidine and augite, the rock locally shows extreme alteration to carbonate and clay minerals. The alteration is probably of hydrothermal origin rather than a result of weathering. The general color of the altered rock is light gray to purplish gray. The syenite contains abundant inclusion of Precambrian basement rocks.

Two other areas of syenite are in secs. 23 and 24, T. 28 N., R. 17 E. and secs. 16 and 21, T. 28 N., R. 18 E. The rock at the first locality is light gray and has a meshed fabric of sanidine tablets, whereas that at the second locality is greenish brown to tan, porphyritic, and has a well-defined planar fabric.

PORPHYRITIC LATITE

A great number of bodies of porphyritic latite intrude both sedimentary and volcanic rocks, and because of their resistant nature they form conspicuous topographic features. This rock type occupies about 7 square miles. The name "porphyritic latite" is used in preference to the name "monzonite" because the rock commonly has phenocrysts of feldspar in a fine-grained to glassy groundmass. In texture and color many varieties are identical to latite flows in the felsic volcanic unit. The greatest amount of intrusive porphyritic latite occurs in stocks and plugs of the volcanic field and most likely these intrusions were the source of much of the nearby latitic volcanic rocks.

The rock is light gray to brownish and greenish gray. It normally disintegrates to small, angular fragments. Characteristically the rock contains a great variety of inclusions of Precambrian basement rock. Phenocrysts of sanidine and plagioclase rarely are unaltered and are imbedded in a groundmass whose minerals are distinguishable in thin section only in a few varieties. The porphyritic latite that forms an elongate plug in sec. 36, T. 29 N., R. 17 E. is less fine grained than most other varieties and quartz is abundant in its groundmass. Quartz is generally absent as phenocrysts but must be an essential constituent of the groundmass in some varieties that are identical to rocks for which chemical analyses are available. As shown by Weed and Pirsson (1896), chemical analyses of similar rocks elsewhere in the Bearpaw Mountains contain 65–68 percent SiO_2.

PORPHYRITIC POTASSIC SYENITE

Dikes of prophyritic potassic syenite are abundant in the northern part of the quadrangle, where they intrude sedimentary, intrusive, and extrusive rocks. They are the tinguaites described by Weed and

Pirsson (1896). Commonly they form prominent linear topographic features. The dikes are as wide as 30 feet, as long as 2 miles, and occur in clusters and swarms having a predominantly eastward trend. A few have a northward trend. They are the youngest of all the intrusive rocks in the quadrangle.

This variety of syenite is light gray and weathers to greenish gray and light green. It is characteristically porphyritic with tabular phenocrysts of sanidine arranged in planar fabric parallel to the walls of the dikes. In a few dikes the phenocrysts constitute as much as 60 percent of the rock but more commonly they make up 20 to 30 percent. The groundmass is very fine grained and composed of sanidine and aegirite. Some dikes have subordinate amounts of either nepheline or quartz. When broken with a hammer, some speciments emit a fetid odor. Disseminated sulfides occur in many dikes and Pecora (1956) believes that the porphyritic potassic syenites are genetically related to most of the mineral deposits in the Bearpaw Mountains. Zircon from one locality was dated as 40 to 50 million years old by the lead-alpha method (Pecora and others, 1957).

EXTRUSIVE ROCKS

The extrusive rocks of the Maddux quadrangle constitute the eastern part of the southern volcanic field—the wide expanse of interlayered lava flows, and pyroclastic rocks (including sedimentary volcanic rocks) forming the south flank of the Bearpaw Mountains. They underlie most of the southern two-thirds of the quadrangle and are unconformable on rocks of Late Cretaceous, Paleocene, and early Eocene age. Their total areal extent is about 140 square miles, or 70 percent of the quadrangle. Locally the volcanic field includes some irregular bodies of intrusive rock indistinguishable from and merging with the flows. Plant fossils occur in the sedimentary volcanic rocks at several horizons within the volcanic pile. They are the same as fossil plant assemblages of middle Eocene (Green River) age that occur within the main part of the volcanic pile in the adjacent Warrick quadrangle (Pecora and others, 1957), according to R. W. Brown of the U.S. Geological Survey.

Within the Maddux quadrangle, the volcanic rocks form a monoclinal structure dipping northward at an average inclination of about 30°. The volcanic rocks in the northern part of the field are thus the younger part of the volcanic section. The present dip of the flows and pyroclastic beds is probably not an initial dip, because the flows are interbedded with fine-grained plant-bearing volcanic sandstones and shales which have the same inclination as the flows and presumably were deposited in nearly horizontal position. Because of the peculiar structural arrangement of the volcanic rocks, the aggregate measured thickness of the layered volcanic rocks does not necessarily represent the thickness of the volcanic pile. For example, the calculated maximum stratigraphic thickness, measured across the upturned edges of the flows and pyroclastic beds, is about 30,000 feet. This figure may actually represent a total of the thicknesses of moderately to steeply dipping flows and pyroclastic beds having a shinglelike arrangement within a broad gently dipping lenslike volcanic pile. If such a structural arrangement exists, the thickness of the volcanic pile actually ranges from a feather edge at its margins to a few thousand feet near its center.

Because the volcanic rocks were erupted during a very short interval of time, show repetitive lithology, and have the same plant fossils, it has not been possible to subdivide them into formal stratigraphic units that can be traced and identified from one place to another. Consequently, for mapping purposes, they have been separated on the basis of composition and fabric into four major lithologic units: mafic flow rocks, mafic pyroclastic rocks, felsic flow rocks, and felsic pyroclastic rocks.

MAFIC FLOW ROCKS

Mafic flow rocks are the most widespread of all the volcanic-rock units and occupy more than half the outcrop area of the volcanic rocks, or about 70 square miles. They occur throughout the volcanic pile, interlayered with mafic and felsic pyroclastic rocks and felsic flow rocks, and their aggregate stratigraphic thickness probably exceeds 15,000 feet.

The unit is made up principally of lava flows but probably includes some dikes, sills, plugs, and irregular intrusive bodies, that are indistinguishable from and merge with the flows. The flows consist largely of thick layers of reddish-gray, purplish-red, and dark-gray, highly altered and oxidized, rubbly, vesicular rock, interlayered with thin, irregular layers of dark-gray to black, fine-grained, massive rock. They are irregular to tabular in form and commonly of wide areal extent. Because of their complex layering it is difficult to estimate the thickness of individual flows. Flows built of alternating rubbly and massive layers are probably as much as 50 to 100 feet or so thick. Other flows are massive and only a few feet thick. Banding is common in many flows.

In general, fresh specimens of the mafic flow rocks are dark gray to dark brown or black, fine grained, porphyritic, and massive to vesicular. As mapped, they include mafic phonolite, with or without feldspathoids, and some mafic trachyte and mafic latite. Flows of mafic trachyte are next in abundance to mafic phonolite and flows of mafic latite are rare. Essential minerals are sanidine, euhedral analcime, augite, olivine, and biotite; common accessory minerals are magnetite and apatite. The principal alteration minerals are calcite, fibrous natrolite, clear analcime, and other zeolites. Mafic analcime phonolite is the most abundant type of rock in the unit. It is devoid of plagioclase and quartz, is locally rich in olivine, and commonly contains light-gray, greenish-gray, and reddish-gray euhedra of analcime and pseudoleucite. The analcime has the same crystal form and habit as leucite, and it cannot be satisfactorily determined if some or all the analcime is primary in origin or if most is secondary and results from a late magmatic alteration of original leucite. Fresh leucite has not been positively identified in any of the rocks from the Maddux quadrangle, although it occurs in some rocks from adjoining quadrangles. The mafic trachyte flows are characterized by oriented laths of sanidine and are devoid of feldspathoids. The mafic latite flows have plagioclase (principally andesine) as an essential constituent, in addition to sanidine, and generally are devoid of feldspathoids.

The color index of the mafic flow rocks is generally between 40 and 70. However, in the field, a strict dividing line cannot be established to separate these rocks from related less-mafic but still dark-colored varieties of phonolite, trachyte, and latite, and small amounts of these intermediate types are probably included within the mafic flow rock unit.

The generally tabular shape and wide areal extent of the mafic flows suggests that they were extruded in relatively quiet fashion as fairly fluid lavas, probably from many different fissure and central vent sources during several episodes of volcanic activity.

MAFIC PYROCLASTIC ROCKS

Pyroclastic rocks of predominantly mafic character occur at several horizons within the volcanic pile interlayered with mafic and felsic flow rocks and with felsic pyroclastic rocks. They are distinguished from the mafic flow rocks by their fragmental nature and from the felsic pyroclastic rocks by their composition. They are exposed over a total area of about 12 square miles, and their aggregate stratigraphic thickness within the volcanic pile probably exceeds 4,000 feet.

In general, the unit consists of interbedded layers of light- to dark-gray, dark-green, black, or red to purplish variegated breccias, tuff-breccias, tuffs, and associated sedimentary volcanic rocks such as sandstone, mudstone, siltstone, and conglomerate. The predominant type of pyroclastic rock is tuff-breccia, in which large angular to subrounded blocks of mafic rock, as much as 3 feet in diameter, are enclosed in a matrix of coarse tuff. Lapilli tuffs and fine- to coarse-grained tuffs are scarce.

The mafic pyroclastic rocks are composed chiefly of angular to subrounded blocks of several varieties of mafic phonolite, but there are also blocks and smaller fragments of mafic trachyte and mafic latite. Locally, the rocks contain accessory fragments of such felsic rocks as latite, quartz latite, and trachyte; commonly where such fragments are abundant, the rocks also contain a great variety of inclusions of Precambrian basement rocks. At one locality, in secs. 17, 18, and 19, T. 28 N., R. 17 E., the deposits also contain numerous fragments of silicified and metamorphosed shale and sandstone and a few of limestone from the Cretaceous sedimentary rocks underlying the volcanic field.

A typical occurrence of the pyroclastic rocks is the thick sequence at the base of the volcanic pile in the eastern and extreme southern parts of the quadrangle. In the southern part of the quadrangle the thickness of the deposits is about 2,000 feet and the beds dip northward 30° to 65°. At many places along the eastern border of the volcanic field the basal part of the mafic pyroclastic unit contains beds of fossiliferous volcanic sandstone, mudstone, siltstone, and conglomerate, which are locally well stratified.

The fragmental character of the pyroclastic rocks indicates that they were produced by explosive volcanic activity. Probably they were erupted from several vent sources. The associated sedimentary volcanic rocks were formed by local reworking of volcanic materials on slopes and in streams, and some of the clastic deposits probably accumulated in small ponds and lakes.

FELSIC FLOW ROCKS

Felsic flow rocks occur throughout the volcanic pile and are interlayered with mafic flow rocks and mafic and felsic pyroclastic rocks. They are noticeably less widespread than the mafic flow rocks and have a total extent of about 50 square miles. Their aggregate stratigraphic thickness probably exceeds 5,000 feet. They are distinguished from associated mafic flow rocks chiefly by their lighter color and from felsic pyroclastic rocks by their massive internal structure.

The unit is principally one of lava flows and flow breccias, but includes some sills, dikes, plugs, and irregular intrusive bodies that are indistinguishable from and merge with the flows. The flows are generally light gray, yellowish gray, brownish gray, and tan, fine grained porphyritic, and massive. Some are conspicuously banded and a few are vesicular. The flow breccias are composed of similar rock that has been fragmented during flow, and, where exposures are poor, it is generally impossible to distinguish these rocks from massive flows. Many of the thicker felsic flows have a composite structure, in which the basal and marginal portions are brecciated and rubbly and the upper part is massive and banded. Generally individual felsic flows are highly irregular in form and thickness and are continuous only over short distances. The thickness of the flows ranges from a few feet to perhaps several hundred feet. The maximum lateral extent of a single flow is about 3 miles. In contrast to the mafic phonolite flows, the felsic flows tend to be massive and uniform and lack a well-developed layered structure.

Within the unit, the most common type of rock is quartz latite. Latite plagioclase-bearing trachyte, and trachyte are less abundant. Essential minerals are sanidine, plagioclase (oligoclase to andesine), quartz, augite, biotite, and hornblende. The common accessory minerals are magnetite and apatite; zircon is rare. Alteration minerals include chalcedony, calcite, blue-green celadonite, and, locally, green heulandite. The rocks are commonly porphyritic and characterized by small phenocrysts of feldspar, augite, and biotite enclosed in a fine-grained to glassy groundmass. The proportion of plagioclase and sanidine is widely variable in different rocks. Quartz is generally absent as phenocrysts but is common in the groundmass of the quartz latites. Biotite is abundant in some varieties of latite and trachyte. The color index of the rocks ranges from 5 to 40 but is generally between 5 and 20.

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

The irregular shape and thickness of the flows and their small lateral extent suggest that they were relatively viscous when erupted and formed as short stubby flows. Probably they were derived from many vents during several episodes of volcanic activity. Many units mapped as flows may well be sills intruding older volcanic rocks near the source vents.

FELSIC PYROCLASTIC ROCKS

Pyroclastic rocks of predominantly felsic composition are interlayered with mafic and felsic flow rocks and mafic pyroclastic rocks at several horizons in the volcanic pile. They have a total extent of about 8 square miles and are slightly less abundant in the volcanic pile than the mafic pyroclastic rocks. Their aggregate stratigraphic thickness within the volcanic-rocks sequence probably exceeds 3,500 feet. They are distinguished from associated felsic flow rocks by their fragmental structure and from mafic pyroclastic rocks by their felsic composition.

In general, the unit consists of interbedded light-gray, brownish-gray, yellowish-brown, greenish-gray, and variegated breccias, tuff breccias, tuffs, agglomerate, mudflows, and associated sedimentary volcanic rocks such as sandstone, conglomerate, siltstone, and mudstone. The predominant types of pyroclastic rock in the unit are breccia and tuff breccia, some deposits containing blocks as much as 6 feet in diameter. Tuff is not abundant.

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

A typical exposure of the felsic pyroclastic rocks is along the eastern border of the volcanic field in sec. 29, T. 27 N., R. 19 E. Here these rocks have a maximum aggregate stratigraphic thickness of about 1,500 feet. The most conspicuous deposit is a thick bed of breccia consisting of an unsorted jumble of large blocks of quartz latite and latite set in a finer matrix of tuff and having a chaotic internal structure similar to that of valconic mudflows or deposits of vent breccia.

At several localities, notably in the SW¼ sec. 18, T. 28 N., R. 18 E., the felsic pyroclastic rocks contain beds of coarse volcanic sandstone and finer mudstone. These beds are ordinarily well stratified and contain plant fossils of middle Eocene age.

The felsic pyroclastic rocks are the products of explosive volcanic activity and probably were erupted from several source vents during several episodes of eruption. The sedimentary volcanic rocks represent local reworking of primary pyroclastic materials by streams, and some of the materials may have been deposited in small ponds and shallow lakes.

STRUCTURAL GEOLOGY

REGIONAL SETTING

The Bearpaw Mountains uplift is one of several isolated uplifts of Tertiary age in the stable area east of the deformed belt of the Rocky Mountain geosyncline. The relative positions of these uplifts in the northern Great Plains in Montana is well shown on the Montana State geologic map (Ross and others, 1955) and on the structure contour map of part of the State prepared by Dobbin and Erdmann (1955). The principal structural feature of the Bearpaw Mountains uplift is the "Bearpaw Mountains structural arch" which trends eastward for a distance of about 40 miles. The arch is bordered on the north and on the south by a volcanic field. In most places along the border of the volcanic fields the flows and pyroclastic rocks rest with angular unconformity on older sedimentary rocks, but in several places the border is marked by normal faults. Intrusive masses also occur at the border in many places.

BEARPAW MOUNTAINS STRUCTURAL ARCH

The northern part of the Maddux quadrangle covers part of the crest and southern flank of the Bearpaw Mountains structural arch, an eastward-trending belt of uplifted and deformed sedimentary rocks that has been extensively intruded by many types of igneous rocks. Within this quadrangle the maximum difference in elevation between stratigraphic horizons along the crest of the arch and the same horizons in the plains area is about 5,000 feet.

In the northwestern part of the quadrangle, in the Greenough Coulee area, the sedimentary rocks of the arch are tightly folded and highly metamorphosed. The dome in secs. 28, 29, 32, and 33, T. 29 N., R. 18 E. displays a fault pattern that suggests an early stage in the evolution of "trap door" faulted domes so common in the Bearpaw, Little Rocky, and Judith Mountains. The dome probably represents the exposed roof area of a concealed, stocklike, igneous mass (structure section A–A′, pl. 3.). A prominent northward trending synclinal structure east of the dome is transverse to the main trend of the arch and has preserved the Judith River formation of the Montana group (Upper Cretaceous) at the same general elevation as the Jurassic and Lower Cretaceous rocks to the west and east. South of Peoples Creek the Montana group is only gently folded and forms the southern flank of the arch.

On the limbs of tightly folded structures in the arch, tectonic thinning of the shaly formations is common. Faults in the arch area are of high angle, and their maximum displacement is about 500 feet. Dike swarms reflect a prominent fracture set that follows the trend of the arch.

SOUTHERN VOLCANIC FIELD

The southern volcanic field, as shown in this quadrangle, is an irregular mass formed essentially of a pile of layered rocks dipping northward toward the arch, mostly at angles of 10°–65°. The average dip is about 30° for the pile. Their attitude is certainly not one of initial deposition for interlayered sedimentary volcanic rocks have the same dip as the enclosing flows. Reeves (1924a, 1924b, 1925, 1946) suggested that this inward dip toward the arch is the result of plainsward landsliding of the volcanic pile simultaneously creating shallow thrusts in the bordering plains area. However, Reeves' landslide hypothesis cannot be supported by the observations of the present writers.

DEFORMATION PRIOR TO VOLCANISM

Along the margin of the southern volcanic field in the Maddux quadrangle and in adjoining quadrangles to the west, a jagged pattern of graben blocks containing displaced Upper Cretaceous and Tertiary formations is overlain unconformably by the earliest volcanic rocks, indicating that faulting of the sedimentary floor, on which the volcanic pile accumulated, occurred prior to volcanism. The stratigraphic displacement on these faults is as much as 3,000 feet. Adjacent to the faults, folding was intense locally. The jagged pattern of graben blocks does not extend more than a mile beyond the present border of the volcanic field. Exposures along re-entrants into the volcanic field suggest, moreover, that other graben blocks are concealed beneath volcanic pile.

DEFORMATION INVOLVING VOLCANIC ROCKS

Evidence for deformation of the volcanic rocks is abundant in the southeastern corner of the quadrangle, particularly in the area northeast of Goat Mountain. Here tuff breccia and stratified, waterlaid volcanic deposits that rest unconformably on different sedimentary formations have undergone such intense deformation that the unconformity itself is now a warped and broken surface. Sheared and slickensided surfaces are common both in volcanic rocks and in sedimentary rocks.

The prominent northwestward-trending fault cutting volcanic rocks in sec. 3, T. 26 N., R. 19 E. is most probably a recurrent fault; for along Als Creek, in sec. 29, T. 27 N., R. 19 E., its trace appears to be offset and passes under a massive pile of tuff breccia, agglomerate, and waterlaid volcanic rocks dipping 40°–50° to the northeast. Although the fault cannot be traced northwestward beyond Als Creek, the topography along the presumed northwestward extension of the fault trace certainly suggests some type of structural control.

The northward-dipping monoclinal structure of the volcanic pile presumably developed at some time after volcanism. It cannot be established from field evidence whether this monoclinal structure developed during a single episode or during successive stages as volcanism progressed. The absence of reliable and extensive marker beds in the pile hinders any inquiry into the nature of this deformation. Displacement of initially horizontal or nearly horizontal layers of sedimentary volcanic rocks to their present attitude is incontrovertible evidence, however, of some kind of large-scale deformation involving the volcanic pile.

The crescentric fault near Peoples Creek, roughly parallel to the border of the volcanic field, may have displaced this part of the volcanic pile downward 500–1,500 feet. The strike of the volcanic rocks recorded in that general area swings more northerly than those in the central part of the quadrangle. In and near sec. 3, T. 27 N., R. 19 E. the flows of mafic and felsic rocks form a gentle synclinal structure. In and near secs. 1 and 12, T. 27 N., R. 18 E. the attitude of the flows suggest a doubly plunging anticline and a northward-plunging synclinal warp.

The northern border of the volcanic field along Peoples Creek, near Murphy Butte, is concealed by a dense growth of timber along a prominent scarp. If this is a fault scarp, the fault does not appear westward in the valley of Clear Creek, where the rocks are well exposed. The latite of Murphy Butte is intrusive, but the volcanic rocks east and west of it are interlayered flows that dip toward the scarp.

AGE OF DEFORMATION

Deformation in this area interrupted deposition of the Wasatch formation in late early Eocene time and continued through middle Eocene time. It is most probable that the Bearpaw Mountains structural arch and its folded and down-faulted bordering area was an area of low relief at the beginning of volcanism. Both the arch and the sedimentary floor beneath the volcanic pile were continually pierced by dikes, plugs, and stocks and faulted during the course of igneous activity. The arch was an active structural element, therefore, throughout middle Eocene time. It cannot be established from the geologic evidence in this quadrangle whether the general dip of the volcanic rocks northward toward the arch is the result of successive collapse in the area or of wholesale landslide. Collapse faulting is preferred by the present writers, from the information at hand.

ECONOMIC GEOLOGY

Early homesteaders in the area obtained lignite and low rank coal for home use from the Judith River and Fort Union formations. Their excavations are now caved and abandoned. The coal of best grade in the quadrangle is in the Fort Union formation in sec. 22, T. 26 N., R. 19 E., where the coal is of subbituminous rank and the seam is 6–10 feet thick.

Natural gas and petroleum are recovered in other parts of the region. The Bowes dome, located 20 miles north of the northeast corner of this quadrangle, has yielded gas from the upper part of the Eagle sandstone since 1926 and petroleum from the Sawtooth formation since 1949. Exploration for gas and petroleum is active in this area.

Bentonite beds are plentiful in the marine-shale formations, but they are rarely more than a foot thick. Multiple beds occur as a zone at the base of the Clagget shale and in some parts of the Niobrara shale equivalent. The thick Clay Spur bentonite bed (Knechtel and Patterson, 1956) in the upper part of the Mowry shale of northern Wyoming and southern Montana has not been observed in this quadrangle. Dams constructed of shale containing bentonite have less leakage than those built of other materials.

Sand and gravel deposits are rare in this area; but many rock formations can be used for special construction purposes. Vesicular mafic phonolite provides an excellent surface material for roads. Many of the intrusive-rock masses are also excellent sources of abundant road metal. The dense, jointed rock of the plug at Blue Stone Peak is especially well suited for riprap and is similar to that used for surfacing the Bull Hook Creek dam near Havre, Montana.

Prospect pits exposing metalliferous deposits are numerous in the northwestern part of the quadrangle. Galena, pyrite, and chalcopyrite are the principal ore minerals (Pepperberg, 1909). The veins, however, are rarely more than an inch wide and occur in discontinuous fracture zones rather than in persistant fractures. No metal production is known from this quadrangle either through shaft or placer mining.

Because rainfall is meager, springs are few. Water of the best quality issues from springs in the lower part of the Eagle sandstone. Springs issue also from permeable zones in the volcanic rocks. Wells dug in surficial deposits are shallow but productive.

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