Geology of the Northwest Quarter of the Anaconda Quadrangle Deer Lodge County, Montana

By ALEXANDER A. WANEK *and* C. S. VENABLE BARCLAY

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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Geology and mineral resources of part of the Anaconda quadrangle near Butte, Montana

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CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY OF THE NORTHWEST QUARTER OF THE ANACONDA QUADRANGLE, DEER LODGE COUNTY, MONTANA

By ALEXANDER A. WANEK and C. S. VENABLE BARCLAY

ABSTRACT

The northwest quarter of the Anaconda quadrangle covers about 52 square miles in Deer Lodge County in southwestern Montana. This quarter of the quadrangle includes the southeastern part of the Flint Creek Range, the extreme northeastern part of the Anaconda Range, and part of the west side of Deer Lodge Valley.

Rocks of Precambrian, Cambrian, Mississippian, Pennsylvanian, Cretaceous, Tertiary, and Quaternary age are exposed in the quadrangle. Certain units of Cambrian, Devonian, Permian, Jurassic, and Cretaceous age are present in the subsurface but are missing at the surface because of faulting. The stratigraphic units are exposed in normal succession in the adjoining Philipsburg quadrangle.

The Eocene rocks are divided into a threefold volcanic sequence correlated with the Lowland Creek Volcanics exposed near Butte, Mont. These Eocene rocks are overlain by a conglomerate unit of probable Miocene age and beveled by gravel of middle Pliocene age. Coal beds are in the volcanic breccia and red-bed member, which is the youngest unit of the Lowland Creek Volcanics, and in the overlying conglomerate unit.

Glacial moraine deposits are along Lost Creek. Colluvium and landslide deposits occur along steep slopes above the valleys, and alluvium and terrace gravel are along stream channels.

In general, the Precambrian and Paleozoic rocks crop out in the northwestern part of the quadrangle, where they are thrust faulted against Mesozoic strata and intruded by granite along zones of faulting. The major deformation occurred in Late Cretaceous or early Tertiary time, and periods of minor deformation followed during the Eocene, Miocene(?), and the Pliocene Epochs. Tertiary strata consecutively bevel the older rocks and in many places are in fault contact with them.

Granitic intrusions were concurrent with the thrusting and penetrated Precambrian, Paleozoic, and Mesozoic strata. Later intrusions consisted of andesite plugs emplaced in Eocene and Miocene(?) rocks in the valley of Warm Springs Creek.

Coal and other mineral resources in the area have not been exploited. The coal beds are thin and composed of lignite and are of no economic value. Phosphate occurs in the Phosphoria Formation at depths greater than 2,000 feet below the surface. Gold mining has been abandoned. The gravel deposits are utilized in highway construction and in concrete aggregate.

INTRODUCTION

The northwest quarter of the Anaconda quadrangle covers an area of about 52 square miles in Deer Lodge County in southwestern Montana. The south and north boundaries are at lat 46°07′30″ N. and 46°15′ N., respectively, and the east and west boundaries are at long 112°52′30″ W. and 113° W., respectively (pl. 1). The town of Anaconda, Mont., is in the southwestern part of the report area. U.S. Highway 10A connects Anaconda, Philipsburg, and Butte, Mont. Deer Lodge, Mont., the county seat, lies about 10 miles north of the northeast corner of the quadrangle in Deer Lodge Valley and can be reached via U.S. Highways 10A and 10 from Anaconda. Jeep trails and several good gravel roads serve the area. The Chicago, Milwaukee, St. Paul, and Pacific Railroad and the Northern Pacific main line traverse Deer Lodge Valley from Butte north to the cities of Deer Lodge, Missoula, and Helena. The Butte, Anaconda, and Pacific Railroad operates a spur track between Butte and Anaconda to haul ore concentrates and processing materials for the Anaconda smelter. Several commercial airlines maintain airport facilities at Deer Lodge and Butte.

Physiographically, the northwest quarter of the Anaconda quadrangle is divisible into three areas: the east slope of the Flint Creek Range, part of the north slope of the Anaconda Range, and part of the west side of Deer Lodge Valley (fig. 1). The foothills of the Flint Creek Range are rounded and grass covered and rise abruptly from the floor of the valley. They merge in the west with the rugged central peaks of the range. South of the valley of Warm Springs Creek, the relief is great, and the land surface rises steeply to the crest of the Anaconda Range. The floor of Deer Lodge Valley is flat and surfaced by dissected terraces that slope eastward to the alluvial plain of the Clark Fork of the Columbia River.

All drainage in the area is tributary to Clark Fork of the Columbia River, which flows northward through the Deer Lodge Valley. Perennial streams such as Lost Creek, Warm Springs Creek, Antelope Creek, and other smaller streams drain the east slope of the Flint Creek Range and the north slope of the Anaconda Range.

Deer Lodge Valley lies in the rain shadow of the Flint Creek and the Anaconda Ranges. Mean annual precipitation ranges from approximately 10 inches at Deer Lodge to 13 inches at Anaconda. Part of the land in the valley is irrigated, and an abundant crop of potatoes is raised annually. Much of the foothills is used for grazing cattle and sheep. The higher slopes of the Flint Creek Range are covered by heavy stands of lodgepole pine and some Engelmann spruce (*Picea engelmanni*). Logging operations began in 1961, and all the cut timber is processed at the sawmill in Deer Lodge.

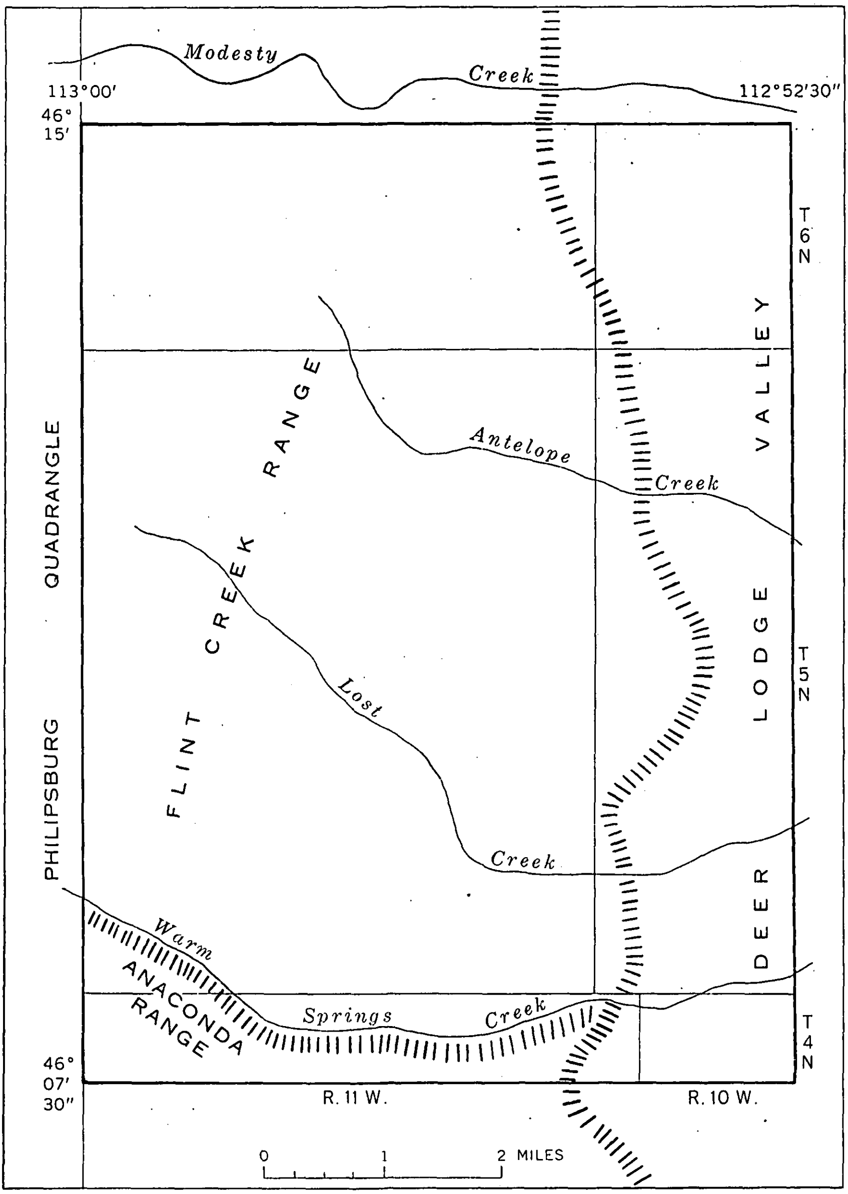

Figure 1.—Northwest quarter of the Anaconda quadrangle and part of the adjoining area.

Several geologists have worked in the Anaconda quadrangle or adjacent areas. Douglass (1909) made a reconnaissance in which he studied the Tertiary history of Montana and the occurrences of Tertiary rocks just east of the Philipsburg quadrangle. Emmons and Calkins (1913) and Calkins and Emmons (1915) studied the geology and the ore deposits in the Philipsburg quadrangle and reported on the western part of the Anaconda quadrangle. Pardee (1913) included the quadrangle in his coal investigations of the Tertiary lake beds of southwestern Montana. Pardee (1917), in connection with studies of the Garrison and Philipsburg phosphate fields, described briefly the stratigraphy and structure of the Flint Creek Range. A reconnaissance of the quadrangle was made for the geologic map of Montana (Ross and others, 1955). Alden (1954) correlated the glacial geology of the Flint Creek Range with adjacent areas in western Montana. McGill (1959), Mutch (1960), and Gwinn (1961) mapped the geology of parts of the Flint Creek Range and the Drummond quadrangle. Ruppel (1961) made a reconnaissance study of the geology and mineral deposits of the Deer Lodge quadrangle. Konizeski, McMurtrey, and Brietkrietz (1961) made a preliminary report on the ground water resources of the northern part of the Deer Lodge Valley. Smedes (1962) correlated the Tertiary volcanics of the Butte area with the volcanic rocks near Anaconda.

The present investigation was done in 1961 and 1962 as part of the geologic quadrangle mapping and land classification program of the U.S. Geological Survey. A. F. Bateman, Jr., contributed valuable geologic information and criticism during this investigation.

Geologic mapping was done on aerial photographs at a scale of 1:20,000. All geologic and cultural data were plotted on the photographs and later transferred to a topographic base at scale 1:24,000 by inspection or by means of a reflecting projector. Spot altitudes on contacts, obtained by aneroid barometer surveys, aided in accurately transferring the geology to the topographic maps.

STRATIGRAPHY

The sedimentary rocks in the northwest quarter of the Anaconda quadrangle range from late Precambrian to Tertiary in age (pl. 2). In general, Precambrian and Paleozoic rocks crop out in the northwestern part of the quadrangle; they are intruded by granite and faulted against Mesozoic strata. Mesozoic and Cenozoic rocks are in the foothills of the Flint Creek and the Anaconda Ranges. Glacial moraine deposits are along Lost Creek; colluvium and landslide deposits occur along steep slopes above the valleys, and alluvium and terrace gravel are along stream channels.

The Silver Hill, Hasmark, and Red Lion Formations of Middle and Late Cambrian age, the Maywood and Jefferson Formations of Late Devonian age, the Phosphoria Formation of Permian age, sedimentary rocks of Jurassic age, and the Kootenai Formation of Early Cretaceous age are present in the subsurface but are absent at the surface due to faulting. These rocks are well exposed in the adjacent Philipsburg quadrangle to the west.

PRECAMBRIAN SYSTEM

The oldest rocks exposed are the Newland and Spokane Formations of late Precambrian age; these two formations have been assigned to the Belt Series (Walcott, 1899). The Belt rocks occupy about 4 square miles in the northwestern part of the quadrangle but are more extensively exposed in the upper canyon of Lost Creek within the adjacent Philipsburg quadrangle to the west. In general, the strata are silty shale, sandstone, and thin limestone beds that were deposited in shallow seas. The sequence is unconformably overlain by the Flathead Quartzite of Middle Cambrian age. In places the Belt Series is truncated by volcanic rocks of Tertiary age. The aggregate thickness of the Belt is about 14,000 feet (Emmons and Calkins, 1913).

Several periods of deformation occurred in the late Precambrian and in the Paleozoic. The most intense deformation, however, was much later during the Laramide orogeny in the Late Cretaceous and the early Tertiary. Compressive folding and intrusion by granite locally altered the Precambrian and younger rocks into schist and low-grade metamorphic rock.

NEWLAND FORMATION

The Newland Formation, the older unit in the Belt Series, is well exposed in the steep cliffs along Lost Creek. Emmons and Calkins (1913, p. 42) believed that the Newland Formation is about 4,500 feet thick in the Philipsburg quadrangle. In the northwest quarter of the Anaconda quadrangle, the calcareous argillaceous strata of the Newland Formation have been altered to hornfels in areas bordering large granite intrusions. The low-grade metamorphic rocks are very fine grained, siliceous, and dark gray to grayish green. The weathered strata show bedding 1–6 feet thick. The "beds" have a banded appearance ranging from white to grayish green and are deeply grooved along pseudobedding planes on the weathered surface. In places the rocks are discolored by small masses of limonite and ferromagnesian minerals. The thick beds of purer limestone have been locally altered to light-gray marble on the divide between Timber Gulch and Modesty Creek in secs. 27, 28, and 34, T. 6 N., R. 11 W.

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In thin section the limestone of the Newland Formation shows alteration to a diopside-quartz-calcite-hornfels which includes minor amounts of plagioclase. Chlorite is probably an alteration product of diopside. The accessory mineral is magnetite. The shale beds near intrusions are altered to greenish-gray and brownish-black scapolite and diopside-bearing schist.

Emmons and Calkins (1913, p. 43) stated,

> The common alteration of the Newland rocks is to dense hornfels containing abundant diopside or amphibole, or both, accompanied by quartz and feldspar, with titanite as a constant accessory. Biotite is commonly present, but subordinate to the other magnesian silicates. Residuary calcite may occur in considerable or insignificant amount, the maximum proportion which is rarely approached being approximately 50 percent.

Correlation of the Newland Formation with formations in the Belt Series in other places in Montana and Idaho is tentative. Ross (1949, 1959) correlated the Newland Formation with the Wallace Formation of western Montana and Idaho and with the Siyeh Limestone of Glacier National Park and adjoining areas. The Newland Formation is conformable and transitional to the overlying Spokane Formation.

SPOKANE FORMATION

The Spokane Formation, the uppermost unit in the Belt Series, is exposed in discontinous outcrops along faults north of Lost Creek and in more extensive outcrops at the head of Timber Gulch. Emmons and Calkins (1913) estimated that the thickness of the Spokane Formation ranged from 200 to more than 9,000 feet in the Flint Creek Range and recognized that the variation in thickness is caused by an unconformity at the top of the formation. The Spokane rocks in the area are medium- to thick-bedded dark-gray impure quartzite intercalated with dark-green, greenish-gray, and brownish-black cordierite schist. The quartzites are banded light gray to light greeen, and the dark layers seem to be composed of hematite and biotite. Colorless mica and amphibole are abundant.

The schistose rocks are brownish gray and contain abundant round dark protuberances on weathered surfaces. Emmons and Calkins (1913) found that the protuberances are small masses of cordierite and andalusite. Some masses are distinctly crystalline and contain large flakes of mica.

In the Philipsburg quadrangle, the Spokane Formation exposed in the canyon of Flint Creek is unaltered medium- to thick-bedded reddish-brown to grayish-orange sandstone and siltstone; the rocks are cross laminated and ripple marked. The reddish color is a characteristic feature in distinguishing these strata. The Spokane rocks are not resistant to erosion and generally weather into low rounded hills.

Ross (1949) correlated the Spokane Formation with part of the strata in the Missoula Group and also considered it to be equivalent in part to the "Red Band" of the Siyeh Limestone in Glacier National Park (Ross, 1959). The Spokane Formation is unconformably overlain by the Flathead Quartzite.

CAMBRIAN SYSTEM

FLATHEAD QUARTZITE

The Flathead Quartzite (Peale, 1893) of Middle Cambrian age forms several isolated outcrops in the northwestern part of the quadrangle where blocks of the quartzite are preserved along the faults. The quartzite is very resistant to erosion, and west of the mapped area it forms steep cliffs. Emmons and Calkins (1913) estimated the Flathead Quartzite to be 20–200 feet thick. This unit is cliff-forming massive- to thick-bedded light-gray to white vitreous quartzite that locally is tinted rose by hematite and limonite impurities. The white vitreous quartzite can be readily distinguished from the gray quartzite beds in the Spokane Formation.

The base of the Flathead Quartzite was not observed in the northwest quarter of the Anaconda quadrangle. Emmons and Calkins (1913) described an angular discordance between the Flathead and the Spokane Formations near the Carp mine in the Philipsburg quadrangle. At another locality south of Lost Creek, just west of the Anaconda mapped area, the contact between these formations seemed discordant. At that locality the Flathead Quartzite contains a basal conglomerate.

The Flathead is widespread in Montana and northwestern Wyoming, and has been generally recognized as the base of the Paleozoic section in this region. At most places it rests unconformably on the Belt Series or older Precambrian schist or gneiss. The rocks of the Spokane and the Flathead Formations are believed to have been deposited in shallow-water environments.

The Flathead Quartzite is conformably overlain by the Silver Hill Formation, which is not exposed in the Anaconda quadrangle.

CAMBRIAN AND DEVONIAN ROCKS NOT EXPOSED

The rocks above the Flathead Quartzite and below the Madison Limestone are not exposed at the surface in the northwest quarter of the Anaconda quadrangle because of faulting, but they are believed to occur in normal stratigraphic position at depth. The formations between the Flathead Quartzite and the Madison Limestone are briefly described herein, but more detailed descriptions of these rocks in the Philipsburg quadrangle are given by Emmons and Calkins (1913).

The Silver Hill Formation of Middle Cambrian age is 100–600 feet thick and consists of light-gray, brown, and greenish-gray calcareous shale and intercalated limestone beds that contain thin siliceous laminae. The Silver Hill Formation is conformably overlain by the Hasmark Formation.

The Hasmark Formation of Late Cambrian age is about 1,000 feet thick and is composed mainly of carbonate rocks. The upper 350 feet and the lower 550 feet consist of cliff-forming thick-bedded light-gray dolomite separated by 150 feet of dark-brown shale and nodular limestone. The Hasmark Formation is conformably overlain by the Red Lion Formation.

The Red Lion Formation of Late Cambrian age is about 280 feet thick and is composed of an upper part of thin-bedded light- to blue-gray limestone which has closely spaced wavy siliceous laminae and a lower part of black shale which has some interbeds of olive-green shale, gray-green sandstone, and flaggy red magnesian limestone. The Red Lion Formation is unconformably overlain by the Maywood Formation.

The Maywood Formation of Late Devonian age is about 250 feet thick and consists mainly of thin-bedded reddish- and light-gray dolomitic limestone intercalated with gray and olive-green calcareous shale. The Maywood Formation is conformable with the overlying Jefferson Dolomite.

The Jefferson Dolomite of Late Devonian age is about 1,000 feet thick and consists mainly of cliff-forming massive light-gray dolomite and intercalated limestone beds. The formation is conformably overlain by the Madison Limestone, which crops out at the surface in the quadrangle.

MISSISSIPPIAN SYSTEM

MADISON LIMESTONE

The Madison Limestone (Peale, 1893) of Early and Late Mississippian age crops out in a wide belt that crosses Lost Creek near its confluence with Timber Gulch in secs. 9, 10, and 15, T. 5 N., R. 11 W., and also crops out north of Warm Springs Creek in sec. 17. The unit is about 1,200 feet thick and consists of cliff-forming massive dark-gray fossiliferous limestone containing numerous thin chert layers. Rocks in the lower part of the formation are thin bedded and contain some intercalated shale beds. Beds of light-gray limestone are increasingly numerous in the upper part of the formation, and the limestone comprising these beds is finely crystalline. The abundance of chert varies by locality. The chert layers are, in general, irregular masses roughly parallel to bedding and are most abundant in the upper massive limestone.

Most of the Madison Limestone exposed in the quadrangle is in the upper part of the formation. The strata are fossiliferous, and crinoid stems are the most abundant fossil remains. In localities where the rock is altered by contact metamorphism, the Madison Limestone is coarsely crystalline or marbelized and varies from light gray to very dark gray. White or gray tremolite occurs in the contact zones in abundance.

The lower part of the Madison Limestone is not exposed in the quadrangle but is well exposed along the highway in the vicinity of Silver Lake near Georgetown. The lower part consists of an estimated 300 feet of very dense flaggy limestone that is dark bluish gray to nearly black. Thin beds of black compact shale are intercalated with the limestone beds.

G. H. Girty (*in* Emmons and Calkins, 1913) examined the fossil collection from the Madison Limestone in the Philipsburg quadrangle and referred these rocks to the Lower Mississippian. The lower and upper parts of the Madison in Montana and western Wyoming are believed by the authors to be correlative with the units mapped as the Lodgepole Limestone and the Mission Canyon Limestone, respectively, if the usage of Collier and Cathcart (1922, p. 173) is followed.

The upper part of the Madison Limestone is conformable and gradational with the Amsden Formation.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

AMSDEN FORMATION

The Amsden Formation (Darton, 1904) of Mississippian and Pennsylvanian age forms several isolated outcrops in secs. 4 and 16, T. 5 N., R. 11 W. This formation is about 300 feet thick and near Lost Creek consists of slope-forming soft reddish-brown shale interbedded with thin grayish-red fossiliferous limestone and medium- to thick-bedded fine- to medium-grained sandstone. The Amsden Formation is overlain conformably by the Quadrant Formation. In sec. 16, south of Lost Creek, the top of the Amsden is concealed by soil cover and its contact with the Quadrant Formation is arbitrarily placed at the break in slope below the lowest massive sandstone bed in the Quadrant. Elsewhere in the quadrangle, the Amsden Formation is faulted against Precambrian, Paleozoic, and Mesozoic strata. The Amsden is poorly exposed but the extent of the formation is usually indicated by red float.

Emmons and Calkins (1913) included the Amsden Formation as a unit of the Quadrant Formation.

PENNSYLVANIAN SYSTEM

QUADRANT FORMATION

Strata assigned to the Quadrant Formation (Peale, 1893) of Pennsylvanian age crop out in the high ridge between Warm Springs Creek and Lost Creek in secs. 16 and 17, T. 5 N., R. 11 W., and in Timber Gulch in secs. 9 and 10, T. 5 N., R. 11 W. The Quadrant is 150–200 feet thick and consists of cliff-forming massive light-gray quartzitic sandstone that is locally much fractured and cut by veinlets of calcium carbonate. The massive beds show poorly defined cross-lamination. The sandstone is well sorted, medium grained, and cemented by quartz and some iron oxide. The weathered surface of the sandstone is generally buff. In the quadrangle the base of the Quadrant Formation is usually covered, and the contact is mapped at the break in slope below the lowest massive sandstone. Along Timber Gulch the Quadrant Formation is faulted against the Madison Limestone and Amsden Formation.

In the Philipsburg quadrangle the Quadrant Formation as mapped by Emmons and Calkins (1913) included units which, in accordance with present usage, are subdivided into the Amsden, Quadrant, and Phosphoria Formations. Pardee (1917), on the basis of the occurrence of phosphate, separated the Phosphoria Formation from the Quadrant Formation in the Garrison and Philipsburg phosphate fields. The Quadrant Formation is overlain conformably by the Phosphoria Formation, which was not found at the surface in the northwest quarter of the Anaconda quadrangle.

PERMIAN, JURASSIC, AND CRETACEOUS ROCKS NOT EXPOSED

The rocks above the Quadrant Formation and below the Colorado Shale are not exposed at the surface because of faulting but are believed to occur in normal stratigraphic position at depth in the northwest quarter of the Anaconda quadrangle. The formations between the Quadrant Formation and the Colorado Shale are briefly described. More detailed descriptions of these rocks in the Philipsburg quadrangle are given by Emmons and Calkins (1913).

The Phosphoria Formation (Richards and Mansfield, 1912) of Permian age ranges from 150 to 200 feet in thickness. The lower part consists of interbedded cherty limestone, black calcareous shale, and a thin dark-gray oolitic phosphate bed, and the upper part is massive- to thick-bedded gray to grayish-orange quartzitic sandstone and some thin beds of soft calcareous shale. The Phosphoria Formation is unconformably overlain by sedimentary rocks of Jurassic age.

The sedimentary rocks of Jurassic age are about 400 feet thick; the lower part consists of black calcareous shale interbedded with limestone and is overlain by thin- to thick-bedded grayish-green to dark-gray sandstone containing a few beds of chert conglomerate. The sedimentary rocks of Jurassic age are overlain unconformably by the Kootenai Formation.

The Kootenai Formation (Fisher, 1909) of Early Cretaceous age is about 1,500 feet thick and consists in the lower part of a basal cliff-forming reddish-brown to grayish-green conglomerate which is overlain by 500 feet of reddish-brown and grayish-green shale and intercalated thick-bedded dark-gray limestone. The upper part is chiefly reddish-brown and greenish-gray shale and gray limestone and contains abundant fresh-water gastropods.

The Kootenai Formation is conformable and gradational with the overlying Colorado Shale, which is widely distributed at the surface in the quadrangle.

CRETACEOUS SYSTEM

COLORADO SHALE

Strata of the Colorado Shale (Hayden, 1876, p. 45) of Early and Late Cretaceous age are exposed in a northward-trending outcrop in the central part of T. 5 N., R. 11 W. The base of the Colorado Shale is not exposed in the mapped area, and the top of the formation is beveled by erosion and overlain unconformably by Tertiary volcanic rocks. The Colorado Shale is about 1,500 feet thick in the Philipsburg quadrangle (Emmons and Calkins, 1913)

The lower part of the Colorado Shale is predominantly dark-gray to grayish-brown calcareous shale interbedded with siltstone and thin limestone beds. Overlying these strata are several massive cliff-forming dark-gray to grayish-brown quartzitic chert-pebble conglomerate beds. The conglomerate beds crop out in the hogback immediately west of the quarry on Lost Creek in the NW¼NW¼ sec. 25, T. 5 N., R. 11 W. Here, these beds are truncated by basal Tertiary strata, and the erosion channeling along the unconformity is well exposed in the outcrops in the NW¼NW¼ sec. 25 behind the ranchhouse.

The upper part of the Colorado shale consists of thick-bedded dark-gray coarse-grained sandstone intercalated with thin dark-gray to olive-green shale beds. Near the top the sequence grades into thick dark-greenish-gray siltstone, black calcareous shale, and some thin flaggy limestone A few thin pebbly quartzitic sandstone beds are exposed in a shallow pit in NE¼SE¼ sec. 10, T. 5 N., R. 11 W. The thick-bedded sandstone in the upper part is dark gray on a fresh surface and weathers brown. The sand grains are chiefly quartz, black chert, and feldspar. The shale zone in the formation weathers into rounded hills and into sharp ridges where quartzitic sandstone is present.

In general, the strata of the Colorado Shale are folded, faulted, and locally altered to phyllites and quartzites. Collections of fossils from this area are few, and the formation was not separated into units. Gwinn (1961) estimated the thickness of the Colorado Group of Early and Late Cretaceous age in the Drummond quadrangle to be 9,170–11,500 feet. He divided the Cretaceous rocks that are younger than the Kootenai Formation and correlated these units with the Colorado Group described by Cobban and others (1959) on the Sweetgrass arch in western Montana and with the Colorado Formation described in the southern Elkhorn Mountains by Klepper, Weeks, and Ruppel (1957).

The Colorado Shale is overlain unconformably by strata of the Lowland Creek Volcanics.

TERTIARY SYSTEM

LOWLAND CREEK VOLCANICS

The Lowland Creek Volcanics of early Eocene age (Smedes and Thomas, 1965) crops out extensively in the mapped area (pl. 1). Smedes (1962) reported that these volcanic rocks are distributed over 600 square miles in Jefferson, Silver Bow, Deer Lodge, and Powell Counties, Mont. The type locality is Lowland Creek in the Elk Park quadrangle northeast of Butte, Mont., where the stratigraphic and structural relations of the rocks were first determined.

The Lowland Creek strata are at the surface in the barren foothills of the Flint Creek and the Anaconda Ranges (fig. 1) and are well exposed along the valleys of Warm Springs Creek, Lost Creek, and Antelope Creek in the northwest quarter of the Anaconda quadrangle. The rocks have an aggregate thickness in excess of 4,000 feet and consist predominantly of intercalated beds of volcanic breccia, quartz latite flows, ash-flow tuff, welded tuff, and sedimentary strata.

The Lowland Creek Volcanics in the mapped area has been divided into three members. In ascending order they are the basal member, the ash-flow tuff member, and the volcanic breccia and red-bed member. These members correlate generally with units described by Smedes (1962). The basal member, locally as much as 400 feet thick, consists of massive- to thick-bedded grayish-brown cross-laminated arkose, lenticular conglomerate beds that contain abundant volcanic pebbles, and gray to buff tuffaceous siltstone and claystone beds. A basal conglomerate is present locally.

The unconformity between the Colorado Shale and the basal member is well exposed in the cliff behind the ranchhouse in sec. 25, T. 5 N., R. 11 W. Here, the basal conglomerate which consists of boulders of decomposed granite, volcanic rocks, and quartzite cobbles, rests on an erosion surface that has more than 50 feet of relief. Blocks of quartzite in the basal member of the Lowland Creek Volcanics were derived from the underlying rocks and accumulated as talus along the slopes of an ancient valley.

Intercalated dark-grayish-brown to dark-brown coarse arkose beds and cobble conglomerate beds overlie the basal conglomerate and generally constitute the main body of the basal member. The beds are cross-laminated, friable, and weather into rounded benches. The cobbles in the conglomerate beds are chiefly quartzite and are as much as 4 inches in diameter; however, pebbles of volcanic rock are abundant, and some limestone pebbles are present. The matrix is coarse sand consisting of quartz, feldspar, and mafic minerals and in places some tuff.

The arkose interbeds are thick, cross-laminated, coarse grained, and weather readily to gravel and soil. The arkose is chiefly quartz but includes a high proportion of feldspar and hornblende cemented by iron oxide and clay.

The thickness of the basal member varies as a result of an erosion surface which separates it from the overlying ash-flow tuff member.

The ash-flow tuff member is widely distributed along Lost Creek and Antelope Creek, and in secs. 20, 21, 29, 32, and 33, T. 5 N., R. 11 W., and secs. 4 and 5, T. 4 N., R. 11 W., in the valley of Warm Springs Creek. It is from 0 to about 3,000 feet thick and is composed chiefly of massive light-gray ash-flow tuff and gray, buff, and grayish-red quartz latite flows that are interlayered with gray lapilli tuff, some welded tuff, and a few beds of greenish-gray conglomerate. In some places near the base of the member, thin beds of coarse-grained arkose are interbedded with the ash-flow tuff.

The ash-flow tuffs and lapilli tuffs are hundreds of feet thick and seem to lack any distinctive structures. They are, therefore, difficult to separate. These volcanic rocks contain abundant crystals of quartz, feldspar, biotite, and hornblende in a fine-grained matrix. In some ash beds, sanidine occurs in distinct euhedral crystals. Fragments of quartz latite rock and pumice lapilli are also abundant in the ash beds. Some strata along Antelope Creek are partly welded and show a pseudovesicular structure where the pumice has weathered out (Smedes, 1962). The main mass, however, seems to be nonwelded ash-flow tuff.

The quartz latite lavas form thick flows that are gray, brown, and grayish red. A grayish-brown lava unit crops out in prominent spurs along the ridge in SE¼NE¼ sec. 22, T. 5 N., R. 11 W. The rock is coarse grained and has some phenocrysts of quartz with finer grained hornblende, plagioclase, and biotite; euhedral crystals of sanidine are abundant. The groundmass is quartz, plagioclase, and dust or clay. Veinlets of silicified material occur at places in the flow. The flows are interstratified with tuff beds and weather into a sharp relief. In other localities the flows are from 5 to 10 feet thick and many contain flow structure. Some are brecciated at the base. Several flow units in SE¼SE¼ sec. 26, T. 5 N., R. 11 W., have been altered and show a color change from grayish red to predominantly green. These flows are fine grained, but the larger crystals of plagioclase, biotite, and hornblende are altered to epidote and chlorite.

The greenish-gray conglomerate beds are lenticular and were probably deposited in water. Well-rounded cobbles and pebbles of volcanic rock and some quartzite occur in a matrix of pumice, lapilli tuff, and sand. Alteration of the constituent minerals in the cobbles and coarse-grained matrix has changed the conglomerate to dark green. The alteration products, as in the other units, are chlorite, epidote, and celadonite.

The ash-flow tuff member is truncated by erosion and overlain unconformably by the volcanic breccia and red-bed member, and in some places it is unconformably overlain by a conglomerate of probable Miocene age.

The third and youngest unit of the Lowland Creek Volcanics is the volcanic breccia and red-bed member that is exposed in secs. 25, 26, 34, 35, and 36, T. 5 N., R. 11 W., and in a wide belt of outcrop north of Antelope Creek. It is from 0 to about 600 feet thick.

In the southern part of the mapped area, the member consists of massive gray to reddish-brown quartz latite breccia and agglomerate interstratified with quartz latite flows, thick-bedded buff conglomerate, sandstone, and thin coaly shale beds. To the north, this sequence intertongues with buff and grayish-orange conglomerate beds containing boulders and cobbles of limestone, gneiss, and some volcanics. The conglomerate is interbedded with reddish-brown coarse-grained sandstone and gray tuffaceous siltstone. Some thin lignitic coal beds 4–6 inches thick crop out in a gulch in NE¼NW¼ sec. 35, T. 5 N., R. 11 W., and in the drainage cuts in NE¼NW¼ sec. 36, T. 5 N., R. 11 W.

The lower part of the volcanic breccia and red-bed member is well exposed in the north-trending gully in the SE¼SE¼ sec. 35, T. 5 N., R. 11 W., where the rocks crop out along the axis of a faulted anticline. Massive beds of breccia containing latite blocks as much as 3 feet long in a matrix of volcanic ejecta are exposed in the outcrop. Interstratified with breccia are light-gray ash beds containing pumice bombs as much as 4 inches in diameter, latite flows, and, near the andesitic plug at the mouth of the gully, some welded tuff. In places, beds of light-gray to white ash-flow tuff are conspicuous in the outcrop. The tuff contains abundant euhedral crystals of sanidine, smoky quartz, and biotite in a chalky matrix of ash. Thin veinlets of chalcedony are common in the tuff beds. Thin to thick lenticular beds of cobble conglomerate are scattered through the sequence, usually associated with some reddish-brown tuffaceous siltstone and thin coal beds. Near the head of the gully are massive units of ash-flow tuff containing some coalified stumps and pieces of silicified wood.

Near the top of the member, the volcanic rocks grade into sedimentary strata. In NW¼ sec. 36, T. 5 N., R. 11 W., the gully that drains northward into Lost Creek cuts through intercalated beds of boulder and cobble conglomerate, coarse arkosic sandstone, reddish- to grayish-brown tuffaceous siltstone, tuffs, and thin coal beds. These beds are steeply inclined along a northeastward-trending fault zone and abut against the ash-flow tuff member.

Along Antelope Creek, a thick sequence of red beds is present. These beds overlie the ash-flow tuff member and consist of a massive conglomerate that contains large boulders of limestone and Precambrian rocks, arkosic sandstone, siltstone, and gray tuff beds. The red beds are correlated with the upper part of the Lowland Creek Volcanics in the south on the basis of stratigraphic position and lithology. The red-bed sequence intertongues with the volcanic strata south of Lost Creek. The red beds rest unconformably on the Colorado Shale along Antelope Creek and are overlain unconformably by the gravel of middle Pliocene age. In the southern part of the quadrangle the volcanic breccia and red-bed member is overlain unconformably by the conglomerate of Miocene(?) age.

CONGLOMERATE

A conglomerate of probable Miocene age is exposed in the southern part of the quadrangle where it truncates rocks of Eocene and Cretaceous age. It has a maximum thickness of about 400 feet and generally weathers into boulder rubble. The best outcrops are along the old tramway above the valley of Warm Springs Creek in the SE¼ sec. 35, T. 5 N., R. 11 W. There the rocks exposed generally are typical of the formation. The conglomerate unit consists of moderately indurated thick-bedded gray to buff conglomerate containing cobbles of gneissic granite, quartzite, and volcanic detritus intercalated with thick beds of tuffaceous siltstone and thin lenses of carbonaceous material and lignitic coal beds. The coal beds are 4–6 inches thick and weather rapidly. The carbonaceous material contains an abundance of plant impressions.

The conglomerate rests unconformably on the volcanic breccia and red-bed member near an andesite plug at the tramway; the relief of the erosion surface is considerable. In secs. 27, 28, 33, and 34, T. 5 N., R. 11 W., the unit rests unconformably on the quartzite beds of the Colorado Shale. In sec. 36 the conglomerate bevels the ash-flow tuff member and the volcanic breccia and red-bed member of the Lowland Creek Volcanics.

On the basis of the fossil pollen content, E. B. Leopold and L. M. Weiler (written commun., 1963) suggested that these strata (USGS Paleobat. loc. 1976) are probably of Miocene age.

GRAVEL

Locally, the Lowland Creek Volcanics and older rocks are unconformably overlain by coarse gravel of middle Pliocene age (Konizeski, 1957). These strata are here informally called "gravel." The gravel is widely distributed over Deer Lodge Valley and forms the high terraces along the east side of the valley. The gravel beds are poorly indurated thick-bedded gray to buff cobble conglomerate intercalated with soft coarse-grained sandstone, tuffaceous siltstone, and thin lenticular carbonaceous shale beds. In some places surficial glacial outwash material was mapped in conjunction with the gravel. Several conglomerate beds that crop out in the gravel pit in sec. 36, T. 6 N., R. 10 W., near Galen, Mont., are thickly coated with manganese minerals. The individual pebbles are covered by black sooty pyrolusite which sharply defines the cross-lamination in the beds.

The upper 10 feet of strata in the gravel pit in sec. 36 are composed of beds of poorly sorted fluvioglacial outwash material of Pleistocene age. These beds have been mapped and combined with the middle Pliocene gravel, but in places they rest unconformably upon the gravel.

The highest gravel beds crop out at an altitude of about 6,500 feet in the northeastern part of the quadrangle. This altitude corresponds generally to the high terrace levels on the east side of Deer Lodge Valley. There are some exposures of the underlying conglomerate of probable Miocene age in the deeper gullies on the west side of the valley. Where this conglomerate is exposed, the strata dip steeply and probably were brought up along the northwestward-trending faults that seem to be reflected in the unconsolidated surficial deposits. The maximum thickness of the gravel in the quadrangle is about 800 feet.

G. E. Lewis (written commun., 1963) identified a fossil tooth found in the gravel pit in sec. 36, T. 6 N,. R. 10 W., as an upper cheek tooth of *Pliohippus* sp., a fossil horse of probable middle Pliocene age. Konizeski (1957) collected a middle Pliocene faunal assemblage from this gravel unit at several other localities in Deer Lodge Valley.

QUATERNARY SYSTEM

Surficial deposits include glacial moraine deposits, terrace gravel, landslide deposits, colluvium, and alluvium. Along Lost Creek and some of its adjoining tributaries the bedrock is covered locally by glacial moraine deposits. Large blocks of granite and poorly sorted materials left by ice in the lateral and terminal moraines are along the slopes near the confluence of Timber Gulch and the canyon of Lost Creek. They occur up to an altitude of 6,500 feet and probably represent the highest occurrence of ice in this area. The ice advanced in Lost Creek as far as sec. 23, T. 5 N., R. 11 W. Most of the glacial deposits have been removed by erosion; coarse glacial debris remains along the slopes of the valley of Lost Creek, but much of the smaller sized material has been reworked by stream action.

Emmons and Calkins (1913) identified at least two periods of glaciation in the Flint Creek Range west of the mapped area, but only one period of glaciation is indicated by evidence along Lost Creek. One mile north of the quadrangle, however, in Racetrack Creek, several periods of glaciation are indicated by the successive lapping of terminal and lateral moraines. Pardee (1951, p. 80) believed that there were three periods of glaciation in the Flint Creek Range and classified the glacial drift as early, intermediate, and late. The deposits of the late glacial period can be recognized generally by the well-preserved moraines and the unweathered granite boulders. The authors, who follow the description of Pardee (1951), believe that the deposits in the canyon of Lost Creek represent the late glacial period. The late glacial period here and in other areas in the Flint Creek Range is correlated with the Pinedale Glaciation, which has been identified with certainty in most areas of the northern Rocky Mountains.

In sec. 32, T. 5 N., R. 11 W., older terrace alluvium borders the present flood plain along the valley of Warm Springs Creek. This alluvium is probably an older coalescing fan deposited by the several tributaries to Warm Springs Creek.

The landslides that were mapped are deposits formed by mass gravity movements of earth or bedrock. A large landslide is in the NW¼NW¼ sec. 21, T. 5 N., R. 11 W., where strata of the Quadrant Formation, much fractured along a major fault, has slid down over the Tertiary rocks to the level of the valley. Another landslide is in sec. 36, T. 6 N., R. 11 W., in the volcanic breccia and red-bed member of the Lowland Creek Volcanics where landsliding in the tuffaceous siltstone and conglomerate has left a noticeable scar in the upper part of the valley. Other smaller areas of landsliding occur in the vicinity of faults where the strata are softened by water seepage.

Colluvium, composed of unconsolidated cobbles and boulders embedded in clay, sand, and gravel, was mapped where it obscured the underlying bedrock.

The deposits of alluvium consist of clay, sand, and gravel deposited along the principal streams. These deposits locally include glacial outwash in the lower parts of valleys and in some of the coalescing fans where they terminate at Deer Lodge Valley (fig. 1). Several silt deposits resulting from the formation of lakes in the glacial drift were mapped as alluvium.

IGNEOUS ROCKS

Granite, diorite, andesite, and trachyandesite rocks of Tertiary age occur locally. They chiefly form stocks or smaller plugs and, to a lesser extent, dikes and sills. The older intrusive rocks are granite and diorite and seem to be genetically related to the Philipsburg batholith and the Royal batholith in the Flint Creek Range (fig. 1). The younger intrusive rocks are andesite and trachyandesite plugs which intrude Tertiary sedimentary rocks.

GRANITE AND DIORITE

A pluton of granitic rock is intruded into Precambrian and Paleozoic rocks in the canyon of Lost Creek. It covers several square miles in the canyon and in an area to the south of the quadrangle just north of Warm Springs Creek. The best exposures are in the glaciated walls of the canyon of Lost Creek where the granite shows conspicuous curved jointing or sheeting near the surface of the intrusion. The granite that is exposed on the slope north of the valley of Warm Springs Creek and just west of the mapped area weathers in barren knobs that rise to about 50 feet above the ground surface.

The rock is a biotite granite that is light gray on the fresh surface and weathers buff to light orange. It is medium to coarse grained and in places pegmatitic. The megascopic constituents are feldspar, quartz, biotite, and abundant hematite.

Thin sections show a medium- to coarse-grained biotite granite containing quartz phenocrysts and perthitic intergrowths of albite and crudely grid-twinned microcline, and lesser amounts of biotite. Accessory minerals are apatite, zircon, fluorite, and hematite. The mineral constituents are quartz, 20–28 percent; total feldspar, 30–57 percent; biotite, 3–13 percent; and accessories, 2 percent. Fluorite is present in all samples and is generally associated with biotite; it also occurs in fractures in albite. Hematite is generally present as grains and small irregularly shaped masses occurring interstitially and as fracture fillings in albite. The fluorite is late magmatic and much of the hematite is probably derived from the alteration of biotite by the corrosive action of fluorine. The locally fractured and bent albite associated with hematite, and the fluorite filling in fractures may indicate minor adjustments within the intrusive body just prior to or during the late stage of crystallization.

A light-colored finer grained zone near the roof of the intrusion was sampled and found to contain higher percentages of quartz, feldspar, and mica than the average granite. The sample contained 30 percent quartz and a larger percentage of albite, usually about 79 percent of the total feldspar if microcline and albite in perthite are counted separately, and 11 percent mica. The mica is chiefly hydromuscovite and muscovite rather than biotite.

Schlieren within the large granite mass is generally a schistose biotite-rich rock. One sample of schlieren contains quartz, biotite, plagioclase, potassium feldspar, and perthite; hornblende(?), apatite, and zircon occur as accessory minerals. The plagioclase is sodic oligoclase.

The border zone of the granite intrusive at the east entrance to the canyon of Lost Creek is sheared and altered cataclastic granite. The granite is in contact with locally marbleized, silicified, and mineralized Madison Limestone. The granite is medium to fine grained, kaolinized, silicified, and iron stained. It contains 21–29 percent quartz phenocrysts and perthitic intergrowths of sodic oligoclase (An 11–16) and crudely grid-twinned microcline. The accessory minerals total 1 percent and include fluorite, zircon, apatite, and hematite. Alteration products are sericite, kaolinite, hydromuscovite, and chlorite. Quartz and feldspar are commonly granulated, and the quartz is recrystallized. Plagioclase laths are commonly bent and broken and have hematite filling the fractures. The higher calcium content of this plagioclase in relation to the plagioclase in the main body of granite is probably the result of reaction with the intruded Madison Limestone. Fluorite is interstitial. Hematite occurs disseminated or as fracture fillings in the plagioclase and as thin subparallel veinlets in quartz and clay. Sericite and kaolinite are alteration products of plagioclase and microcline. Hydromuscovite and chlorite, which are often associated with the hematite, may be alteration products of the original biotite.

Medium- to coarse-grained granite dikes cut the granite mass and also the Newland Formation. In general, the dikes are more leucocratic than the normal granite of the quadrangle although some dikes contain megascopically visible biotite in small quantities; the dikes generally contain a higher percentage of quartz and albite than the normal granite. They also contain partly chloritized epidote associted with the hematite and in addition the accessory minerals zircon, apatite, and fluorite. One granite dike that cuts a basic dike intruding the Newland Formation contains sparse allanite as well as epidote and the usual accessories; hydromuscovite(?) and muscovite replace biotite. Much of the quartz and feldspar is partly recrystallized; many phenocrysts are bent and broken and fluorite fills many broken phenocrysts.

Hornblende-plagioclase-sphene-biotite quartz dikes and sills cut the Newland Formation. The dikes and sills are finely layered and consist of thin alternating hornblende-sphene layers and plagioclase-rich layers. The accessory minerals are magnetite, apatite, zircon, and hematite.

There are two plugs of granitic rock along Lost Creek in sec. 15, T. 5 N., R. 11 W. The granite is fluorite bearing and similar to the granite in the canyon of Lost Creek. The intrusives are considered apophyses of the granite exposed in Lost Creek. The apophyses are medium-grained quartz-rich gneissoid granite that contains 34 percent quartz phenocrysts and perthitic intergrowths of albite and grid-twinned microcline and about 3 percent muscovite. Accessory minerals constitute 1 percent and include fluorite, hematite, zircon, and apatite. The plagioclase laths are commonly bent or broken, and hematite fills the fractures. The muscovite is commonly bent. Fluorite is interstitial.

The dioritic intrusion near the northwest corner of the quadrangle probably is related to the large diorite mass along Racetrack and Thornton Creeks just north of the mapped area. The diorite in the mapped area is faulted against Precambrian and Paleozoic rocks and shows some mineralization in fracture or shear zones near the faults. It is very coarse grained, and the main constituents in order of abundance are plagioclase, hornblende, biotite, and quartz. Microcline and augite are present in small amounts. Accessory minerals are magnetite, zircon, and sphene. The diorite is cut by aplite dikes and small intrusions of muscovite-biotite granite. Several small plugs of the granite are intruded into Precambrian strata along the canyon that drains northward into Modesty Creek in NE¼ sec. 27, T. 6 N., R. 11 W.

ANDESITE OR TRACHYANDESITE PLUGS

Small plugs of andesite or trachyandesite are intruded into the Tertiary sedimentary rocks along the valley of Warm Springs Creek in sec. 2, T. 4 N., R. 11 W., and secs. 35 and 36, T. 5 N., R. 11 W. The plugs are composed chiefly of volcanic breccia or vent agglomerate and weather into talus that accumulates downslope from the intrusive outcrop. The breccia is reddish brown on fresh surfaces but is brownish black to black on weathered surfaces.

The small pluglike mass in SE¼SE¼ sec. 35, T. 5 N., R. 11 W., is best exposed in the abandoned tramway where its relation to a bed of ash-flow tuff in the Lowland Creek Volcanics is clearly defined. A thin vertical crush zone occurs along the periphery of the intrusive pluglike mass, and the rock fragments are oriented parallel to the wall. Inward from the contact, a zone of breccia contains blocks of intrusive material as large as 1 foot in diameter. The core of the pluglike mass is finely porphyritic locally brecciated and silicified trachyandesite which contains broken partially altered plagioclase (andesine), abundant biotite, potassium feldspar, and clay. Clumps of radiating fibrous silica, magnetite grains, and sparse accessory zircon and apatite are present.

The country rock surrounding this pluglike mass is a latite or quartz latite(?) ash-flow tuff containing crystals of biotite, sanidine, plagioclase (andesine), and lesser amounts of zircon, muscovite, and magnetite grains. The strata are horizontal except near the contact with the intrusive where the beds are vertical.

Several small coalescing andesitic masses form a dikelike body in SW¼ sec. 36, T. 5 N., R. 11 W. The andesitic rock is brownish black on weathered surfaces. In thin section the porphyritic rock contains small crystals of oxyhornblende; augite and accessory apatite and zircon occur in a microcrystalline groundmass that consists of feldspar needles, shreds of pyroxene and oxyhornblende, and very fine grains of magnetite, hematite, and felsic material. Plagioclase laths are commonly broken and the fractures are filled with intergrowths of calcite, hematite, and zeolitic material. Oxyhornblende phenocrysts are generally broken, and skeletal oxyhornblende which has thick opacite rims is abundant. Partial to complete replacement of oxyhornblende cores by magnetite, pyroxene (probably orthopyroxene), and plagioclase grains is fairly common. The pyroxene generally has been altered to bastite. Augite commonly has opacite rims and is generally skeletal; augite cores partially replaced by calcite, plagioclase, and chlorite are fairly abundant.

Phenocrysts comprise 16–33 percent of the rock, and of this fraction, hornblende ranges from 10 to 20 percent, augite from 4 to 5 percent, bastite from 7 to 22 percent, and plagioclase from 53 to 75 percent. Accessory apatite and zircon phenocrysts are less than 1 percent.

An andesitic plug crops out in Stucky Ridge in NW¼SE¼ sec. 36, T. 5 N., R. 11 W., is intruded in the volcanic breccia and red-bed member of the Lowland Creek Volcanics, and is possibly the source of the thin lava flow downslope. Another plug is exposed in the drainage between secs. 25 and 36, T. 5 N., R. 11 W.; it crops out in the gully, and the intrusive relation to the surrounding country rock is evident.

Other small intrusive bodies cut the Tertiary strata at localities south and west of the northwest quarter of the Anaconda quadrangle. These plugs are of similar andesitic composition and may represent volcanic pipes that were a source of lava flows now removed by erosion.

GEOLOGIC STRUCTURE

The major geologic structure in the region are folds and faults in the Flint Creek Range; these features formed during the Late Cretaceous and the early Tertiary. They are nearly contemporaneous with the intrusions of the granite batholiths (Emmons and Calkins, 1913). In the northwestern part of the quadrangle, Precambrian and Paleozoic rocks are thrust faulted against Mesozoic strata, and granite is locally intruded along the thrust fault. Tertiary strata bevel the older rocks and in many places are in fault contact with them. Minor deformation occurred during the Eocene, Miocene, and the Pliocene Epochs.

LATE CRETACEOUS AND EARLY TERTIARY DEFORMATION

Along the lower slopes of the canyon of Lost Creek, Precambrian rocks are thrust faulted against Carboniferous strata. Vertical to overturned limestone beds of the Amsden Formation are against the Spokane Formation in S½ sec. 4, T. 5 N., R. 11 W. The thrust plane is very steep and is obscured in most places by granite intrusion or by Tertiary strata. In Lost Creek the Precambrian rocks are separated from Paleozoic strata by the granite intruded along the thrust fault. The displacement, based on the relative position of the sedimentary rocks, seems to be in excess of 3,000 feet. North of Lost Creek the thrust fault strikes northeastward beneath surficial deposits along the west slope of Timber Gulch. Rocks assigned to the Belt Series are in juxtaposition with strata in the Colorado Shale. The thrust fault is concealed beneath Tertiary strata from the divide at the head of Timber Gulch to Modesty Creek just north of the quadrangle. It is possible that this thrust fault is a continuation of the overthrust described by Emmons and Calkins (1913, p. 149) along Thornton Creek several miles northwest of the mapped area where Precambrian rocks are thrust over Paleozoic strata.

Two major reverse faults younger than the overthrust in Lost Creek cut rocks near the border of the granite stock in secs. 15, 16, 20, and 21 and in secs. 3, 4, and 10, T. 5 N., R. 11 W. They are high-angle reverse faults and seem to have several thousand feet of vertical displacement at places where Carboniferous rocks are against Colorado Shale. The faults probably join beneath Quaternary cover in sec. 15, T. 5 N., R. 11 W. In sec. 4, T. 5 N., R. 11 W., the relation of the northwestward-trending reverse fault to the overthrust in Lost Creek could not be determined because of the predominance of surficial deposits. Emmons and Calkins (1913) described the southwestward-trending reverse fault in secs. 16, 20, and 21, T. 5 N., R. 11 W., as one of the more extensive faults in the Lost Creek and Warm Springs Creek area. This fault, in secs. 20 and 21, is concealed by Tertiary strata. It is thought by the authors that the reverse faults formed nearly concurrently with the overthrusting and the emplacement of the granite and that the faults consequently are related more to the intense diastrophism of the Laramide orogeny than to the period of normal faulting that followed.

In the area underlain by Precambrian and Paleozoic rocks, normal faulting occurred after the major thrusting but earlier than the period of normal faulting that cut the Tertiary rocks. In the E½ sec. 5, T. 5 N., R. 11 W., a normal fault striking northwestward and downthrown to the east has placed Newland Formation against Spokane rocks. It intersects a system of faults that strike northeastward and are downthrown to the east or west. Just west of the fault, Precambrian rocks are folded in a northwestward-trending anticline.

A system of subparallel faults cuts the Precambrian rocks in sec. 33, T. 6 N., R. 11. W., north of Lost Creek and west of Timber Gulch. The displacement on some of these faults is as much as several hundred feet. Near the northwestern part of the quadrangle, several intersecting faults and small folds occur in the Precambrian rocks near a granite intrusion and in the overthrust plate. In secs. 9 and 10, T. 5 N., R. 11 W., two parallel westward-trending faults cut the Paleozoic rocks and place Quadrant Formation against the Madison Limestone and the Amsden Formation. The faults are truncated by the major reverse fault to the east and are lost in the granite to the west. In secs. 9 and 10 the Madison Limestone is warped in a sinuous asymmetric anticline whose east flank is cut by the northwestward-trending reverse fault. South of Lost Creek, the Madison strata are sharply folded against the southwestward-trending reverse fault.

The Colorado Shale is exposed in a large broad faulted anticline that seems parallel to the trace of the overthrust in the canyon of Lost Creek. In secs. 10 and 15 T. 5 N., R. 11 W., strata in the west flank of the anticline are folded in a syncline trending parallel to the reverse fault. The shale beds in the Colorado Shale are altered to slate and phyllite and have excellent cleavage. The sandstone and chert conglomerate beds are altered locally to quartzite. The metamorphism and folding can be attributed to the early phases of the Laramide orogeny and the consequent granite intrusion. Minor folds in the Colorado Shale in secs. 10, 21, and 25, T. 5 N., R. 11 W., seem related to the period of earlier normal faulting.

LATE TERTIARY DEFORMATION

Some folding and the system of normal faults that cuts the Tertiary strata are related to the latest deformation in the area. In general, the normal faults strike northward and northeastward and are downthrown to the east; in places they are intersected by transverse faults. In the east half of T. 5 N., R. 11 W., the faults are along a broad anticline which has exposed the Colorado Shale, and the Tertiary strata dip away from the axis of the anticline. The throw on the faults seems to increase to the south where strata of Miocene(?) age are in juxtaposition with Eocene rocks. North of Lost Creek the basal Tertiary rocks are locally in fault contact with the Colorado Shale. In this area Tertiary rocks bevel steeply dipping older formations, and the unconformities can be easily mistaken for faults.

In sec. 35, T. 5 N., R. 11 W., the conglomerate of Miocene(?) age is folded and cut by faults. The large anticlinal fold exposed in the abandoned tramway is cut on the north end by a northeastward-trending fault. Another anticline that is subparallel and lies to the east is cut by two eastward-trending cross faults. The axis of this anticline is offset to the east. Other faults occur in the vicinity of small andesite intrusive bodies. At these localities the faults seem to have been emplaced concurrent with the intrusive bodies or shortly thereafter.

Southwest of Anaconda, Eocene rocks are folded in a northward-plunging syncline. On the east flank of this structure the dip is from 30° to 35°, and on the west flank about 33°. The overlying gravel beds are too unconsolidated to determine any deformation.

In secs. 29, 30, and 32, T. 6 N., R. 10 W., along Deer Lodge Valley, two fault scarps are in the Pliocene gravel. In this area the underlying Miocene(?) strata are sharply folded in a northwestward-trending anticline which seems to be on the upthrown side of the fault zone. On areal photographs the fault scarps appear as linear features where they cut the Pliocene gravel. The gravel beds are not as tightly folded as the underlying Miocene(?) rocks, and the faults that cut the gravel beds probably are superimposed on an older fault system. This latest period of faulting is related to the most recent deformation in the area.

ECONOMIC GEOLOGY

COAL

No coal has been mined in the northwest quarter of the Anaconda quadrangle although coal beds are in the volcanic breccia and red-bed member of the Lowland Creek Volcanics of Eocene age and in the conglomerate of Miocene(?) age. The coal in the Eocene beds is classified as lignite; a sample tested 5,740 Btu (British thermal units) on an "air dried" basis and 4,780 Btu on an "as received" basis. Several coal beds crop out in a gulch in the E½SE¼ sec. 35 and in the drainage in the NE¼NW¼ sec. 36, T. 5 N., R. 11 W. The coal in these exposures is compact and dull and has an irregular fracture. The coal beds are thin, from 5 to 12 inches thick, and discontinuous; they are interbedded with beds of ash-flow tuff, conglomerate, and volcanic breccia.

Coal beds in the conglomerate of Miocene(?) age are thin, lenticular, and very impure. They contain much carbonaceous shale and weather quickly where exposed. The coal is brown to black lignite and is intercalated with thick conglomerate beds and thin shale beds. In most localities the coal beds are 4–12 inches thick.

According to Pardee (1913), a coal bed about 3 feet thick was reported to occur along Lost Creek nearly 2 miles north of Anaconda. No coal beds of this thickness were found to crop out at this locality. In general, coal beds of commercial value are not present in the area.

OIL AND GAS

The oil and gas potential in the area seems poor. The thick carbonate rocks of Paleozoic and Mesozoic age in the subsurface have been subjected to considerable compression, metamorphism, and faulting. It is likely that intrusions of granite and volcanic rocks probably caused a migration of fluids away from possible source beds. The Colorado Shale is too altered to be geologically favorable for oil or gas accumulation.

PHOSPHATE

Phosphate deposits occur in the Phosphoria Formation of Permian age. The Phosphoria Formation is not present at the surface in the northwest quarter of the Anaconda quadrangle owing to faulting, but is present in the subsurface. The Phosphoria crops out to the west in the Philipsburg quadrangle where a phosphate bed is exposed below massive sandstone in the quarry in sec. 25, T. 5 N., R. 12 W. This phosphate bed is about 3 feet thick and is composed of a dark-gray oolitic phosphate rock. This bed should be in the subsurface below 2,000 feet in the central and eastern part of T. 5 N., R. 11 W., in the northwest quarter of the Anaconda quadrangle. The phosphate bed was not sampled, and whether the percentage of P_2O_5 and the thickness of the bed at depth would make phosphate mining economical is unknown.

GOLD

Warm Springs Creek, Lost Creek, and Antelope Creek drain the east slope of the Flint Creek Range (fig. 1) where lode deposits of gold occur in igneous and sedimentary rocks. It is possible, therefore, that the gravel beds in low terraces and stream channels might contain placer deposits of economic value. Gold-bearing gravels were mined at one time in the upper part of Modesty Creek just north of the mapped area. Much of the recent gravel is glacial outwash and very coarse and consequently difficult and expensive to remove.

Many pits dug to prospect for gold can be seen along Timber Gulch. The prospects have all been abandoned. A mine was reopened in 1961 near the confluence of Timber Gulch and Lost Creek. The float in the dump showed some sulfide minerals.

The basal member of the Lowland Creek Volcanics may contain placer deposits of gold or other resistant metals. The sedimentary materials in these strata were derived from local sources, including granitic bodies that contain ore deposits. Gold or heavy minerals might have accumulated in the old stream channels. The basal beds are thick friable conglomerate units that weather readily and could be stripped by bulldozers.

LIMESTONE

The Madison Limestone crops out extensively along Lost Creek in sec. 10, T. 5 N., R. 11 W. It was quarried at this locality; the limestone was burned in a kiln near the quarry, and the lime was used as a flux in the Anaconda smelter. The Madison Limestone is quarried for the manufacture of cement in the vicinity of Drummond where it averages 98 percent calcium carbonate (Perry, 1949, p. 36).

FIRE CLAY

Several quarries were opened in the basal member of the Lowland Creek Volcanics, and at one time the tuffaceous beds were mined for use in ceramics and as fire clays. The Anaconda Copper Mining Co. used clay from the Deniff quarry in the NW¼ sec. 25, T. 5 N., R. 11 W., to make fire brick and refractory furnace lining. The quarry is in a thick-bedded light-gray to white tuffaceous clay unit that dips about 35° E. The quarried material averages about 75 percent SiO_2 and 16 percent Al_2O_5 and has a little lime and iron. These clay beds seem to be extensive in the volcanic sequence and were mined at several localities in and outside of the area.

GRAVEL

The gravel beds of Pliocene age and the more recent glacial outwash deposits are used locally as road metal. If properly screened and washed, these deposits can be used as concrete aggregate in the preparation of bridges, abutments, and culverts. The deposits of gravel cover extensive areas in Deer Lodge Valley (fig. 1).

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