DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

~~196~~

~~J. F. Springfield~~

GEOLOGIC ATLAS
OF THE
UNITED STATES

PHILIPSBURG FOLIO

MONTANA

BY

F. C. CALKINS AND W. H. EMMONS

WASHINGTON, D. C.
ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY
GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS S. J. KUBEL, CHIEF ENGRAVER
1915

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geological Survey is making a geologic atlas of the United States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval.* Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

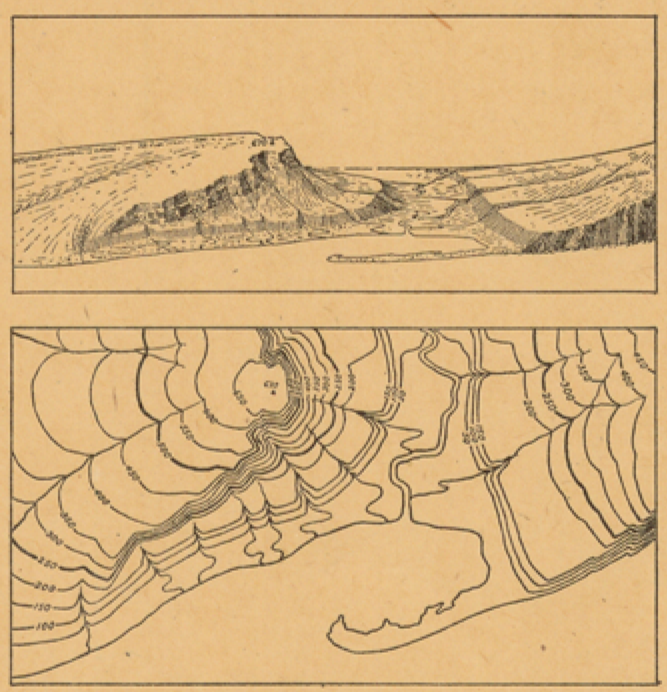


FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles.* Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous.* Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive.* Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike;* where it fills a large and irregular conduit the mass is termed a *stock.* Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava,* and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive.* Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic ejecta deposited in lakes and seas, or of materials deposited in such water bodies by chemical precipitation are termed *sedimentary.*

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata,* and rocks deposited in such layers are said to be stratified.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks, with reference to the sea, and shore lines are thereby changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land areas are in fact occupied by rocks originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium.* Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic.* In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates.* Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity.* The rocks characterized by this structure are *schists.*

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations.* A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members,* or by some other appropriate term, as *lentils.*

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods.* Smaller time divisions are called *epochs,*

DESCRIPTION OF THE PHILIPSBURG QUADRANGLE.

By F. C. Calkins and W. H. Emmons.[1]

INTRODUCTION.

POSITION AND AREA.

The Philipsburg quadrangle is bounded by parallels 46° and 46° 30′ and by meridians 113° and 113° 30′ and covers 827.42 square miles. It is in central-western Montana, not far from the State boundary (see fig. 1), and includes parts of Granite and Deer Lodge counties and a little of Powell County. The town of Philipsburg, from which the quadrangle is named, is in the north-central part of the area, about 50 miles northwest of Butte.

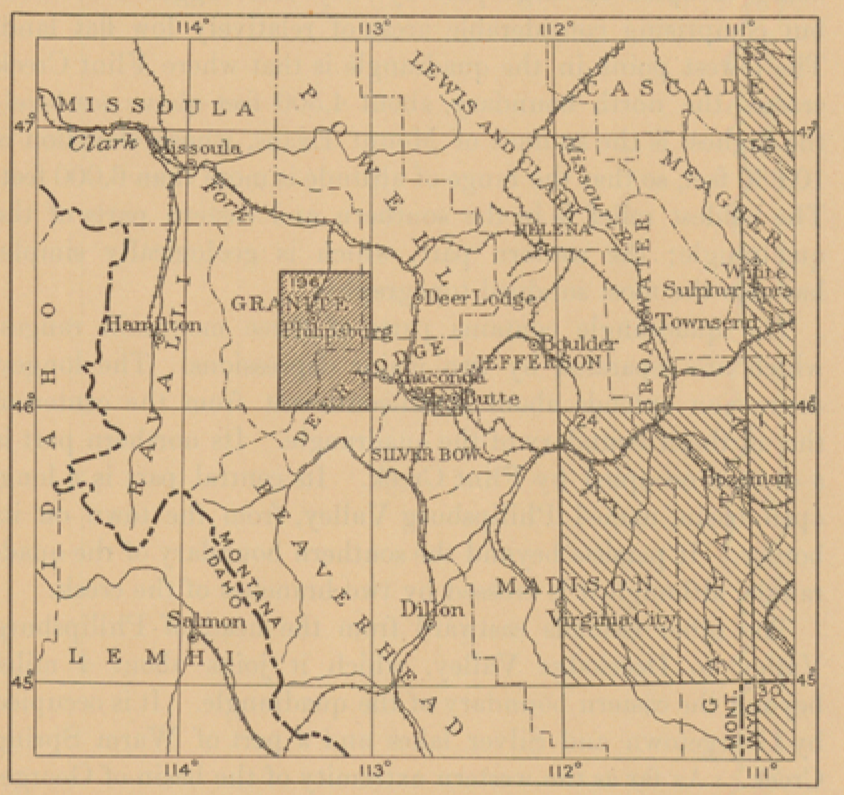


FIGURE 1.—Index map of part of Montana.

The location of the Philipsburg quadrangle (No. 196) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are the following: Nos. 1, Livingston; 24, Three Forks; 30, Yellowstone National Park; 38, Butte special; 55, Fort Benton; 56, Little Belt Mountains.

INDUSTRIES AND SETTLEMENTS.

The wealth of the Philipsburg district lies chiefly in its deposits of gold and silver ore, and mining is still its greatest industry. Agriculture, however, supports much of the population. Small herds of horses and cattle are grazed upon the hills, and considerable hay is grown in the valleys. The climate is too cool for growing most fruits and vegetables and was formerly regarded as prohibiting the commercial production of any grain except rye, but it has recently been proved possible to mature the hardier varieties of wheat.

Philipsburg, whose site was determined by its convenience as a receiving and distributing point for the mines of the Flint Creek district, is the largest town in the quadrangle and is accredited by the census of 1910 with a population of 1,109. The only other post offices are at Cable and Flint. Some settlements, notably Granite, formerly second to Philipsburg in importance, have shared in the decline of the mines upon which they depended.

Philipsburg is connected with the transcontinental route of the Northern Pacific Railway by a spur 26 miles long, which follows Flint Creek and joins the main line at Drummond. A spur of the Butte, Anaconda & Pacific Railway enters the quadrangle from the southeast. At the time of the survey on which this folio is based it was used solely for hauling rock from the quarries at Browns, but it has recently been extended to Cable.

CLIMATE AND VEGETATION.

The temperature of the region, owing to the considerable altitude, a relatively high northern latitude, and great distance from the ocean, is rather low on the average and is subject to wide seasonal and daily ranges. The greater part of the somewhat scanty precipitation falls during the winter in the form of snow, but the distinction between the wet and the dry season is less marked in this region than in regions farther west, and occasional showers fall here in all the summer months.

A rather open forest of moderate-sized conifers originally covered a large proportion of the mountain slopes below the 9,000-foot contour, but the broad lowlands and the sunny parts of the lower slopes appear to have been always barren, or but sparsely wooded, and are well covered with grass.

PHYSICAL FEATURES OF THE REGION.

RELATIONS OF THE QUADRANGLE.

In its general geographic and geologic relations the Philipsburg quadrangle forms a part of the Rocky Mountain province, which lies between the Great Plains on the east and the Great Basin, Columbia Plateau, and Northern Interior Plateaus on the west, and extends from northern New Mexico northward into Canada. That part of the province in and adjacent to western Montana, including the region immediately about the quadrangle, is characterized by certain general stratigraphic, structural, and topographic features, which give it some measure of geologic and physiographic unity. The quadrangle lies on the boundary between an area of relatively simple geology and uniformly mountainous topography at the west and one of more complex geology and more diversified topography at the east, and it illustrates the features of both regions with a fullness that could be equaled in few other areas of equal size.

A brief description of the region that includes the quadrangle will be given as an introduction to the more detailed description of the quadrangle itself. A generalized map of the region forms figure 2.

RELIEF.

The term Rocky Mountains is applied, according to the best American usage, to a broad zone trending in general northwest and southeast, whose prevailingly mountainous character is diversified by extensive tracts of lowland. It is almost a necessary consequence of this diversity that the boundaries of the zone should not everywhere be well defined. In the region especially considered here the western boundary is more definite than the eastern. Between the forty-fifth and forty-seventh parallels the Rocky Mountains are bounded on the west by the great basaltic plateau that is drained by Columbia River. Near the forty-fifth parallel the eastern edge of the plateau swings westward and the boundary of the Rocky Mountains north of that latitude may be regarded as formed by a remarkably long and narrow intermontane depression, called by Daly the Purcell Trench, which virtually meets the Columbia basalt plateau near the south end of Lake Coeur d'Alene, and extends thence northward beyond the international boundary.

The eastern boundary of the Rocky Mountains is commonly regarded as contiguous to the Great Plains, but on this side the main mountain system has many outliers, such as the Little Rockies, in northern Montana, and the Big Horn Mountains and the Black Hills, farther south. Apart from these, the main mass of the Rockies in Montana has a far more definite eastern boundary at the north than at the south. The southeastern part of the State is occupied in large part by ranges, such as the Little Belt, Big Belt, and Crazy Mountains, which are separated by broad valleys or even completely surrounded by lowlands. The region of broadly alternating heights and lowlands is bounded on the north by a more continuously mountainous mass, whose east front rises with striking boldness from a vast expanse of plain. Although the boundary between these two regions is not sharp the difference in their topography is significant as an expression of geologic differences: the area of partly isolated ranges may be identified in figure 2 as that in which the areal geology is relatively complex; the more continuous highland area farther north and west is occupied almost wholly by pre-Cambrian rocks.

The more or less isolated ranges of southwestern Montana have a dominant but not general northwestward trend. The altitude of their higher summits exceeds 10,000 feet and their topography is rugged, the details of sculpture near their crests being largely of glacial origin and therefore characterized by steep-sided cirques and rocky cliffs. At the higher levels in some parts of the region, however, there are relatively flat surfaces that cut across steeply inclined strata of various kinds as well as great masses of igneous rock. Such features are notably distinct in the Livingston and Three Forks quadrangles.

In the region of simpler areal geology north and west of that just described the ranges are broader and the depressions narrower. Perhaps the most typical landscape to be seen from the summits in this tract is a succession, extending to the horizon, of ridges of nearly uniform height separated by intricately ramifying canyons. But this vast expanse of mountains is naturally divided into several ranges and these ranges are more or less diverse in topographic character.

The natural boundaries between the ranges are constituted by certain depressions which differ from the multitude of mountain canyons by their relative persistence, straightness, and breadth. One of these depressions, the Purcell Trench, has already been mentioned as constituting part of the western boundary of the Rocky Mountains. Within the main body of the mountains there are other tracts, trending northwestward, which afforded routes for the transcontinental railways. One of the longest extends from Spokane, Wash., nearly to Deerlodge, Mont., a distance of 300 miles. Its western part is occupied by Coeur d'Alene River and its central and eastern parts mainly by Clark Fork of the Columbia. Another depression that has nearly the same direction, extending from Lake Pend Oreille southeastward for about 150 miles, is occupied by a stretch of Clark Fork and by the lower part of Flathead River. But the most remarkable is that which Daly calls the Rocky Mountain Trench. It extends in a direction somewhat east of south from a point more than 200 miles north of the international boundary to a point near Kalispel, about 50 miles south of that boundary, where it divides into two branches, either of which may be regarded as its chief southerly prolongation. The western branch, which is the broadest depression in this part of the Rocky Mountains, extends due south and is occupied by Flathead Lake and by Bitterroot River and some smaller streams. The eastern one, though narrower, lies more directly in line with the Canadian part of the trench. Its northern part is occupied by Swan River, and a more southerly part of it is constituted by the valley of North Fork of the Big Blackfoot, which heads opposite the Swan. Though obscure and interrupted beyond this point the depression may be traced still farther south, and the principal valley of the Philipsburg quadrangle may be regarded as a part of it.

The highest and most picturesque mountains of the region are in Montana, on the east side of the depression occupied by Flathead Lake. Here lie the Mission, Lewis, Clark, and other ranges, several of whose summits exceed 10,000 feet in height, and whose crests have a rugged alpine character attesting the work of glaciers. Although most of the glaciers have passed away, many yet remain, particularly in the area of the Glacier National Park, where their survival is more favored than in the tract farther south, not only by their northerly situation but by the greater height of their crests. Of the mountains farther west, the most lofty constitute the well-defined Sierra which overlooks the Bitterroot Valley on the west and to which the name Bitterroot Range is restricted by Lindgren. It is only by its dominating height, exceeding 10,000 feet for some peaks, and its rugged character that this range is marked off from the mountains still farther west, above which it rises abruptly. A similar domination of its surroundings is shown in a minor degree by the central part of the Cabinet Range, which lies between Clark Fork and Kootenai River in northern Idaho. The highest peaks of this range are about 8,500 feet high and one or two small glaciers still linger here on shady northern slopes. These especially lofty ranges occupy but a rather small fraction of the entire region. Throughout the remainder of the area the ridges are for the most part from 6,000 to 7,000 feet high, are not accented by many conspicuous peaks, and in general views appear comparatively subdued. Viewed in detail, however, their higher crests, having been deeply chiseled by the extinct alpine glaciers, of which the region once contained many hundreds, do not seem lacking in picturesque and vigorous character.

DRAINAGE.

The drainage of the region goes partly to the Pacific and partly to the Atlantic. The Continental Divide in the region runs in general southward, but its course is very irregular in detail. It forms the boundary between Montana and Idaho south of a point near the forty-sixth parallel, where it turns abruptly eastward and follows that parallel nearly to Butte, continuing thence northward through the eastern part of the main range. The Pacific drainage is all gathered into Columbia River, whose principal tributaries in the region, named in order from north to south, are the Kootenai, Clark Fork, the Clearwater, and the Salmon. The east slope of this part of the Rockies, except a small area near the international boundary, which sends its drainage to Hudson Bay by way of Bow River, is drained by tributaries of the Missouri. The chief of these, beginning at the north, are Milk River, Marias River, and Jefferson, Madison, and Gallatin forks of the Missouri.

There are many lakes in the region, most of them mountain tarns too small to be represented in figure 2, which, however, shows three larger lakes—Flathead, Pend Oreille, and Coeur d'Alene. These lakes and nearly all the small ones are

---

[1] The account of the metalliferous mineral resources was prepared by Mr. Emmons; the remainder of the text by Mr. Calkins.

dammed by morainal or other glacial gravel and most of the others lie in rock-rimmed basins scooped out by ice.

STRATIGRAPHY.

Most of the geologic systems from the Archean to the Recent are abundantly represented in this region by sedimentary and igneous rocks, which are shown on the generalized geologic map forming figure 2 and will be described in order of age.

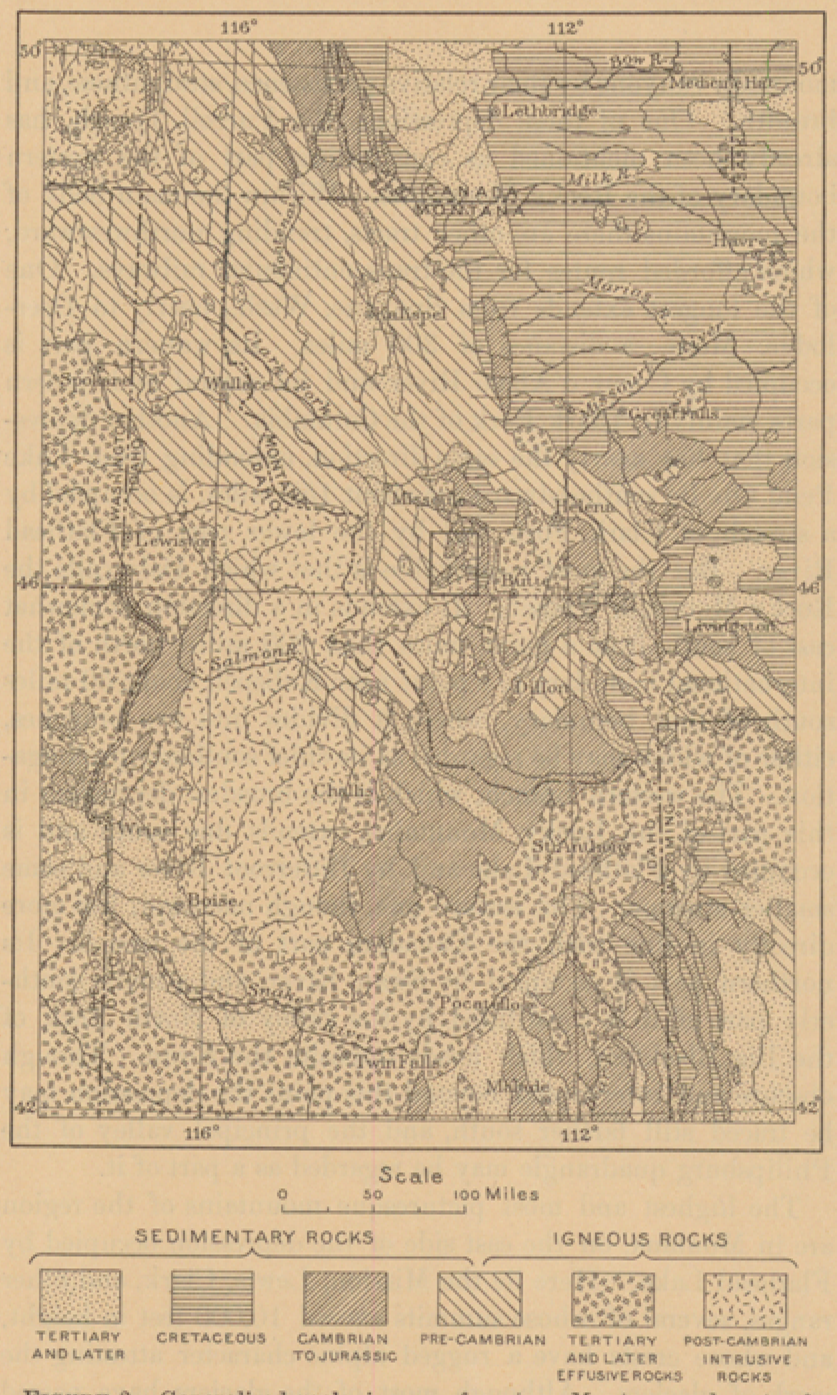


FIGURE 2.—Generalized geologic map of western Montana and parts of adjacent States.

Philipsburg quadrangle indicated by small rectangle near the center of the map. From geologic map of North America in Professional Paper 71, slightly modified.

Along the west side of Purcell Trench, in northern Idaho, and in parts of southwestern Montana, there are rocks, partly of igneous and partly of sedimentary origin, that have been sheared, contorted, and rendered crystalline by profound metamorphism. Though it is not possible to determine the age of all these rocks, it has been proved that some of them are of Archean age. These rocks are overlain, with conspicuous unconformity, by the Belt series, of Algonkian age, which occupies nearly all the area shown as pre-Cambrian in figure 2. In contrast to the Archean rocks, the Belt series is not in general perceptibly altered. It consists in greater part of shale, but comprises quartzite and impure limestone, the whole constituting a series of thick and in general fairly distinct, though intergrading, formations. The shales and the thinner-bedded quartzite are characterized in large part by ripple marks and sun cracks, showing that they were deposited on mud flats that were frequently exposed to the air. The thickness of the Belt series is estimated by Walcott to be about 37,000 feet.

A widespread though far less conspicuous unconformity than that between the Archean and Algonkian rocks separates the Belt series from the Paleozoic strata. The lowest Paleozoic formation is the Flathead quartzite, which lies on various formations of Algonkian age. Most of the remaining Paleozoic rocks consist of alternate shales and limestones, whose total thickness is several thousand feet. The uppermost Paleozoic formation—the Quadrant—is partly quartzitic. There are gaps in the Paleozoic column, Ordovician and Silurian strata, for example, having been recognized at but few places.

Although the two systems are generally separated by a surface of erosion, the Mesozoic rocks overlie those of Paleozoic age without marked angular unconformity. The Mesozoic series consists chiefly of beds of shale and sandstone and comparatively thin beds of limestone. The Triassic system is but sparingly represented and there are other gaps in the series. The Jurassic rocks are marine, and those of Cretaceous age, thicker and more varied than the earlier strata, are partly of marine and partly of fresh-water origin. The total thickness of the Mesozoic rocks amounts to thousands of feet.

Intrusive rocks, chiefly granite, granodiorite, and quartz monzonite, are abundant in the southern part of the region. It is impossible to determine closely the age of all of the intrusions, but most of those in southwestern Montana appear to be either late Cretaceous or early Tertiary. The largest intrusive mass is the Idaho batholith, in the southwestern part of the region, a mass consisting of quartz monzonite. The next largest is the Boulder batholith, also of quartz monzonite, near whose border lie Butte and Helena. Many smaller intrusive masses lie between these two large bodies and others are somewhat sparsely distributed in the northern part of the region. The more or less isolated ranges east of the main Rocky Mountains consist in large part of intrusive rocks, which are in general more alkalic than those farther west.

The Tertiary rocks other than the intrusives are largely the products of volcanic eruption. As already noted, the Rocky Mountains are flanked on the west in these latitudes by a vast area of Miocene basalt. A great tongue of this basalt and other lavas, including the thick rhyolite flows of the Yellowstone National Park, extends nearly across the Rocky Mountains in southern Idaho and northwestern Wyoming. Smaller areas of lava are fairly numerous in southwestern Montana, one of the largest lying north of Butte.

Some of the volcanic eruptions in Tertiary time were of the explosive kind and produced tuff and volcanic ash, such materials being as abundant in southwestern Montana as the lavas. They cover a large part of the area mapped in figure 2 as Tertiary deposits, but are at some places intimately associated with sediments of erosional origin. The tuffaceous and other sedimentary beds are confined chiefly to the broad intermontane valleys, but the lavas are not so restricted in distribution.

Of the Quaternary deposits those due directly or indirectly to glaciation are all that require special mention. Moraines are everywhere associated with the mountain cirques. Very large moraines that occupy some of the more persistent depressions, particularly those near Flathead Lake and Spokane, evidently mark the termini of great glaciers coming down from the north. The waters set free by the melting of these glaciers were heavily laden with gravel that built up the floors of some of the main valleys higher than the floors of their tributaries, so that many lakes were formed in the lower parts of stream valleys near their junction with larger valleys. Lakes Coeur d'Alene and Pend Oreille appear to have been formed thus. Much larger lakes were impounded by dams of ice when the glaciers had reached nearly their maximum extent and left vaguely terraced deposits of silt in some of the larger valleys.

STRUCTURE.

The complexity of the geologic structure in the region varies according to the age of the rocks and according to locality. The structure of the Archean rocks is everywhere extremely intricate. The Algonkian, Paleozoic, and Mesozoic strata, whose unconformities are not of primary structural importance, are little deformed in some large areas, especially in the lowlands and in parts of the plateau-like mountains, but at some places they are minutely folded and faulted. The deformation of the Tertiary rocks is, on the whole, much less complex. These rocks are notably less deformed, for example, than rocks of similar age in the Cascade Mountains. The Quaternary deposits are not visibly disturbed.

The most prominent decipherable structural features of the region are found in the pre-Tertiary and post-Archean rocks. The structure in the isolated ranges is especially characterized by dome-shaped uplifts and by broad folds trending north or northwest. The ranges are in general anticlinal, and their central and higher parts consist of the oldest rocks or of intrusive masses, which are flanked by later strata. The region of continuous mountains, which lies northwest of the isolated ranges, though apparently simpler as to its areal geology is probably not less complex in structure. Here the strata, chiefly Algonkian, have been thrown into fairly strong folds, whose prevailing trend, from which, however, there are many local variations, is about parallel to that of the Rocky Mountains. Faulting is here more common relatively to folding than in the region farther southeast. The faults have all possible directions, but the strike of the most persistent ranges from north to west-northwest, and most of these are followed by persistent depressions.

Of preeminent importance in the structure of the region are a number of thrust faults striking about north, which have been recognized at intervals from the vicinity of the Canadian Pacific Railway in Canada to the southeastern part of Idaho and the adjacent parts of Wyoming and Utah. The one whose effect is most conspicuous on the map is the Lewis overthrust, which crosses the Canadian boundary and which determines the deeply indented contact between the pre-Cambrian and Cretaceous rocks along the east base of the main Rocky Mountains in northern Montana. One of these faults is the most conspicuous structural feature in the Philipsburg quadrangle. Wherever the overthrusts have been recognized the thrust was from the west, and the original dip of the thrust plane was westward at a low angle. The fault planes, however, have been much deformed. In southeastern Idaho they are gently folded and in the Philipsburg quadrangle the main thrust fault is distinctly folded and faulted.

The early Tertiary deposits have at many places undergone considerable folding and some faulting. Most of the deposits (mainly Miocene and Pliocene) in the interior of the mountains are rather gently warped. There is evidence that the region is traversed by some relatively late faults which are comparable in length and throw to those that affect only the pre-Tertiary rocks. One such fault is regarded by Lindgren as the direct cause of the unusually high altitude of the sierra overlooking the west side of Bitterroot Valley.

TOPOGRAPHY.

The purpose of the following description is to give a general idea of the location and character of the principal features of the quadrangle shown on the topographic map. A descriptive classification of land forms with reference to origin rather than location is given under the heading "Physiography" (p. 21).

RELIEF.

The Philipsburg district is one of strong and varied relief, being occupied in large part by lofty and rugged mountains but comprising considerable areas of relatively low flat land. The lowest point in the quadrangle is that where Flint Creek crosses the north boundary, about 4,500 feet above sea level; the highest is the summit of Mount Evans, whose elevation is 10,630 feet, so that the range of altitude is more than 6,000 feet. The boldest relief is in the southern and eastern parts of the quadrangle; the western part, which is geologically simple, has also the most subdued topography.

The quadrangle contains parts of three mountain ranges, which are separated by two major depressions. The longest depression extends about south-southwest from the center of the northern boundary of the quadrangle. Its northern part is a canyon occupied by Flint Creek. Its central part is a long, open basin, named Philipsburg Valley, from the town on its border. It persists beyond the southern boundary of the quadrangle, although it is crossed by two branches of the creek.

The other extends eastward from the head of Philipsburg Valley to Deerlodge Valley, which it joins about 4 miles beyond the eastern boundary of the quadrangle. It is occupied by Georgetown and Silver lakes and a part of Warm Spring Creek. As far as the western extremity of the basin of Georgetown Lake it is a well-defined valley, considerably broader than those which open into it. Its extension west of Georgetown basin is not so distinct, but may be considered as formed by the uppermost part of the drainage basin of Trout Creek.

The three mountain ranges are the Flint Creek Range, the Anaconda Range, and the Sapphire Mountains. The Flint Creek Range, which occupies the northeastern part of the quadrangle, is named for the stream that drains its western slope. It is bounded on the west by Philipsburg Valley and the canyon and valley occupied by Flint Creek north of that depression, on the south by the valley containing Silver Lake, on the east by the broad Deerlodge Valley, and on the north by the valley of the section of Clark Fork that is generally known as Hellgate River. Its northern and eastern boundaries are wholly outside the quadrangle. The Anaconda Range, named for the town that lies at its eastern base, extends across the southern end of the quadrangle from the low Deerlodge pass, in which the Oregon Short Line crosses the Continental Divide, to a short distance west of Mount Warren, where its lofty crest subsides. The northern base of the range coincides with the trough containing Silver Lake along the entire length of that depression. The southern base adjoins the broad hollow that is locally known as the Big Hole, which is drained by the Wisdom or Big Hole River.

The Sapphire Mountains are named from a small mining camp—probably the largest settlement within them—where sapphires are washed from placer deposits. The southern limit of the range is rather indefinite; on the east it abuts against the Anaconda Range and narrows out gradually. Its western and northern limits are well defined, being formed by the valleys of Bitterroot River and of Clark Fork of the Columbia. Its eastern boundary is formed by Philipsburg Valley and its northward and southward extensions.

Each of these ranges has a distinctive topographic character. The Sapphire Mountains, viewed broadly, have the aspect of a somewhat maturely dissected plateau, typically shown in the hills that lie southwest of Philipsburg. Few points in the range rise higher than 8,500 feet. In marked contrast to the Sapphire Mountains is the lofty and rugged Anaconda Range—a true "sierra." (See Pl. I.) Its lofty serrate crest closes the vista up the valley from Philipsburg and, as seen from most commanding points within the quadrangle, its peaks form the boldest features of the view. The range includes many summits over 10,000 feet high, the highest being Mount Evans (10,630 feet) and the second highest Mount Haggin. The Flint Creek Range is intermediate in character and elevation between the Sapphire Mountains and the Anaconda Range. The tops of many of its peaks and ridges lie near an imaginary undulating surface that would stand 8,000 to 9,000 feet above sea level, but it has no dominant crest, and from no point of view does its profile appear deeply indented. The most rugged portion of the range lies northeast of the trench occupied by Boulder and Racetrack creeks, and its highest summit, Mount Powell, 10,145 feet high, lies a little east of the boundary of the quadrangle. In the character of its sculpture it resembles the Anaconda Range in that its higher peaks are flanked by typical ice-carved amphitheaters, but these are smaller than those in the higher range to the south.

DRAINAGE.

Streams.—Perennial streams abound in the quadrangle except in the hills west of Philipsburg Valley and about Georgetown Lake, where the smaller brooks are intermittent. The largest streams, however, are but "creeks" of moderate size.

The waters that flow from the quadrangle are very unequally apportioned between the Atlantic and Pacific slopes. The Continental Divide follows the crest of the Anaconda Range, and the small area south of it drains, by way of Seymour, Sullivan, and a few other mountain creeks, to Big Hole River, a branch of the Jefferson Fork of the Missouri. The greater part of the quadrangle is drained by tributaries of Clark Fork of Columbia River. The streams that cross the eastern boundary of the quadrangle south of latitude 46° 20′ flow into the stretch of Clark Fork locally known as Deerlodge River. The largest of these affluents is Warm Spring Creek.

The part of the quadrangle not drained by the streams already mentioned is drained by tributaries to the stretch of Clark Fork locally known as Hellgate River and gives its waters mainly to Flint Creek and to Rock Creek (the larger of the two streams so named; not the Rock Creek in the northeastern part of the quadrangle). Flint Creek, whose basin includes about a third of the quadrangle, has a curiously indirect course. Rising near the center of the quadrangle, it flows southwest to Georgetown Lake, then northwestward to Philipsburg Valley, and northeastward across the center of the north boundary. Rock Creek is one of the largest tributaries of Hellgate River, which it enters far to the northwest of the quadrangle, near Bonner, Mont. The largest branch of Rock Creek in the quadrangle is the East Fork, which heads in deep cirques near the Continental Divide. The Middle Fork comes just within the west edge of the quadrangle and one of its tributaries occupies the deep canyon north of Carp Lake. The main stream of Rock Creek runs closely parallel to the west boundary of the quadrangle for several miles until it is joined by Willow Creek proper—a stream distinct from the like-named tributary of Flint Creek. Rock Creek and Willow Creek thus occupy together a long north-south depression almost coincident with the west boundary of the quadrangle.

Lakes.—Most of the many lakes of the quadrangle are small tarns in high mountain cirques. The largest ones of this sort are Fred Burr Lake, in the Flint Creek Range, and Storm Lake, in the Anaconda Range, both of which have been augmented by the construction of dams and are used, like several others, as reservoirs. Three larger bodies of water, Echo, Silver, and Georgetown lakes, lie at a moderate elevation near the center of the quadrangle in connected basins surrounded by gently rounded slopes. On at least one side of each of these lakes there are rough-surfaced glacial deposits of bowlders, sand, and gravel, behind which the waters have accumulated. Silver Lake has been deepened by an artificial dam at its west end, and Georgetown Lake owes its present existence wholly to the construction of a dam at its north end. The basin was occupied in glacial time by a lake which was emptied by the cutting-down of the outlet and restored by artificial repair of the breach.

Springs.—A few very copious springs in the quadrangle are worthy of special mention. One great spring is said to have issued from the midst of the flat now covered by Georgetown Lake. Another lies about half a mile southeast of Georgetown Lake, at the mouth of a small gulch whose catchment is far from adequate to supply the abundant flow of the spring. The water that issues from this spring is doubtless drawn chiefly from the basin of Dry Creek to the south through a subterranean channel along the strike of the limestone beds from which the hills of the locality are carved, a supposition that accounts for the absence, during the greater part of the year, of surface flow from the lower course of the channel of that stream, which carries, in its upper courses, about the same quantity of water that issues from the spring. In the basin of Meadow Creek two other large springs issue from limestone near a great fault, their supply presumably being delivered to them through fault fissures widened by solution. The water of all these springs is cold and leaves no conspicuous deposit.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

SEDIMENTARY ROCKS.

AGE AND RELATIONS.

Upon a thick conformable series of Algonkian rocks, the lowest Paleozoic stratum rests with fairly marked unconformity. The numerous Paleozoic and Mesozoic formations are apparently concordant in attitude, but the absence of known Ordovician, Silurian, or Triassic strata, and the incompleteness of some of the other systems, is proof that deposition was not continuous throughout Paleozoic and Mesozoic time.

The pre-Tertiary strata, which have become indurated, are greatly deformed and are extensively intruded by igneous rocks. In common with the intrusives they are overlain unconformably by patches of Tertiary gravel, tuff, and lava, and by Quaternary glacial and alluvial deposits.

A generalized section of the sedimentary rocks is given on the columnar-section sheet.

ALGONKIAN SYSTEM.

BELT SERIES.

GENERAL SEQUENCE AND CORRELATION.

The oldest rocks in the quadrangle were identified with the Belt series by their general character and their unconformable relation to the Cambrian. The correlation of the several formations depends on the similarity of the succession in the Philipsburg district to that in regions previously studied. This succession is exhibited in the following table, where the formations are arranged in vertical order according to age and horizontal order according to geographic position, from west to east.

Correlation of principal sections of Algonkian sedimentary rocks (Belt series) in Montana and Idaho.

Belt Mountains (Walcott).[a]	Philipsburg district (Calkins).	Mission Range (Walcott).[b]	Cœur d'Alene district (Calkins).[c]
Cambrian.	Cambrian.	Cambrian.	
Unconformity	Unconformity	Unconformity	
Marsh. Shale, red; 800 feet.	Absent.	*Camp Creek.* Sandstones, gray, rather thin bedded; 1,762 feet. Shales, sandstones, and limestones; 1,560 feet. Sandstones, mostly reddish; 4,491 feet. Sandstones, largely shaly, colors red and gray, with 198 feet of limestone 700 feet below top; 3,887 feet. Total thickness of Camp Creek, 11,700 feet.	
Helena. Limestone, with some shale; 2,400 feet.			
Empire. Shales, greenish gray; 600 feet.			
Spokane. Shales, with thin beds of sandstone; deep red; 1,500 feet.	*Spokane.* Shale and sandstone, the latter prevailing in upper portion; color chiefly red; 5,000 feet.		*Striped Peak.* Shales and sandstone, red and green; 1,000 feet.
Greyson. Shales, mostly dark gray; 3,000 feet.	*Greyson* may be present and included in Newland.		
Newland. Limestone, impure, weathering buff, with interbedded shale; 2,200 feet.	*Newland.* Limestone, thin bedded, more or less siliceous and ferruginous, passing into shale; generally buff on weathered surface; 4,000 feet.	*Blackfoot.* Limestone, thin bedded, more or less siliceous layers, weathering buff, interbedded with calcareo-arenaceous shales; 4,805 feet.	*Wallace.* Shales more or less calcareous, interbedded with thin layers of siliceous and ferruginous limestones and calcareous sandstone; limestones and calcareous shales weather buff; 4,000 feet.
Chamberlain. Shale, mostly black, with some sandstone; 1,500 feet.	*Ravalli.* Quartzite, gray with some dark bluish and greenish shale; 2,000 feet.	*Ravalli.* Sandstones, quartzitic, fine grained, purplish gray and gray; 2,550 feet. Sandstones, compact, gray; 1,060 feet. Sandstones, greenish gray, fine grained, in layers 4 inches to 2 feet thick; 4,645 feet; base not seen. Total thickness of Ravalli, 8,255 feet.	*St. Regis.* Shales and sandstones, purple and green; 1,000 feet.
			Revett. White quartzite, partly sericitic; 1,200 feet.
			Burke. Indurated siliceous shales with sandstones and quartzites, prevailingly gray-green; 2,000 feet.
	Prichard. Shales, dark bluish, interbedded with sandstone; rusty brown on weathered surface; 5,000± feet.		*Prichard.* Argillite, blue-gray to black, with distinct and regular banding, interbedded with a subordinate amount of gray sandstone; uppermost part arenaceous and marked with shallow-water features; base not exposed; 8,000 feet.
Neihart. Quartzite, with some shale in upper part; 700 feet.	*Neihart.* Quartzite, light colored; base not exposed; 1,000± feet.		
Archean.			

[a] Walcott, C. D., Pre-Cambrian fossiliferous formations: Geol. Soc. America Bull., vol. 10, pp. 199–244, 1899.
[b] Walcott, C. D., Algonkian formations of northwestern Montana: Geol. Soc. America Bull., vol. 17, pp. 1–28, 1906.
[c] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, 1908.

The correlation here set forth depends largely on the opinion of Walcott[1] that the "Blackfoot," "Wallace," and Altyn limestones are equivalent to the Newland limestone of the type section. Since this folio was prepared further work by Walcott and others[2] has cast doubt on the correctness of this opinion, and the formations to which the names Spokane and Newland are applied in the Philipsburg quadrangle should possibly be correlated respectively with the Marsh and Helena and those names be used. Further field study will be necessary before a positive conclusion can be reached.

NEIHART QUARTZITE.

Principal features.—The exposures of the Neihart quartzite in the Philipsburg quadrangle are all in the southeastern part of the Anaconda Range. The relation to the overlying Prichard formation is clear only in the largest exposure, on the east side of Sullivan Creek, where the quartzite forms a cliff and talus, conspicuously light in color by contrast with the dark, rusty rocks of the Prichard on the north. The thickness of Neihart quartzite here exposed is about 1,000 feet, but this does not fully represent the formation, whose base is concealed.

The lowest beds observed are of whitish quartzite without distinct partings. Farther up in the section the prevailing rock is grayish quartzite with thin micaceous partings from 6 inches to 3 feet apart. Still higher there are numerous interbedded layers of mica schist, a few feet or inches in thickness. The horizon where schist predominates over quartzite is taken as the top of the Neihart.

Petrographic details.—The quartzites that make up the bulk of the formation are white to light gray or drab, coarse grained, compact, and vitreous. Clear quartz is their dominant constituent, and all contain at least a little mica. Intense pressure has effected, in the purer quartzites, an obscure lamination, like that of silicified wood, which is especially distinct on weathered surfaces. The mica schist in the uppermost part of the formation is dark greenish or bluish gray, moderately coarse, and shows more or less distinct sedimentary lamination. The scales of mica, which lie rudely parallel to the bedding, determine an irregular cleavage. The weathered surfaces are commonly rusty.

When examined microscopically the vitreous quartzites are found to contain small quantities of muscovite, brown biotite, zircon, rutile, sillimanite, magnetite, and apatite. The quartz manifests the results of metamorphism very strikingly in its marked strain shadows and in the complete obliteration of the outlines characteristic of clastic grains. It forms, for the most part, thin overlapping lenticular bodies. In the schists the same minerals are revealed, but mica and sillimanite are relatively more abundant.

PRICHARD FORMATION.

Principal features.—Exposures of the Prichard formation are confined to a few square miles in the Anaconda Range. The largest area comprises the lofty summits of Mount Evans and Mount Howe, and others lie to the east and south.

The feature of the Prichard formation which first impresses one on seeing it in the field is the deep reddish-brown color of the weathered outcrops. The rocks of the formation are chiefly micaceous schists and gneisses, which are prevailingly dark gray on fresh fractures. They are the highly metamorphosed equivalents of clay shales with which some sandy layers, now represented by quartzites, were interbedded, chiefly near the top and bottom of the formation. The rocks would be soft were it not for this metamorphism, which has made them extremely resistant to erosion.

There is no continuous section of the formation from which an accurate measure of its thickness may be obtained. From the exposures in the area that contains Mounts Howe and Evans and the one south of Mount Evans their thickness is estimated at 5,000 feet, but owing to the discontinuity of the section and the complexity of the structure this estimate may be in error a thousand feet either way.

Petrographic details.—The argillaceous rocks that constitute the bulk of the formation exhibit a wide range of metamorphism. The least altered material shows a regular banding in

---

[1] Walcott, C. D., Algonkian formations of northwestern Montana: Geol. Soc. America Bull., vol. 17, pp. 17–21, 1906.

[2] See Daly, R. A., Geology of the North American Cordillera at the 49th Parallel: Canada Geol. Survey Memoir No. 38, p. 179; citation of Walcott, p. 183. The writer still dissents from some parts of Daly's correlation.

lighter and darker shades of blue-gray and resembles the slate that is typical of the same formation in the Coeur d'Alene district, but it sparkles with abundant minute flakes of mica. Evenly disseminated particles of the bronze-yellow iron sulphide, pyrrhotite, are the evident source of the ocher produced in the weathering of the rock. More common than this fine-grained schist are schists of coarser grain, with more conspicuous crystals of mica. As a rule these strongly metamorphosed rocks are full of little knots of claret-colored garnet, pale-pink andalusite, and white fibrous sillimanite. The most highly metamorphosed originally argillaceous rocks of the Prichard formation occur at the head of Twin Lakes Creek, where there have been several successive intrusions. These are tough, massive, highly contorted gneisses, whose general tone is dark brownish gray. Mica (chiefly biotite), quartz, and a few garnets are the only constituents easily recognized with the naked eye.

The quartzites of the formation are grayish, more or less rusty on weathered surfaces, and on the whole notably less pure and vitreous than those of the Neihart quartzite. Splinters of amphibole and pyroxene are visible in some of them.

Microscopic examination shows that even the least altered rocks of the formation have been thoroughly recrystallized, to the complete obliteration of original clastic textures. The minerals identified in thin section are quartz, biotite (generally reddish-brown), muscovite, sillimanite, andalusite-orthoclase, plagioclase, cordierite, pyroxene, amphibole, titanite, magnet, ite, pyrrhotite, pyrite (?), apatite, zircon, rutile, chlorite, garnet, spinel, and tourmaline. No one specimen contains all these minerals, though many specimens of schist or gneiss contain all but three or four. Amphibole and pyroxene are not found in the rocks that contain cordierite, andalusite, or sillimanite. The plagioclase is in part decidedly calcic.

RAVALLI FORMATION.

Principal features. — The Ravalli formation is composed mainly of light-gray quartzite that is not so pure as the Neihart quartzite. This rock almost exclusively constitutes the lower two-thirds of the formation; the upper third comprises much dark bluish and greenish shale, interbedded with dark quartzitic sandstone and with quartzite like that in the lower part. The transition from the Ravalli to the argillaceous Prichard formation below and the calcareous Newland above is gradual.

The formation occurs in a northeast-southwest zone that crosses the crest of the Anaconda Range near the central meridian of the quadrangle and, being composed of resistant rocks, it is well exposed. A complete and continuous section of the formation is displayed in the cliffs on the north side of the Continental Divide immediately west of Mount Howe, where its thickness is about 2,000 feet. In the area crossed by the divide between Twin Lakes and Barker Creek almost the entire formation, here highly metamorphosed, is exposed. On the whole, however, the formation is considerably less metamorphosed than the older ones.

Lithologic details.—The purer quartzite, whose prevailing color is pale gray, generally forms beds 6 inches to 2 feet thick, separated by thin, dark, argillaceous partings. It shows a delicate color lamination, either parallel to the general bedding or inclined in cross-bedded structure. Its texture is invariably rather fine and, owing to its large content of finely divided mica, it is less hard and vitreous than the typical Neihart quartzite. The less quartzitic sandstones, common in the upper part of the formation, are more distinctly banded in light and dark gray, and some are dull green. The shales in the upper part are dark bluish or greenish gray and have an obscure banding parallel to the stratification and commonly a rude cleavage inclined to this banding.

The most universal change produced in the Ravalli rocks by strong metamorphism is a recrystallization that obscures the clastic texture. In the more siliceous rocks metamorphism causes but little development of new minerals. The quartz becomes more sugary in appearance; the mica forms larger and more conspicuous flakes and tends to segregate in somewhat irregular layers almost parallel to the bedding. The most argillaceous rocks take on a distinctly schistose character and contain dark knots of obscure composition, probably consisting, as a rule, of decomposed cordierite. In some beds of intermediate composition the biotite and other minerals are segregated in specks or in bands without the development of marked schistosity.

The constituents revealed by the microscope comprise all those found in the less altered rocks, as well as andalusite, sillimanite, some minor constituents, and micaceous pseudomorphs after cordierite.

NEWLAND FORMATION (AND POSSIBLY GREYSON SHALE).

Principal features.—The Newland limestone of the Little Belt Mountains is probably represented in this area by a thick body of strata which differs from the older formations and from the overlying Spokane in being distinctly calcareous but which as a whole can not very accurately be called limestone. Its most typical rocks consist largely of carbonates but contain a nearly equal quantity of other matter, chiefly quartz. Little, if any, of the carbonate, moreover, is pure calcite. Lime is probably its most abundant base, but in general considerable magnesia and iron is combined with lime to form a mixed carbonate, whose decomposition is attended by the formation of yellow ocher, which imparts a stain to the beds. The prevalence of such a stain and of thin bedding characterizes the Newland both of the type locality and of the Philipsburg quadrangle.

The intimation in the above heading that the strata mapped as Newland in the Philipsburg quadrangle may comprise beds representing the Greyson shale merely suggests one way of accounting for the most material discrepancy between the succession of Algonkian strata in the Philipsburg quadrangle and in the Little Belt Mountains, namely, the absence from the Philipsburg district of the shales, prevailingly gray and apparently not calcareous, that constitute the Greyson formation of the type region. The alternative correlation suggested on page 3 obviates this difficulty, though it involves others. The lithology of the Belt series in the area described in this folio gives no ground for the separation of a stratigraphic unit lying in the position of the Greyson shale above the Newland and beneath the Spokane. Each of these formations is fairly homogeneous and well individualized, and the passage from the one to the other is gradual. The uppermost part of the Newland, however, is rather more shaly than the remaining part. In the Coeur d'Alene district of northern Idaho the formation comprises beds at the top which are hardly thick or distinct enough for separate mapping but which thicken greatly toward the south, where they may well be regarded as a distinct formation. It is possible that some such thickening and lithologic variation of the uppermost beds in the Newland formation of the Philipsburg quadrangle might be traced eastward.

The Newland formation occupies extensive areas, chiefly in the western half of the quadrangle, but it occurs also northeast of Philipsburg, in the southeastern part of the Flint Creek Range, and in the eastern part of the Anaconda Range. The general appearance of the rocks of the formation depends closely on the degree to which they have been metamorphosed by igneous intrusion. The unaltered rocks in areas free from large intrusive masses, though mostly grayish on fresh fractures, are stained with yellow ocher in a manner that distinguishes them from all other thick formations in the region. The resistance to erosion offered by the unaltered rocks is relatively slight, and in large areas where they are not associated with harder rocks they form such gently rounded hills as those west of Philipsburg Valley and about Georgetown Lake. But all these characteristics are greatly modified by contact metamorphism. Where, as in a large part of the Anaconda Range, the Newland formation is invaded by great masses of granitic or other intrusive rocks, its carbonates react with quartz to form silicates, and its soft limestones and shales become tough hornstones, strongly resistant to decomposition and erosion. The hornstones are greener than their unaltered equivalents, and their weathered surfaces are but little stained with limonite. In the Anaconda Range they form steep cliffs and lofty peaks, hardly less rugged than those of quartzite, but the clearest evidence of their induration is perhaps to be seen in Henderson Mountain, which is conspicuous in the view northward from Philipsburg. Both this eminence and Sunrise Mountain are carved from hornstone produced from the Newland formation by the metamorphic influence of a small intrusive mass exposed in the gorge between the two summits. Their height above the surrounding flat-topped hills is due to the greater hardness of the hornstone as compared with that of the unmetamorphosed shales of which those hills are formed.

Petrographic details.—The calcareous argillites and very impure limestones that make up the greater part of the formation generally break into slabs a few inches to a foot thick. The bedding is also marked by narrow ill-defined bands, which on fresh fracture are dark to pale bluish or greenish gray. The layers differ in hardness and in the extent to which they are discolored by weathering, so that the lamination is accentuated on the weathered surface. Weathered blocks that are deeply grooved by the etching out of the more calcareous laminæ, somewhat resemble dead wood. On application of cold dilute acid to fresh surfaces of these rocks they effervesce rather feebly, a fact which indicates that the carbonate is in considerable part magnesian, and the presence of iron is indicated by the ocherous coating on most weathered surfaces. At certain horizons in the middle and upper parts of the formation purer limestone forms discontinuous layers, thin lenses, and nodules flattened parallel to the bedding planes. Few of these bodies of purer limestone are more than 3 inches thick. On weathered surfaces they are deeply sunken and are blue-gray in color, presenting a contrast to the yellowish-weathered ferruginous matrix. In the altered Newland on Lost Creek and near Mount Haggin there are white to pale-gray beds, a foot or two in thickness, resembling fairly pure marble, but these contain a good deal of silica. A little calcareous quartzite or sandstone is interbedded with the fine-grained rocks. This material, pale gray on fresh fracture, is generally brownish on the weathered surface, which in certain beds near the top exhibits a cross-bedded structure. The uppermost beds of the formation consist of very fissile drab calcareous shale, in which there are mud cracks.

When examined in thin section, the dominant rocks prove to consist mainly of approximately equal amounts of quartz and the mixed carbonates of lime, iron, and magnesia. The grains are a few hundredths or thousandths of a millimeter in diameter. Feldspar can usually be detected and sericite is invariably present; chlorite is rare. Minor constituents generally present are zircon, carbonaceous dust in the dark layers, and white cloudy particles of leucoxene. The grains of the chief constituents interlock and none show rounded outlines that suggest attrition; the quartz and feldspar grains are irregular; the carbonate, in large part, forms rhombohedral crystals.

The common effect of igneous metamorphism on the Newland rocks is their alteration to dense hornstones containing abundant diopside or amphibole, or both, accompanied by quartz and feldspar, with titanite as a constant accessory. Biotite also is commonly present, and residuary calcite occurs in variable amount. These rocks are built up of laminæ whose tints are white, light or dark grayish green, and chocolate-brown. The texture, though in some specimens perceptibly crystalline, is usually so fine that the minerals can not be identified with the naked eye, but the mineral composition of the layers is partly indicated by their color. A brown hue results from the presence of biotite, and dark gray-green from that of amphibole; very pale green layers are likely to be rich in diopside, and colorless layers to consist mainly of quartz and feldspar.

Thin sections examined under the microscope reveal a granular fabric, more uneven and in general not so fine as that of the unaltered rocks. The green amphibole tends more to prismatic elongation than the pale diopside. The biotite, usually reddish, is in minute flakes. Sericite is rarely found in the thoroughly metamorphosed rocks, and the same may be said of carbonates. The amount of feldspar present usually equals or exceeds that of quartz. In most slides it is chiefly or wholly orthoclase, but in some places potash feldspar is accompanied by lime-rich feldspar. Titanite is prominent in all thin sections. Other minerals more or less commonly present in small quantity are epidote, zircon, pyrite, and tourmaline.

Scapolite-bearing rocks are abundantly developed northwest of Cable Mountain. They are not very different in general appearance from the rocks just described except that they rarely contain brown biotitic bands. As a rule the scapolite is inconspicuous, but in some of the more coarsely crystalline rock it is clearly visible as white semitransparent prisms a few millimeters long.

Under the microscope the most abundant and constantly present minerals are seen to be scapolite and pale-green diopside. Scapolite usually forms, roughly, from a fifth to a half of the rock, and diopside has about the same range. Quartz and calcite are generally abundant but their amount varies greatly. Amphibole is scarce and some of that present is clearly derived from diopside. A soda-rich feldspar (albite or sodic anorthoclase) is abundant in places; orthoclase or microcline are scarce, and lime-rich feldspar is not found. Very small quantities of zircon, pyrite, and epidote, and sporadic tourmaline, garnet, allanite, and phlogopite occur. Mica is absent from most specimens.

The scapolite in most specimens shows a double refraction of 0.022 to 0.025, which indicates a composition near Me_2Ma_1. In the specimen where the mineral is most abundant, however, its double refraction is about 0.013, which proves that it is very poor in lime.

Although small quantities of epidote may be found in specimens taken from the Newland formation at many places the mineral is noted in abundance only near small intrusions in the northwestern part of the quadrangle. Here it is conspicuous and is accompanied by garnet—a mineral also scarce in the formation elsewhere. The distribution of these minerals is irregular and seems related to fissures. The epidotic rocks contain calcite, quartz, diopside, titanite, actinolite, and albite. Tremolite and vesuvianite have been found in the same locality, though they are not of common occurrence in the Newland formation.

SPOKANE FORMATION.

Principal features.—The Spokane formation is represented in the Philipsburg quadrangle by a great thickness of shale and sandstone. Its rocks are prevailingly red and are marked by sun cracks, ripple marks, and other evidence of deposition in shallow water, interrupted by frequent exposure to the air. The base of the formation as mapped is the lowest red shale overlying the buff-weathering rocks of the Newland, and the lowest part includes some green shale like that in the upper part of the Newland. For some 2,000 or 3,000 feet above the base the rock is mainly red shale, with subordinate sandstone. The proportion of sandstone is not constant along the strike, however, and much of the lower part of some sections is arenaceous. Sandstone prevails in the upper part of the formation but is interbedded with shale and comprises thin beds of conglomerate.

The most nearly complete section of the Spokane is displayed in the canyon of Flint Creek between Georgetown Lake and Philipsburg Valley. Unless there is duplication by faulting, of which no proof has been found, the thickness here exposed is nearly 10,000 feet. The thickness of the formation in most of the western part of the quadrangle apparently does not differ greatly from this, but at many places in the eastern part it is very much less. This discrepancy is due, at least in large measure, to erosion of the formation before the beginning of Cambrian sedimentation and is therefore discussed later in connection with the unconformity between the Algonkian and Cambrian strata. Because of this unconformity it is of course impossible to learn how nearly uniform the thickness of the Spokane in this district was originally.

Where the Spokane formation is unmetamorphosed its most conspicuous feature is the prevailing deep-red color of its rocks, but the color is radically altered by contact metamorphism. Where the metamorphism is slight the characteristic red changes to a duller purplish hue; where it is thorough the colors are grays, greens, and browns. The metamorphic representatives of the shales and sandstones of the Spokane formation are chiefly quartz-muscovite-biotite rocks and cordierite hornstones, but the transitional partly calcareous beds at the base alter to deep-green flaggy rocks rich in amphibole.

The shaly parts of the Spokane are easily eroded to rather gentle slopes like those along the northwest side of Philipsburg Valley. The upper sandy part is more resistant, and the prominence of the ridge between the two Willow creeks, of Cable Mountain, of Twin Peaks, and of the ridge northeast of the Carp Mine, is due to the fact that these ridges are composed of this rock, which is harder than the limestones and shales that form the surrounding lower surfaces. The resistance to erosion of both shales and sandstones is slightly increased by contact metamorphism.

The distribution of the Spokane is similar to that of the Newland. Most of the area in which the formation is unmetamorphosed lies west of a line drawn from the northeast to the southwest corner of the quadrangle; most of that in which it is much altered lies east of that line. Progressive metamorphism may be observed near Rumsey and Cable mountains in the central part of the quadrangle. In most of the Anaconda Range and in the area traversed by Lost Creek great alteration is general.

Petrographic details.—The shales are more or less arenaceous and are built up of alternating laminæ, generally less than an inch in thickness, of finer-grained and darker and of coarser-grained and lighter material. The prevailing maroon color is here and there relieved by a contrasting shade of olive-green. In contrast to the Newland formation, the Spokane formation is free from carbonates, except in some transitional beds of its lower part. The features that in the Newland formation indicate deposition in shallow water are even better preserved in the shaly beds of the Spokane, almost every outcrop of which shows sun cracks, ripple marks, mud breccias, or, more rarely, impressions of raindrops.

The sandstone grades into shale and much of it is flaggy, the thickness of the beds rarely exceeding a foot. It is partly whitish or greenish but more generally red. Color lamination in red and white is common, and in many places is inclined to the stratification. Cross-bedding whose dip would be easterly if the beds were restored to horizontal position is conspicuous north of the point where Flint Creek enters Philipsburg Valley. The texture varies from fine to coarse, but the diameter of the grains rarely exceeds a millimeter. Where the texture is not too fine much feldspar and mica can be distinguished.

Like red sediments in other regions the sandstones and, less commonly, the shales contain pale-green or nearly white spots, probably due to reduction of the iron about organic particles of which no other trace remains.

A highly characteristic feature of the sandstone is the presence, in many layers, of abundant flat pieces of dark-red argillite ranging in diameter from a small fraction of an inch to 2 inches, similar to the finest-grained portion of the shales. Some of these bodies, whose larger dimensions are in the bedding planes, are smooth and well rounded like pebbles; others are sharply angular. (See Pl. XII.) These fragments were evidently derived from mud flakes that curled up in drying. Before they were covered some of these fragments were rolled by wind; other were but little disturbed.

Quite distinct in character and origin from these rocks is the conglomerate or pebbly sandstone in the upper part of the formation, which contains well-rounded pebbles an inch or less in diameter, consisting chiefly of quartz but partly of feldspar and of white or reddish quartzite. These pebbles were evidently formed by long attrition of fragments from consolidated rocks.

Microscopic sections of the sandstone show moderately well rounded grains of quartz and feldspar—chiefly potassic—in a more or less turbid sericitic matrix. In the sandy shales the grains are angular and the cement is more abundant. The finer layers are very rich in iron oxide, some of which appears to be anhydrous, being black by reflected light. The dulling of the color entailed by slight metamorphism is probably the result of further dehydration. The carbonate in some of the lower beds is all in more or less perfect rhombohedral crystals and hence is not calcite, a fact shown also by its failure to effervesce on application of cold dilute acid.

The flaggy green beds found near the base of the formation in most areas where it is greatly affected by metamorphism are like the most common phase of the altered Newland, except that they contain more amphibole and are darker green and rustier on weathered surfaces.

Southwest of Twin Peaks and near the junction of the Spokane with the scapolite-bearing Newland rocks east of Rumsey Mountain, the lower, argillaceous part of the formation has been altered to rocks characterized by poikilitic amphibole, accompanied by scapolite in most specimens, and free from diopside. Scapolite has not been found elsewhere in the formation. These rocks show no conspicuous evidence of alteration but resemble the unaltered banded shales, except that the finer bands are dull purple rather than red and the coarser parts are green and slightly crystalline.

The thin section reveals quartz, green amphibole, green biotite, and scapolite as chief constituents and clastic feldspar, chlorite, calcite, hematite, magnetite, epidote, "leucoxene," titanite, zircon, and tourmaline, as minor ones. The purple hue of the fine-grained parts is due to hematite dust, much of which has escaped reduction and recombination.

In a rudely circular area about a mile in diameter, whose center lies about 1¼ miles west of Flint, the Spokane rocks have undergone a form of alteration not elsewhere observed. Except in color they resemble the typical lower beds of the Spokane formation, but their prevailing color is rather dark grayish green owing to the presence of green biotite and chlorite. This alteration is probably due to masses of diabase or other igneous rock beneath the surface.

Argillaceous beds free from lime are commonly metamorphosed to rocks characterized by cordierite, which is usually accompanied by andalusite. These rocks are gray and are thickly dappled with dark spots a few millimeters in diameter—cross sections of grains of cordierite and andalusite, which form warty protuberances on weathered surfaces. Some specimens are distinctly crystalline and contain large crystals of mica; others are very fine grained.

The microscope shows that the cordierite, as well as the andalusite and large crystals of mica when present, are crowded with inclusions of the associated minerals. These poikilitic crystals are embedded in a mosaic of quartz and feldspar in which little flakes of mica, crystals of magnetite and tourmaline, and needles of sillimanite are disseminated. Andalusite is commonly replaced in part by an aggregate of colorless mica; cordierite is still more commonly replaced by a mixture of white and brown micas.

The more siliceous shales alter to schistose dull olive-green rocks, which, as a rule, cleave obliquely to the obscure bands that mark the bedding. The cleavage faces have a silvery sheen from finely divided mica. These rocks grade into micaceous quartzites derived from the sandstones, which range in color from pale gray to dull greenish brown and which are commonly dappled with dark-greenish biotitic spots about 2 millimeters in diameter.

The microscopic features of these quartz-mica rocks are hardly noteworthy except for the usually prominent development of tourmaline crystals, whose form and size clearly indicate their secondary nature.

CAMBRIAN SYSTEM.

SUBDIVISIONS.

The Cambrian rocks of the Philipsburg quadrangle consist of the Flathead quartzite; Silver Hill formation, chiefly calcareous shale; Hasmark formation, chiefly magnesian limestone, with calcareous shale; and Red Lion formation, chiefly limestone. The formations are named in ascending order and the general sequence is largely similar to that in central Montana, but correlation can confidently be made only of the Flathead, hence the necessity for applying new names to the other formations.

UNCONFORMITY AT BASE.

A marked unconformity between the Belt series and the Cambrian was long ago recognized by Walcott. In the parts of Montana previously explored the chief evidence of unconformable relation is the fact that at different places the basal Cambrian sandstone or quartzite lies upon beds of widely different geologic horizon in the Belt series. In the Philipsburg quadrangle, not only is this evidence of unconformity found, but still clearer evidence is afforded by angular discordance between Cambrian and Algonkian beds and by local development of a Cambrian basal conglomerate with pebbles derived from the immediately underlying Belt series.

The base of the Flathead everywhere in the Philipsburg quadrangle lies on the Spokane formation, but the thickness of red beds between the Newland and the Flathead ranges from several thousand to less than a hundred feet. The great thicknesses are mainly in the western part of the quadrangle. In the Anaconda Range and in the southern part of the Flint Creek Range there is, broadly speaking, a rapid diminution in thickness toward the east and a less marked diminution toward the south. In the northern part of the quadrangle the variations in thickness do not follow the same rule. The Spokane appears to be at least 5,000 feet thick between the two streams called Willow Creek, but its thickness dwindles eastward to the hills just west of Flint, where it is only about 250 feet thick. Farther east it again grows thicker, reaching a thickness of several thousand feet in the drainage basin of Boulder Creek.

In two cliff exposures the Flathead may be seen to lie upon the beveled edges of the strata of the Spokane. One is in the western part of the Anaconda Range, 1½ miles due east of the Carp mine; the other is half a mile northeast of the peak that stands 8,861 feet high on the southern rim of Lost Creek basin. A photograph of the exposure east of the Carp mine is reproduced in Plate IV. The Spokane here strikes north-northeast and dips 50° to 60° W.; the Flathead strikes nearly north and dips 25° W. The surface of contact is nearly but not quite plane.

The relations in the exposure south of Lost Creek are shown in figure 3. The discordance of dip here is much less than at the locality just described; the quartzite strikes N. 60° E. and dips 21° W.; the Spokane immediately below strikes N. 58° E. and dips 25° W. The sandstone tapers to an edge near the crest of the divide just southeast of the high peak.

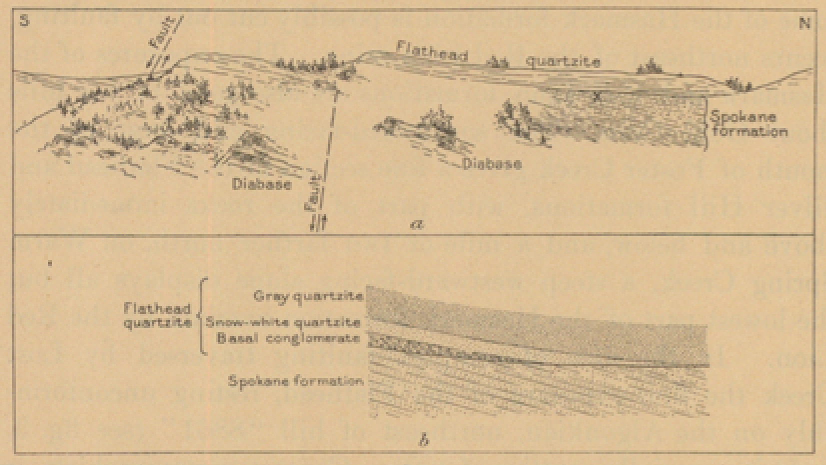


FIGURE 3.—Sketch of unconformable contact of Cambrian on Algonkian rocks, south side of Lost Creek.

a, General unconformity of the Flathead quartzite resting on beveled strata of Spokane formation, small normal fault, and diabase sill.

b, Detail of unconformity at point marked x in *a*, showing overlapping beds at the base of the Flathead quartzite.

At the base of the Flathead on the cliff illustrated in figure 3 there is a lens of conglomerate, the relations of which at the north end of the cliff are shown diagrammatically in the detailed sketch (*b*). The conglomerate has been traced southward for a few rods to a point where it disappears under talus, and no conglomerate has been found elsewhere in the quadrangle in beds known to be Flathead. The pebbles of this conglomerate are subangular to fairly well rounded; the largest are about 6 inches in diameter. They are all of light-gray quartzitic sandstone evidently derived from the Spokane strata immediately underneath.

CORRELATION.

In the preceding paragraphs the unconformable relationship of a certain persistent quartzite to the Belt series has been assumed to justify the identification of that quartzite with the Flathead, which is the basal member of the Cambrian series wherever, in Montana, this part of the geologic column has been studied. The correlation is confirmed by a general similarity in the sequence of formations overlying the quartzite in the Philipsburg quadrangle and the localities farther east. The discovery by E. M. Kindle of Upper Cambrian fossils in the Red Lion formation, which is separated from the basal quartzite by several hundred feet of shale and limestone, proves conclusively the existence in the quadrangle of a fairly thick series of Cambrian strata, and indicates that the Red Lion formation is approximately equivalent to the Yogo limestone, the highest Cambrian formation of central Montana. But the upper limit of the Cambrian series in the Philipsburg quadrangle is less certainly fixed than the lower. The fossiliferous Red Lion formation is overlain by the Maywood, in which no fossils have been found. In the absence of clear evidence regarding its age, the Maywood formation was conjecturally assigned to the Silurian, as is indicated on the geologic map. Since the writing of this text Edwin Kirk has examined exposures of the Maywood and has formed the opinion that they are probably Cambrian, because they resemble Cambrian beds in other parts of the region and are very unlike the nearest known Silurian or Ordovician rocks.

The correlation of the formations between the Flathead and the Red Lion must rest entirely upon lithologic resemblance. A correlation so based is obviously not infallible, for a limestone may grade along its strike into a shale. It is, moreover, impossible to match, bed for bed, the sequence in the Philipsburg quadrangle with that in central Montana. If, however, it be assumed that no radical changes along the strike take place, and that certain shales not regarded as mappable in the Philipsburg quadrangle are equivalent to shales distinguished as formations in the Little Belt Mountains, which may be regarded as the type district for the Cambrian of central Montana, the following tentative correlation may be offered:

Tentative correlation of Cambrian formations.

Philipsburg quadrangle.		Little Belt Mountains.
Maywood formation (?)		Yogo limestone.
Red Lion formation	Upper member	
	Lower member	Dry Creek shale.
Hasmark formation		Pilgrim limestone.
Silver Hill formation	Shale and laminated limestone	Park shale.
	Laminated limestone	Meagher limestone.
	Green shale	Wolsey shale.
Flathead quartzite		Flathead quartzite.

GENERAL DISTRIBUTION.

The northernmost tract in which the Cambrian rocks occur, that comprising Princeton and Flint, affords good sections of the Hasmark and Red Lion formations along Boulder Creek.

In the anticlinal area east of Philipsburg all the Cambrian formations are well exposed. The area has especial interest by reason of the intense metamorphism there developed, particularly in the Silver Hill formation. Metamorphism is likewise prevalent in the long strip flanking the Cable Mountain anticline. A well-exposed section of the Cambrian rocks, in which some of the Hasmark formation is possibly cut out by faulting, occurs northeast of the Red Lion mine. The exposures of the Hasmark and Red Lion formations are also good in the hills about Gold Coin. The southward-facing cliff west of the mouth of Foster Creek gives a fine section of the Flathead and Silver Hill formations, with part of the rocks immediately above and below, and a mile or two farther north, on Warm Spring Creek, a steep westward-facing slope displays all but the lowest part of the Hasmark formation overlain by the Red Lion. In the area of complex faulting traversed by Lost Creek the fine exposure of the Flathead, resting unconformably on the Algonkian, northeast of hill "8861" (see fig. 3, p. 5) is especially worthy of note. Contact metamorphism is general in this tract.

The Cambrian rocks occupy a considerable area and are well exposed in the western part of the Anaconda Range. The eastern slope of Silver Hill gives perhaps the best section in the quadrangle of the Hasmark and underlying formations, and these same formations occur in an isolated tract about Mount Haggin.

FLATHEAD QUARTZITE.

Principal features.—The Flathead is a resistant and usually prominent formation consisting mainly of white or pale-tinted, thick-bedded, pure and vitreous quartzite. At its top, and to a still greater extent in its lower part, it contains some grayish impure quartzite similar to the most siliceous beds of the Spokane. For this reason the base of the Cambrian, notwithstanding that it is a plane of marked unconformity, is hard to locate exactly except where it rests on the shaly part of the Spokane formation or where there is visible angular discordance or a basal conglomerate. Except where these conditions exist no reliable measure of the thickness of the formation is possible. South of Lost Creek, where the basal unconformity is visible, two independent observations gave thicknesses of 165 and 170 feet. The Silver Hill section and that near the mouth of Foster Creek indicate a thickness of about 145 feet, but here the base is not very well defined.

The base of the formation just east of Philipsburg has not been precisely located; here about 250 feet of more or less quartzitic rock lies beneath the Silver Hill formation, but much of this is dappled or reddish and probably belongs to the Spokane formation.

In the vicinity of Mount Haggin the thickness of the Flathead quartzite is far from uniform. The formation is about 50 feet thick in the pass at the head of Mill Creek. On the ridge west of Mount Haggin it tapers out rather abruptly between the Spokane and Silver Hill formations. On spurs to the southeast it is 5 to 75 feet thick, but near the east end of the exposure it swells out to a thickness of 200 feet. The exposures in these localities are good, and the opinion was formed in the field that the variations in thickness were due to overlap, but they may be due in part to thrust faulting.

Petrographic details.—The less purely siliceous beds of the Flathead quartzite are so nearly like the more siliceous beds in the Spokane formation that little need be said of them here. It is not known whether they are partly reddish when unaltered, like rock of the same formation in central Montana, for they are somewhat metamorphosed wherever the exact limits of the formation are known. They do not often show the dappling that is common in the Spokane formation. The more characteristic, purer quartzite is commonly almost white on fresh fracture and evidently consists essentially of compactly cemented quartz grains. Where the original texture has not been too much obscured most of the grains are less than 1 millimeter in diameter, but metamorphism enlarges them and obliterates their boundaries more completely in the pure quartzites than in quartzitic sandstones.

SILVER HILL FORMATION.

Principal features.—The formation above the Flathead quartzite is named for a hill south of Silver Lake on whose eastern face it is well exposed. In the type section it is divisible into three members which are, in descending order, as follows:

Generalized section of Silver Hill formation.

	Feet.
Shale, calcareous, strongly banded in brown, white, and green, interbedded with laminated limestone	90
Limestone with thin brown siliceous laminæ	120
Shale, dark green, not notably calcareous, with a 3-foot dioritic sill near the base	120

The upper and middle members are composed of somewhat similar materials but present a rather sharp lithologic contrast to the lower. The chief reason for mapping these rocks as a unit is that when unaltered they are much less resistant to erosion and therefore much less exposed than the Flathead quartzite below and the Hasmark formation above. Where exposures of the Silver Hill formation are entirely wanting, as they are, for example, about Princeton, subdivision is evidently impracticable.

Notwithstanding the general weakness of the formation it is well exposed at many places. Its preservation is partly due to the induration produced in it by slight metamorphism, which is not altogether absent from the section at Silver Hill; yet in the Anaconda Range, owing to the support of harder rocks and the general strong relief, good sections of the formation almost free from alteration are preserved. Perhaps the best of these is about a mile northwest of the peak 10,100 feet high near the eastern edge of the drainage basin of Rock Creek.

The thickness of the Silver Hill appears fairly uniform in the northern and middle parts of the quadrangle but is less uniform in the Anaconda Range. Three miles northeast of the Carp mine there is an apparently unfaulted section in which both the calcareous and noncalcareous parts have about twice their average thickness. On the bank of the East Fork of Rock Creek the Hasmark rests on the Flathead, but there are evidences of faulting which may account for the absence of the Silver Hill formation. In the vicinity of Mount Haggin the formation is not over 100 feet thick and apparently transgresses the Flathead, so that its upper limy member rests on the Spokane.

Petrographic details.—The shale of the lower part has a nearly uniform olive-green tint and is without conspicuous banding. Where it is not metamorphosed, it may be split into thin flakes, which are spangled with mica. Where it is slightly metamorphosed it is darker and harder and much less fissile. Strong metamorphism converts the green shales to cordierite hornstones like those of the Spokane formation. These rocks are gray and more or less distinctly dappled with dark spots, 1 to 3 millimeters across. Some of them contain conspicuous grains of mica 1 millimeter or so in diameter.

Microscopically examined, slightly altered specimens are found to consist mainly of angular to subangular quartz and feldspar grains embedded in sericite and green biotite and associated with little epidote and tourmaline. A typical specimen of hornstone from the south end of Cable Mountain shows highly poikilitic grains of cordierite and smaller imperfect prisms of andalusite in a matrix chiefly composed of limpid grains of orthoclase. Quartz is very scarce. Tourmaline is exceptionally abundant and well crystallized. Other constituents are biotite, sillimanite, magnetite, and zircon.

The remarkable abundance of orthoclase in the cordieritic hornstone suggested the possibility that potash had been added in the process of metamorphism. To test this hypothesis chemical analyses were made of a shale virtually unmetamorphosed and of the hornstone. The hypothesis is not confirmed by the analyses, which show rather close similarity, especially as regards the content of potash. The original rocks are remarkably rich in potash, and the deposits from which they were formed may have been glauconitic.

Analyses of rocks from lower part of Silver Hill formation.

[By W. T. Schaller.]

	1	2
SiO_2	53.29	63.47
Al_2O_3	22.38	17.33
Total iron as FeO	6.57	5.09
TiO_2	.91	.96
MgO	2.10	1.32
CaO	.53	.64
K_2O	7.43	7.00
Na_2O	1.11	.50
H_2O[a]	4.12	2.66
CO_2	.58	.33
	99.02	99.42

[a] Determined by loss on ignition, corrected for carbon dioxide and oxidation of ferrous iron.

1. Shale on west slope of Cable Mountain.
2. Cordierite hornstone near Cable.

The usual appearance of the limestone that is characteristic of the middle part of the Silver Hill formation is well shown in Plate III, *A*, although this illustration is reproduced from a photograph of the Red Lion formation. The most conspicuous feature of the rock is a peculiar lamination; laminæ of nearly pure pale gray or drab limestone alternate with thinner laminæ of a darker cherty material, which project in relief on weathered surfaces. The siliceous layers are somewhat less than one-half centimeter in average thickness and are spaced at intervals of about 1 or 2 centimeters, but they are uneven in thickness and wavy. Where it is not metamorphosed, as about Princeton and in the basin of the East Fork of Rock Creek, this limestone parts more readily along bedding planes, and the weathered surfaces of the siliceous layers are stained with ocher. The appearance of the rock then recalls the description of the "mottled limestones" of the Cambrian in the earlier Montana folios.

The banded shales predominant in the uppermost part are interbedded with and grade into the laminated limestones. The least limy rock in the upper part of the Silver Hill section is a calcareous shale banded in chocolate-brown and pale-green layers, but this rock is not free from metamorphism; the brown color is due to biotite, and the green to amphibole or pyroxene. The unmetamorphosed shale seen elsewhere is of drab or olive hue.

Moderate alteration of the laminated limestone is illustrated in the section west of Foster Creek. Metamorphism is hardly suggested megascopically except by a slight crystallinity, but the microscope reveals considerable alteration. The siliceous laminæ consist mainly of potash feldspar, reddish-brown biotite, and diopside, with a little calcite, epidote, titanite, lime-rich feldspar, and tourmaline. Quartz is entirely absent. Other specimens, a little more altered, contain tourmaline in conspicuous black crystals about 1 centimeter long.

Intense metamorphism is strikingly exemplified at Philipsburg, where the calcareous beds are altered to coarse aggregates, chiefly of garnet, pyroxene, amphibole, scapolite, epidote, and magnetite, in varying proportions. These altered rocks may be roughly divided into three groups, which are characterized respectively by abundant garnet, scapolite, or magnetite.

The chief constituent of the most abundant rocks is a dark reddish-brown variety of garnet, with which is mingled a green microcrystalline substance consisting mainly of pyroxene with more or less epidote and calcite, rudely interlaminated.

Other constituents, visible only with the aid of the microscope, are amphibole, titanite, chlorite, quartz, and zircon.

The rocks characterized by abundance of scapolite contain calcite, amphibole, and pyroxene as their other chief constituents, and their general color is greenish gray. The scapolite in some specimens forms large irregular individuals, the largest about 2 inches long, with abundant inclusions. Among the minor constituents are quartz, epidote, titanite, and pyrite The composition of the scapolite ranges, approximately, from Me_2Ma_1 to Ma.

Some of the rocks rich in magnetite are distinctly banded, the alternate layers consisting chiefly of magnetite with some interstitial amphibole, iron-poor epidote, and quartz; the layers between are chiefly of amphibole, epidote, and calcite. In another type white laths of scapolite about 1 centimeter long, lying in all positions, are conspicuous in a matrix consisting chiefly of magnetite.

In the contact zone of the porphyritic granite north of Lost Creek, the upper part of the Silver Hill formation is largely altered to obscurely laminated rocks rich in vesuvianite and diopside and containing epidote, calcite, quartz, and sporadic scapolite.

HASMARK FORMATION.

Principal features.—The Hasmark formation is named for a partly abandoned village southeast of Philipsburg.

It consists of three members, which are, in ascending order, (1) magnesian limestone, mostly blue-gray, about 550 feet; (2) calcareous shale, 100 feet or less; (3) magnesian limestone, mostly white, about 350 feet. The character of the formation is fairly constant throughout the quadrangle except that the shale varies considerably in thickness. In the central and southeastern parts of the quadrangle its maximum thickness is 100 feet. In the western part of the Anaconda Range it is about 20 feet; at Philipsburg no shale is exposed; near Princeton the middle member is represented by about 25 feet of ferruginous limestone and shale.

The limestones crop out rather strongly as a rule, the white outcrops of the upper member being especially conspicuous. The shale is at few places well exposed.

Petrographic details and fossils.—The lower magnesian limestone is for the most part pale blue-gray and of rather fine, sugary texture. One of its constant features is its gritty weathered surface, which is not due, as might be supposed, to projecting grains of sand. The rock is a mixture of irregular grains of calcite and crystals of dolomite, which, being the less soluble, project in relief. Uneven distribution of the crystals of dolomite possibly effected by some low form of organism, gives rise to characteristic mottling, obscurely visible in Plate IX. The same illustration shows white tubular bodies which, according to Edwin Kirk, may be the fossil cases of annelids; and Plate XI illustrates ellipsoidal bodies of concentric structure, identified by the same authority as probably formed by calcareous algæ of the genus Girvanella. Both these types of probable organic remains are found near the base of the lower dolomite.

The magnesian character of the limestone is indicated not only by its texture but by its weak effervescence with acid. A partial analysis by Mr. Schaller follows:

Partial analysis of lower limestone of Hasmark formation.

Insoluble in HCl	0.45
CaO soluble in HCl	44.35
MgO soluble in HCl	6.46

Besides this dominant phase, the lower member of the Hasmark comprises some dark iron-gray limestone, chiefly in the upper part, and some finer-grained white limestone, chiefly in the lower part. Thin transitional beds of calcareous shale occur near the top and bottom of this member.

The shale member is thickest and best exposed in the vicinity of Warm Spring Creek, where it is composed mainly of material like that in the upper part of the Silver Hill formation. Especially characteristic is a chocolate-brown argillaceous rock with elliptical nodules and lenticular layers of gray limestone usually less than an inch thick. The chocolate color is due to biotite and indicates a little metamorphism. In some other places where the shales are unaltered they are olive-green to reddish purple.

The upper magnesian limestone is like the lower in having a similar though somewhat finer texture, but its prevailing tint is grayish-white on fresh fracture and cream-white on the weathered surface. The peculiar markings characteristic of the lower limestone have not been found in the upper except that the mottling appears rather faintly in some grayish beds near the base.

Metamorphism of limestones.—Contact metamorphism has virtually the same effect on both limestone members, which are not, as a rule, so much coarsened by metamorphism as the less magnesian limestones of the higher formations. The metamorphic minerals characteristic of them are forsterite, diopside, minerals of the humite group, tremolite, phlogopite, spinel, and pale chlorites. These minerals are most common in the southeastern part of the quadrangle, especially in the contact zone of the porphyritic granite south of Thornton Creek, where the forsterite and chlorites form large crystals. Forsterite, which is the most abundant of these minerals, is not readily visible when fresh, being then almost colorless; when partly altered, however, as it usually is, to pale-yellowish serpentine, it is more conspicuous.

The formation of magnetite deposits in the limestone of the Hasmark formation at certain granite contacts, notably at Cable and Philipsburg, is a special phase of metamorphism. (See Pl. X.) Next to magnetite, olivine poor in iron is the most abundant mineral of these deposits, but it is relatively inconspicuous. Near Philipsburg humites and the rare magnesium-iron borate ludwigite are associated with the magnetite.

Metamorphism of shales.—The most general effect of slight metamorphism on the shales of the Hasmark formation is the development in the more aluminous layers of biotite, which produces a chocolate-brown color and, in the more calcareous layers, of diopside, which is pale green. The effect of more intense metamorphism is much the same as on the rocks of the Silver Hill formation. Cordierite hornstones occurring in Olson Gulch apparently represent the least calcareous phase of the shales of the Hasmark.

RED LION FORMATION.

Principal features.—The greater part of the Red Lion formation, named for the Red Lion mine, near which it is well exposed, consists of siliceous laminated limestone, a typical exposure of which is shown in Plate V. The basal part is chiefly calcareous shale. The thickness of the laminated limestone is about 250 feet; that of the underlying shaly beds is irregular and in most places less than 40 feet. The limestone, which forms prominent outcrops and is readily identified by its peculiar character, is a very useful horizon marker.

Petrographic details.—The basal member consists of coal-black shale with olive-green shale, thin lenticular beds of greenish-gray fine-grained indurated sandstone and flaggy limestone. The limestone is of sugary texture, generally of reddish-purple color, or mottled in purple and cream-white or pale green. It becomes covered with ocher on weathered surfaces and is more or less siliceous and magnesian, as if ferruginous. The character of the lower member as displayed in other parts of the quadrangle varies in detail, but in general its most conspicuous rocks are deep-red impure thin-bedded limestones. Near the base of the upper member the limestone is subordinate and forms isolated nodules or lenses in the siliceous material, which is deep reddish purple, the limestone being a lighter shade of the same hue. In the main body of the formation the limestone is dark or blue-gray, and predominates in volume over the siliceous material, which weathers yellowish, brownish, or reddish. The highest layers ascribed to the formation are of white limestone, with thin, rather widely spaced siliceous laminæ that weather yellow or orange.

The upper part of the Red Lion formation contains in places intraformational conglomerates consisting of small subangular pieces of limestone embedded in argillaceous material.

The effect of metamorphism on the laminated limestone is essentially the same as on the similar rocks of the upper part of the Silver Hill formation. In the vicinity of Twin Peaks the siliceous layers are altered to material rich in vesuvianite.

Contact metamorphism affects the basal beds as it affects the similar rocks in the Hasmark and Silver Hill formations. A mile north of Gold Coin, the basal beds have been converted at their contact with the granodiorite to coarse aggregates of garnet, epidote, pyroxene, amphibole, calcite, quartz, magnetite, and other minerals. Some of the reddish-brown garnet crystals are nearly 2 inches in diameter.

Fossils and correlation.—Fossils were collected from the upper part of the Red Lion formation by Kindle in 1907 and submitted to Secretary Walcott of the Smithsonian Institution for identification. In a lot from Rock Creek, in the western part of the Anaconda Range, he found *Billingsella coloradoensis* Shumard and Anomocare sp.; in a lot from the vicinity of Princeton he found the same forms, together with Cyrtolites sp. and Agraulos sp. All the specimens, according to Walcott, are of Upper Cambrian age and correspond to the fossils of the Yogo limestone but appear to be of a younger facies than those that have been found in the Yogo limestone farther east.

SILURIAN (?) SYSTEM.

MAYWOOD FORMATION.

Principal features.—The Maywood formation is named for Maywood Ridge, west of Princeton, on whose northeast face, 2 miles above the mouth of South Boulder Creek, the best exposure occurs. The formation, in most places, is poorly exposed, being less resistant to erosion than the Red Lion formation below or the Jefferson limestone above. It consists mainly of red to gray flaggy magnesian limestone and calcareous shale, and includes calcareous sandstone near the base.

Although the formation as a whole presents a marked lithologic contrast to the Red Lion and to the Jefferson its limits are not sharply defined. It is provisionally considered to embrace about 40 feet of limestone below the sandstone but similar to that in the main body of the formation. At the top the Maywood seems in most places to grade into the Jefferson limestone. The uncertainty regarding the limits of the Maywood formation, prevents an exact measure of its thickness, but it is about 200 or 300 feet thick.

The distribution of the formation is similar to that of the Cambrian series. The only continuously exposed section of the unaltered rocks, apart from that of Maywood Ridge, is on the East Fork of Rock Creek, in the southwest part of the quadrangle. Some of the best exposures of metamorphosed Maywood rocks are between Tower and Philipsburg and on the spur east of Cable.

Petrographic details.—The sandstone, which is the rock most frequently found in outcrops and float, is cream-white on fresh fracture but is stained yellow by limonite on weathered surfaces, which are rough and in places show cross-bedding.

The character of the shale and limestone, which grade into each other, is best exhibited in the fine exposure south of Boulder Creek. The main body of the formation is banded in various shades of gray, red, and yellow. The yellow hues are due to the weathering of shales and limestones that are gray to dull olive green on fresh fracture. Those of reddish hue are less discolored by weathering. Near Princeton, where there is no contact metamorphism, they are bright brick-red on fresh fracture, but where slightly metamorphosed they assume a more purplish hue. The weathered surfaces of the limestones are, as a rule, somewhat gritty owing to siliceous impurities and a magnesian character.

Strong metamorphism of the Maywood rocks, as of the Newland and Spokane formations, turns the red beds green by recombining the iron of oxides and carbonates into silicates and forms rocks that do not weather yellow. Metamorphism of the sandstone is exemplified on Silver Hill, where the calcareous cement is abundantly charged with minute needles of tremolite. The calcareous shales become altered to green hornstones characterized by diopside and other silicates of magnesia and lime. In the contact zone of the granodiorite at Cable some of the Maywood has been converted to distinctly crystalline rocks rich in scapolite. Some of the metamorphosed limestone east of Philipsburg contains about 25 per cent of forsterite or olivine.

Age.—As intimated in the account of the Cambrian series, the age of the Maywood is uncertain. No fossils have been found in it, and though it lies stratigraphically between the Jefferson limestone, which is of Devonian age, and the Red Lion formation, which is Upper Cambrian but does not represent the latest Cambrian time, its stratigraphic place does not show whether it is Cambrian, Ordovician, Silurian, or Devonian. Its tentative assignment to the Silurian was largely conjectural. Since this assignment was made, Dr. Edwin Kirk has pointed out a lithologic resemblance between the Maywood formation and some of the highest Cambrian strata in central Montana; he has, moreover, observed that it is, in one place at least, separated from the Jefferson by a conglomerate, which virtually excludes the possibility of its being Devonian.

DEVONIAN SYSTEM.

The only formation of known Devonian age in the Philipsburg quadrangle is the Jefferson limestone. This is immediately overlain by the Madison limestone, of Carboniferous (Mississippian) age, without the intervention of the Threeforks formation, which represents the Upper Devonian farther east.

JEFFERSON LIMESTONE.

Principal features.—The base of the Jefferson limestone is most clearly defined in the Philipsburg quadrangle near the northeast base of Maywood Ridge, 2 miles from the mouth of South Boulder Creek, where it is marked by a conglomerate. The conglomerate is here about 15 or 20 feet thick, but it is of slight lateral extent and has not been observed elsewhere. It is overlain by a few score feet of flaggy dark-gray impure limestone, above which lies the great body of thick-bedded, white, grayish, and black magnesian limestone that constitutes the bulk of the formation. The thickness of the Jefferson in this quadrangle is about 1,000 feet.

The Jefferson limestone is comparatively resistant and extensively exposed. The exposures near Princeton are among the best. It forms the hill northeast of Philipsburg and is the principal country rock of the Hope mine. Good exposures occur in the hills between Georgetown and the Gold Coin mine, in the canyon of Flint Creek west of Silver Hill, on the East Fork of Rock Creek, and along Foster Creek.

Petrographic details.—The rock most common in the Jefferson of the Philipsburg quadrangle is a white or cream-colored, rather fine-grained, thick-bedded limestone, which forms large rounded outcrops. Many beds are blue-gray, and some, exposed just north of the Maywood ranch on Boulder Creek, are of an almost sooty blackness. Alternation of light and dark layers is well illustrated in Plate VIII. The range of tint from white through blue-gray to black is characteristic of the strata where they have undergone more or less metamorphism. At the few localities, most of them in the northern part of the quadrangle, where they have wholly escaped such alteration, the limestones, whether light or dark, have a brownish hue. The opacity of the limestone and its weathered surfaces show that it is magnesian, like that of the Hasmark formation. Irregular nodules of chert occur in the Jefferson but are not abundant.

Strong metamorphism accentuates the crystallinity of the limestone, and produces metamorphic silicates, the most common of which is tremolite. Less common and conspicuous are diopside, phlogopite, forsterite, and humite.

Fossils and correlation.—The Jefferson limestone is not conspicuously fossiliferous, yet many species have been collected from it in the Philipsburg quadrangle by E. M. Kindle, who supplies the following statement:

> The faunal, stratigraphic, and lithologic evidence agrees in indicating that the magnesian limestone which occurs below the Carboniferous in the Philipsburg quadrangle should be correlated with the Jefferson limestone. Its distinctive physical characters and stratigraphic relations enabled geologists to identify the dark saccharoidal magnesian limestone over a considerable area in Montana with that at Threeforks, the type locality of the Jefferson, before its fauna was sufficiently well known to determine with certainty its age. This limestone in the Philipsburg quadrangle has furnished a sufficient fauna, however, to establish with certainty the Devonian age of the formation.
>
> The following list includes all of the species which have been determined from this formation in the Philipsburg quadrangle. They have been obtained from two localities, one of which is 2½ miles northwest of Princeton, Mont., and the other is on the east fork of Rock Creek, 20 miles south of Princeton.

Favosites cf. limitaris.
Productella cf. subaculeata.
Schuchertella chemungensis var. arctostriata.
Stropheodonta cf. macrostriata.
Hypothyris globularis.
Atrypa missouriensis.
Atrypa reticularis.
Athyris parvula.
Athyris montanensis.
Spirifer occidentalis.
Spirifer engelmanni.
Spirifer argentarius.
Spirifer utahensis.
Loxonema approximatum?
Straparollus sp.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

MADISON LIMESTONE.

General character.—Although mapped as a unit, the Madison limestone of the Philipsburg quadrangle might be divided like that in other parts of Montana into two or three members. The lower part consists mainly of dark flaggy limestone, with which a little black shale is interbedded. Above the flaggy strata lie thicker beds, also dark for the most part, which contain abundant chert. (See Pl. VI.) The upper part consists of still more massive limestone, mostly white to pale gray, and also cherty. The middle part of the formation is less distinct from the upper than from the lower part. The thicker, upper strata of the Madison generally form bold outcrops; the lower, flaggy strata are less resistant to erosion and generally ill-exposed.

Distribution.—The areas occupied by the Madison limestone in this quadrangle are grouped in two or three zones. The most westerly extends from Flint to a point about 5 miles south of Philipsburg. It affords readily accessible exposures, a nearly complete cross section of the formation being visible just west of Stewart Lake. The dark cherty beds in the lower middle part of the formation are especially well exposed at this locality, where the photograph reproduced in Plate V was taken. A second zone extends through the middle of the quadrangle nearly from its northern to its southern boundary, and some of the best exposures of the formation may be seen near Princeton, in the northern part of this zone, and on the East Fork of Rock Creek, in the southern part. From the middle part of the zone a strip occupied mainly by the Madison limestone extends southeastward, but in this tract the formation is so much faulted and metamorphosed that its exposures are not very useful for stratigraphic study.

Almost the entire section is exposed north of Stewart Gulch, and the cliff shown in Plate VI gives one of the best sections of the lower middle part. The best exposures in the quadrangle perhaps occur south and southwest of Georgetown Lake, particularly along the East Fork of Rock Creek, where the only good section of the flaggy basal beds is found.

Thickness.—In the Rock Creek section, 280 feet of the lower, flaggy limestone is exposed, and a little is concealed, so that the total thickness of this member is here probably about 300 feet. The thickness of the overlying beds in the same vicinity is about 1,000 feet. Rough measurements near Princeton and Philipsburg give 1,200 to 1,500 feet as the total thickness.

At one place between Foster and Warm Spring creeks the total thickness is less than 800 feet. The diminution does not appear to be due to faulting but rather to nondeposition or to erosion before the deposition of the Quadrant formation.

Petrographic details.—The shale that occurs near the base of the formation is dull black and fairly hard and breaks into small rectangular fragments. It is highly calcareous and grades into fine-grained flaggy limestone which occurs in beds ranging in thickness from an inch to a foot and makes up most of the lower part of the Madison. This rock is dark blue-gray to nearly black on fresh fracture, but its weathered surfaces are a characteristic much lighter blue-gray, passing to drab or dove color. The limestone between the flaggy basal beds and the massive upper beds is similar to the flaggy limestone in color and texture.

Thin beds of white limestone, which do not occur in the lowermost part of this formation, appear below the middle, become increasingly abundant upward, and predominate in the upper half. The chert in the upper part of the Madison forms larger and less regularly distributed masses than that in the dark beds below. The thick-bedded white and light-gray limestones of the upper part of the Madison resemble those of the Jefferson in general views but show distinct differences when closely examined. Chert is far more abundant in the Madison than in the Jefferson. The Madison limestone, moreover, is not magnesian like the Jefferson, and is consequently smoother on weathered surfaces and more translucent in thin fragments. Fossils, again, are far more abundant and conspicuous in the Madison limestone than in the Jefferson.

Chert.—The chert, as shown by the microscope, consists chiefly of quartz but contains more or less calcium carbonate. Its texture is in general fine but not uniform. No organic remains have been observed in the chert. It does not follow from this fact, however, that organic agencies have had no part in the formation of this material, but an origin at least partly secondary is suggested by the special abundance of the chert along the great overthrust that passes near Philipsburg. East of the point where the fault crosses the canyon of Flint Creek there is a great mass of dark chert, nearly 100 feet thick, which apparently belongs to the Madison. The Newland formation, which is thrust over the Madison, also is silicified and cherty at this place. Local silicification of both these calcareous formations may have been effected by solutions rising through fault fissures.

Effect of contact metamorphism.—The limestones of the Madison are more readily recrystallized by metamorphism than the older magnesian limestones, and the purer beds in its upper part are in places changed to coarsely crystalline marble. The mineral most commonly produced in the Madison limestone by contact metamorphism is tremolite, which is more abundant in this formation than in magnesian limestones below. Diopside is locally developed but never conspicuous. Scapolite occurs in the slightly altered basal flaggy limestones, where it forms sharply developed dull-black eight-sided prisms.

Small black orthoclase crystals occur similarly at two localities, one on the east slope of the knob 7,694 feet high, west-northwest of the summit of Silver Hill, the other about 1½ miles northwest of bench mark 5605, on Warm Spring Creek.

Fossils and correlation.—G. H. Girty refers the numerous fossils collected from the Madison limestone in the Philipsburg quadrangle to the same widely distributed lower Mississippian fauna by which this formation is characterized through such a large area in the west. A composite list of the fossil forms identified by him in this quadrangle follows:

Syringopora surcularia.
Syringopora sp.
Aulopora geometrica.
Menophyllum ulrichanum.
Amplexus sp.
Echinocrinus sp.
Fenestella, 2 sp.
Schuchertella inflata.
Rhipidomella pulchella.
Rhipidomella michelini?
Chonetes illinoisensis.
Productus lævicosta.
Camarotœchia metallica.
Spirifer centronatus.
Composita immatura.
Composita sp.
Eumetria marcyi.

The lithologic character of the rocks supports the paleontologic evidence.

PENNSYLVANIAN SERIES.

QUADRANT FORMATION.

General character.—The Quadrant formation as developed in the Philipsburg quadrangle comprises two members that present strong lithologic contrast. The lower member consists chiefly of red magnesian limestone and shale. These rocks are soft and are exposed at but few places. The upper member, mainly quartzitic, comprises three strata, the lowest consisting of light-colored pure thick-bedded quartzite, the middle of calcareous shale and impure cherty limestone, the uppermost of somewhat impure quartzite and quartzitic sandstone. In the vicinity of the East Fork of Rock Creek the upper quartzite stratum is not identifiable, and the calcareous beds usually overlain by it are apparently thicker than in most places. The quartzite strata crop out boldly; the calcareous beds between them are rarely well exposed. The rocks of the lower member are highly susceptible to metamorphism, which ultimately changes the prevailing hue from red to green.

Distribution.—The Quadrant formation is found in the same general zones as the Madison. Its most extensive exposures lie northeast of Boulder Creek, where the nearly vertical beds of quartzite form bold parallel reefs striking for miles across ridges and ravines. The lower, red beds in this vicinity are as a rule concealed, but their position is indicated in places by float. Good exposures of the lower member and of the calcareous beds between the quartzites, strongly metamorphosed, are found southeast of Goat Mountain. Other extensive areas occur farther south, on both sides of Foster Creek, where the rocks are strongly metamorphosed and still farther south, near Warm Spring Creek, where they are not greatly altered. The best exposures of the unaltered lower beds are those on the west slope of the hill 7,780 feet high near the East Fork of Rock Creek.

Near Philipsburg the quartzite of the Quadrant is one of the most conspicuous terranes. It forms Red Hill north of the town, the knob west of the high school, sometimes called "Flagstaff Hill," and a similar knob 3 miles farther south. The red beds of the lower member are concealed at most places near Philipsburg but are partly exposed north of Stewart Gulch.

Thickness.—The greatest observed thickness of the lower member of the Quadrant is on the East Fork of Rock Creek, where there is about 500 feet of the shaly beds. The thickness of the beds north of Philipsburg is roughly estimated at 200 to 300 feet. West of Foster Creek, where the upper part of the Madison limestone is also of less than normal thickness, the apparent thickness of the lower member of the Quadrant is less than 100 feet.

The best measure for the upper member was obtained on Flagstaff Hill, where its thickness is 430 feet. On Rock Creek the single massive stratum of quartzite is about 350 feet thick and the overlying calcareous beds assigned to the Quadrant formation are nearly 200 feet thick. The total thickness of the formation at this locality thus exceeds 1,000 feet.

Petrographic details.—The most characteristic rock seen in the float of the lower member of the Quadrant is a deep brick-red to maroon shale with round or oval pale-green spots which would suggest at first glance that the rock had been spattered with paint. These spots are cross sections of nodules not greatly different from their matrix except in color. In places the nodules weather out as spheroids or irregular lumps. Much of the shale contains calcium carbonate, which is no more abundant in the nodules than in their matrix.

The other characteristic rock of the lower member of the Quadrant, into which the red shale grades, is flaggy impure magnesian limestone, ranging in color from dull red to white.

Where the red shale that is poor in carbonates is slightly metamorphosed it is darker and more purplish than the unaltered rock, and its characteristic spots are less distinct. The microscope shows green biotite as the only mineral developed in appreciable amount by the metamorphism. Stronger metamorphism would presumably produce cordieritic rocks like those produced from the similar beds in the Spokane formation. Some chocolate-brown biotitic hornstones derived from the red shales were observed.

The more limy beds alter to greenish banded fine-grained compact rocks, composed chiefly of diopside, quartz, and amphibole, with more or less feldspar, epidote, and titanite.

The quartzite forming the lowermost part of the upper member of the Quadrant formation is pure and thick bedded, and resembles the Flathead quartzite, though more rusty on weathered outcrops. On fresh fractures it is nearly white. The upper quartzite does not differ conspicuously from the lower where both form weathered reefs, but as it is less pure than the lower and somewhat calcareous near the top its weathered surfaces are rougher and more porous and it becomes more deeply impregnated with limonite. Where it is fresh it is commonly grayish.

Except in the northeastern part of the quadrangle, where they are indurated by strong metamorphism, the soft beds between the quartzites are nowhere continuously exposed. The most characteristic rock seen in this locality is a mixture of mottled gray and white chert with limestone. A little black rusty shale occurs at the top, and a conspicuous white bed of calcareous sandstone lies near the middle. The best exposure of the unaltered rock north of Douglas Creek—an incomplete one—is of very cherty gray limestone. The part of the Rock Creek section in the Anaconda Range which is ascribed to this division of the Quadrant formation comprises rocks like those described and also some gray and white magnesian limestone like that of the Jefferson limestone. The small outcrops near Philipsburg show a yellow, iron-stained cherty rock, interstratified with beds of phosphate rock, the purest of which is dull black on fresh fracture, with a gray "bloom" on the weathered surface, and has an oolitic texture.

Fossils and correlation.—Fossils have been collected from the lower member of the Quadrant formation at two localities in the Philipsburg quadrangle.

Two miles south of Georgetown Lake the red shales below the quartzite have yielded the following forms, identified by G. H. Girty:

Echinocrinus sp.
Fenestella sp.
Rhombopora sp.
Derbya crassa.
Productus cora.
Spirifer rockymontanus.
Schizostoma catilloides.

Mr. Girty says that this fauna is of Pennsylvanian age.

Fossils have also been found in the calcareous beds between the quartzites on Flagstaff Hill at Philipsburg. A collection made at this place by Mr. J. T. Pardee is identified by Mr. Girty as follows. The specimens occur as molds.

Cyathophyllum ? sp.
Camarotœchia (or Rhynchopora) sp., resembling C. sappho.
Camarotœchia (or Rhynchopora) sp., resembling C. congregata.
Myalina sp.
Aviculipecten sp.

Mr. Girty says:

> These fossils must be Pennsylvanian or Permian. The presence of phosphate strata at this horizon suggests the Permian (?) phosphate beds of southeastern Idaho (Phosphoria formation), but the fauna is different. Mr. Gale's suggested correlation of the red lower member of the Quadrant with the Morgan formation of northeastern Utah as given below, is rather confirmed by the paleontologic evidence than otherwise.

The kinds of rock are the same in the Philipsburg section as in the typical Quadrant of the Threeforks and Yellowstone National Park region, although the sharp division into a quartzite and a shaly member does not there seem possible. The assignment of a Carboniferous and probably Pennsylvanian age to the upper quartzitic stratum is based on lithologic rather than on paleontologic grounds, for no fossils have been found in it. The upper quartzite was included in the formation primarily because of its resemblance to the lower. Support is lent to this part of the correlation, however, by the opinion of Hoyt S. Gale, who in 1910 examined a section near Melrose, Mont., that is essentially similar to that of the Philipsburg quadrangle. Mr. Gale considers the lower and purer quartzite equivalent to the Weber quartzite of Utah, and the higher beds here included in the Quadrant as equivalent to the Park City formation of Utah. One reason for this correlation is lithologic resemblance, but a stronger one is the occurrence of a phosphate bed in the Melrose section corresponding to one in the Utah and southern Idaho sections. This phosphate lies between the two quartzitic strata and has been found at this horizon on Flagstaff Hill since the geologic survey of the quadrangle was made. The lower shaly member may have its equivalent in the Morgan formation of Utah or in similar rocks found locally in the base of the Weber quartzite.

JURASSIC SYSTEM.

ELLIS FORMATION.

Principal features and relations.—Triassic rocks are apparently absent from the Philipsburg quadrangle, as they are from a great part of Montana. The Quadrant is here overlain directly by the Ellis formation, which consists of about 400 feet of rusty-weathering shale, sandstone, conglomerate, and limestone and contains marine Jurassic fossils. The lower limit of this formation as mapped is very definite in most places, being at the contact of a soft shale with the hard upper quartzite stratum of the Quadrant. Near the East Fork of Rock Creek, however, the base of the Ellis as mapped is not marked by any such abrupt lithologic change, for, as already stated, the highest beds in this locality that are ascribed to the Carboniferous are shales and limestones. The rocks here mapped as Jurassic consist in the main of rusty-weathering shale and sandstone, such as predominate in the Ellis formation where it is well exposed, but also include some limestone, resembling the Jefferson limestone, which may belong to a fault block of some formation older than the Ellis. Unfortunately no fossils were found that could supplement the rather unsatisfactory lithologic evidence upon which the mapping of this area is based.

Although no angular unconformity between the Ellis and Quadrant formations has been observed in the Philipsburg quadrangle, the times at which the two formations were deposited were evidently separated by an erosion interval. This interval is indicated not only by the absence of Triassic rocks but by the presence in the Ellis formation of chert and quartzite pebbles derived from Carboniferous and older strata. The erosion indicated by these pebbles may have effected the removal of the upper quartzite of the Quadrant at the Rock Creek locality.

Distribution.—The distribution of the Ellis formation is similar to that of the Quadrant, but the Ellis is far the more poorly exposed, because of the weakness of its rocks; its position, indeed, is usually marked by a depression between the outcrops of the quartzite of the Quadrant and the hard basal sandstone of the Kootenai formation. The most complete cross section of the Ellis formation where its limits are well defined and its rocks unaltered is displayed on the north side of Gird Creek 1½ miles west of Mount Princeton. The exposures near Philipsburg are fragmentary. The basin of Rock Creek in the Anaconda Range contains but one good exposure, which is at the locality already mentioned, north of the quartzite crag 7,780 feet high. Fairly extensive outcrops are found on the hill south of Browns on Warm Spring Creek, and metamorphosed rocks of the Ellis formation are exposed in the zone of outcrop that extends northward from the head of Olson Gulch to the vicinity of Racetrack Peak.

Lithology.—The lithologic character of the Ellis formation is illustrated by the following section:

Section on Gird Creek, 1½ miles northwest of Mount Princeton.

	Feet.
Kootenai formation (lower part):	
Shales, reddish and greenish.	
Sandstone, pebbly; deep red above, mottled in purple and drab at base. Pebbles are of quartzite, are well rounded, and not generally more than 2 or 3 inches in diameter	10
Ellis formation:	
Shale, calcareous, olive-green, locally containing nodules of limestone 1 inch or less in diameter, with a little flaggy sandstone; all stained with yellow ocher on weathered surface	150
Sandstone, flaggy, weathering yellowish, with some shale	60
Sandstone, forming prominent ledge, rusty, more or less calcareous, partly cross-bedded, partly flaggy, partly pebbly, with well-rounded pebbles, mostly of dark chert	20
Sandstone, flaggy, with some shale; weathers rusty red and yellow; fossiliferous	100
Limestone, impure; gray on fresh fracture, brown on weathered surface	10
Shale, calcareous, fine grained, homogeneous; black on fresh fracture, buff on weathered surface; fossiliferous	90
Thickness of Ellis formation	430
Quadrant formation (upper part):	
Quartzite, massive, forming bold reef.	

The most obvious general characteristic of these rocks is a tendency to weather in buff or yellow hues. The shale at the base is rarely seen without an ocherous stain due to weathering, but the unweathered basal shale lying on the dump of a shaft at the Gird Creek locality is dull coal-black. The color of the other rocks ranges from pale olive-green to dark gray. The limestone nodules that occur in much of the shale are rather irregularly distributed. The cross-bedded structure near some of the sandstone is made more conspicuous by weathering.

The pebbly bed has not been recognized in the quadrangle except about Mount Princeton and south of Warm Spring Creek. Near Warm Spring Creek and near Drummond, north of the quadrangle, it is more definitely a conglomerate than it is on Gird Creek. Its pebbles are in part quartzitic, but predominance of chert pebbles is its most distinctive feature.

Contact metamorphism has the same effect on the typical Ellis rocks as on the Newland rocks (see p. 4), which they somewhat resemble. The metamorphosed Ellis consists of compact green, white, and chocolate-brown hornstones, of which quartz, feldspar, diopside, and biotite are the commonest minerals. The ordinary type about Princeton is a biotitic hornstone, chocolate-brown on fresh fracture and drab on the weathered surface, with calcareous nodules in which relatively large grains of epidote and hornblende are generally conspicuous.

Fossils.—Stanton has collected characteristic Ellis fossils from the formation on Gird Creek and on the Ovando road about 6 miles east of Drummond. Those collected on Gird Creek lie 50 to 100 feet above the Quadrant formation, and, according to T. W. Stanton, comprise the following forms:

Ostrea strigulecula White.
Camptonectes pertenuistriatus Hall and Whitfield.
Eumicrotis curta Hall.
Trigonia sp.
Pleuromya subcompressa Meek.

In the section east of Drummond calcareous beds 200 to 250 feet above the Quadrant have yielded:

Rhynchonella gnathophora Meek.
Ostrea sp.
Camptonectes bellistriatus Meek.
Lima? sp.
Cucullæa haguei Meek.
Tancredia? sp.
Pleuromya subcompressa.

A conglomerate near the top of the Ellis section here contains *Rhynchonella gnathophora* Meek, Ostrea sp., and Gervillia sp.

CRETACEOUS SYSTEM.

The Lower and Upper Cretaceous are both represented in the Philipsburg quadrangle by the Kootenai and Colorado formations, respectively, and perhaps by some later beds of Montana age. Although the strata appear to be structurally conformable, the Dakota sandstone, which naturally should intervene between the Kootenai and Colorado, is apparently lacking, as in other known Montana sections.

LOWER CRETACEOUS SERIES.

KOOTENAI FORMATION.

General character and thickness.—The Kootenai formation as developed in the northeast quarter of the quadrangle has a total thickness of about 1,500 feet. It consists in greatest part of red and green sandstone and shale, with some limestone and dark calcareous shale, the general sequence being as follows: The base consists of tough red and green pebbly sandstone or sandy conglomerate, rarely more than 20 feet thick, which as a rule crops out rather prominently. This is succeeded above by softer red and green shaly rocks, and these again in places by a peculiar fine-grained buff-weathering limestone, which forms one or two beds that lie about 200 feet from the base of the formation and are 100 to 500 feet in total thickness. Above this limestone lies the main mass of red and green shale, with which a few thin and inconspicuous beds of limestone are intercalated. The main body of the colored rocks is succeeded by gray limestone, containing abundant remains of fresh-water snails or gastropods, which almost invariably forms prominent outcrops. The thickness of this limestone with that of some interbedded shale amounts in the Philipsburg quadrangle to less than 50 feet. The gastropod limestone furnished nearly all the fossils that have been found in the formation. Above these beds a little red shale is usually found and also some olive-green to nearly black calcareous shale and sandstone.

Distribution.—The largest areas occupied by the Kootenai formation are in the northeastern part of the quadrangle and the best exposures of the formation as a whole are about Mount Princeton. Metamorphism due to post-Colorado intrusion becomes apparent in the Kootenai rocks not far south of Mount Princeton and is very marked about Racetrack Peak and farther south, along the ridge between Foster and Warm Spring creeks. In the area near Browns the basal pebbly sandstone is prominent and forms the crest of the hill northeast of the "silica quarry." The hill south of Browns affords good exposures, particularly of the lower buff-weathering limestone.

Lithologic details.—The conglomerate of the Ellis formation and the pebbly bed of the Kootenai formation, though close together, may be distinguished by their lithologic differences. The characteristic features of the conglomerate of the Ellis are the abundant black chert pebbles and the highly calcareous cement. The pebbles of the Kootenai, on the contrary, are chiefly of light-colored quartzite, and the cementing sandstone substance contains little calcite. The average size of the pebbles in the Kootenai is larger than in the Ellis. The pebbles of the conglomerate of the Kootenai near Warm Spring Creek have a maximum diameter of about 6 inches. Most of the pebbles of this stratum are well washed, of oval form, and firmly embedded in their matrix of hard, somewhat quartzitic sandstone, which is red or green where fresh and rusty dark brown on weathered surfaces.

The sandstone and shale that form the greatest part of the Kootenai somewhat resemble those of the Spokane formation but are less vividly colored and less indurated. A highly characteristic feature of the colored shales is a coarse mottling in red and green. The mud cracks and ripple marks that are so common in the Algonkian red rocks have not been observed in the Kootenai, but some beds of this formation have a "mud-breccia" structure similar to that shown in Plate XII, which indicates a terrestrial origin. Calcareous gray nodules of roundish form and about an inch in maximum diameter occur in the shales of the Kootenai as well as in the Ellis.

The lower limestone bed as exposed near Gird Creek is fairly pure and not magnesian. On the weathered surface it is buff; on fresh fracture it is delicate grayish drab. The main part is extremely fine grained and homogeneous, but it is shot through with little twiglike bodies of crystalline calcite about 1 millimeter in diameter. They suggest organic growths but have not been identified as fossils.

The gastropod limestone is strikingly different from the lower limestone, and somewhat resembles the dark beds of the Madison limestone. On fresh fracture it is rather dark gray, on weathered surfaces pale bluish gray. The pieces of fresh-water snail shells with which it is crowded are especially conspicuous on the weathered surface and characterize the rock so strongly that it can instantly be recognized.

The calcareous shale interbedded with the gastropod limestone and overlying it is partly of a more or less sandy olive-green ocherous-weathering type. The uppermost beds mapped as Kootenai on the east slope of Mount Princeton are shale, gray to nearly black on fresh fracture, but weathering to a blue-gray or brownish color. This shale is more or less calcareous, especially in its lower part.

Under the influence of igneous metamorphism the sandstones alter, like those of the Spokane formation, to quartz-mica schists of green or gray color. The shales alter in places to green phyllitic schists, some of which are knotted with andalusite. The red rocks commonly alter to dense chocolate-brown or nearly black, finely dappled cordieritic hornstones similar to those derived from the Spokane. The mottled appearance presented by some unaltered beds persists in beds that have undergone fairly strong metamorphism. The calcareous nodules become more radically altered than their matrix, and develop recognizable crystals of epidote, hornblende, garnet, and other minerals. The gastropod limestones are so pure that strong metamorphism may have no other effect than to recrystallize them and partly obliterate fossils whose presence is indicated only by ill-defined white spots. Impure limestones and calcareous shales have been changed on the ridge east of Twin Peaks to rocks rich in garnet, vesuvianite, and wollastonite. The mineral last named forms a felt of minute snow-white laths, mingled with red garnet and greenish-brown vesuvianite in larger grains.

Fossils and correlation.—The following discussion is contributed by T. W. Stanton:

> These nonmarine beds, occupying in the Philipsburg quadrangle the interval between the marine Jurassic and the marine Upper Cretaceous, have been referred to the Kootenai formation chiefly because of their stratigraphic position and lithologic character, for in its type area, a short distance north of the international boundary, the coal-bearing Kootenai formation, having a thickness of several thousand feet, occupies the same stratigraphic place and includes rocks of the same lithologic character. It has there yielded a considerable flora.
>
> The formation has been identified in the Great Falls and Lewistown coal fields by its stratigraphic position, lithology, and fossil flora. In those two areas Messrs. Fisher and Calvert have recognized the Morrison formation beneath the Kootenai, from which it does not differ greatly in lithologic character. It also is nonmarine and has a wide distribution farther south, in Wyoming, Colorado, and adjoining States.
>
> On Yellowstone River between Yellowstone National Park and Livingston, according to unpublished work of Calvert, the Kootenai is recognized on lithologic and stratigraphic grounds and includes the rocks which in the Yellowstone National Park folio are mapped as Dakota. A characteristic feature of the formation in Yellowstone Park is a "gastropod" limestone which is like those in the Kootenai of the Philipsburg quadrangle and contains some fossils of the same species. The Kootenai flora has not been found in Yellowstone Park nor in the Philipsburg region.
>
> The invertebrates collected from one of the lower limestones near Drummond north of the Philipsburg quadrangle are poorly preserved smooth gastropods, possibly belonging to Goniobasis, although more than one genus may be represented. The upper "gastropod" limestones of the district and the overlying shale have yielded two or more undescribed species of Unio, one related to *U. douglassi* Stanton, and the gastropods *Goniobasis (?) increbescens* Stanton and Viviparus (?) sp. These forms occur also in the so-called Dakota of Yellowstone Park, now believed to be Kootenai.
>
> The rocks in the Philipsburg quadrangle referred to the Kootenai formation may possibly include the equivalent of the Morrison formation, and their upper limit also is somewhat uncertain, but there is now no ground for dividing them into two or more formations.

UPPER CRETACEOUS SERIES.

COLORADO FORMATION.

Principal features.—The rocks mapped as Colorado in the Philipsburg quadrangle comprise about 500 feet of black shale, overlain by strata consisting chiefly of gray sandstone, which at some places in the quadrangle have a thickness of more than 1,000 feet. There is no angular unconformity between the shaly and sandy members, the one grading abruptly into the other. Some very thin seams of coal have been prospected in the upper part of the shale near Drummond, but no coal has been found in the formation in the Philipsburg quadrangle.

Occurrence.—The only considerable areas of the Colorado are in the northeast part of the Philipsburg quadrangle, although there is a very small area south of the quarries on Warm Spring Creek. The best exposure of the unaltered shale is on the northeast side of Mount Princeton, where the thickness was measured, and the best exposures of the upper sandy beds are north of Gold Creek. The shale, changed by metamorphism to an andalusite schist, forms a cliff 1¼ miles north of Rose Mountain.

The lower member, though forming few prominent outcrops, gives rise to characteristic smoothly rounded slopes, usually without much vegetation. The sandstones are moderately resistant, and the lowest bed of sandstone commonly forms a hogback.

Lithology.—The lower member of the Colorado formation is a remarkably homogeneous fine-grained clay shale, blue-black on fresh fracture, and slightly bleached on the weathered surface. It is extremely fissile and disintegrates to paper-thin flakes.

The upper member of the formation contains relatively thin beds of shale which is more or less sandy. Most of this shale is dark blue-gray to olive-green, but a little of it is mottled in red and green.

The commonest and best-exposed rocks of the upper member are sandstones, commonly flaggy, dark gray on fresh fracture, and dull olive-drab to brown on weathered surfaces. The grains are imperfectly rounded and comprise much feldspar and chert. The cement is somewhat calcareous. Certain beds are pebbly, and one bed near the top of the section in the Gold Creek area contains small pebbles of black shale. Gray limestone occurs in the upper part of the formation north of the quadrangle, but none was noted within that area.

Contact metamorphism alters the black shale of the lower member to an andalusite schist. Strong metamorphism of the sandstone in the upper part has not been observed. An intrusive sill in the Gold Creek area has indurated some of the sandstone and has changed a shale to a tough brown hornstone.

Fossils and correlations.—Mr. Stanton, who examined the Cretaceous rocks near Drummond and Mount Princeton and collected fossils from them, makes the following remarks on the correlation of the rocks here described as Colorado:

> The body of black shale that overlies the Kootenai in the Philipsburg and Drummond areas is lithologically like the Colorado shale and has the same stratigraphic position. We found no fossils in it, so that its assignment to the Colorado group must be based only on lithologic character and stratigraphic relations.
>
> In the sandstones above the principal mass of black shale we obtained two small lots of fossils, which are doubtfully referred to Mactra and Callista. They are considerably distorted and otherwise not well preserved, so that I am unable to make positive generic determinations, but I believe them to be marine forms, probably belonging to the fauna of the Colorado group. The thin beds of coal that occur near this horizon, above one of which we found a few Unios, may also belong to the Colorado group, though of course the evidence affords insufficient ground for a positive opinion.
>
> In still higher beds near Drummond we found no fossils except a few plants which, according to Mr. Knowlton, are not sufficient to determine the geologic horizon.

Mr. Knowlton reports as follows on two small lots of fossil plants:

> No. 1300. One and a half miles southeast of Drummond, Mont.
>
> There are three plants in this little collection: A Marchantia, which is probably new; a conifer, which is probably a Glyptostrobus; and a fern that is pretty close to if not identical with *Aspidium oerstedi* Heer. The Aspidium is from Patoot, which is Senonian (Fox Hills). I can not place this material definitively but should be inclined to regard it as possibly Upper Cretaceous.
>
> No. 1303. Top of Mount Princeton, Mont.
>
> A single narrow leaf without nervation except midrib. No age determination possible.

In 1910 Mr. Pardee collected more satisfactory fossils from a limestone outcrop in Coberly Gulch 10 miles north of the quadrangle. The exact horizon is not known, but the limestone bed is underlain by about 400 feet of rocks resembling those characteristic of the upper member of the Colorado and is almost immediately overlain by a dioritic sill which may be the same that occurs in Gold Creek basin.

The list of forms identified by Mr. Stanton and his comment on them follows:

> No. 6552. Specimen No. 10–P, 4. NE. ¼ NW. ¼ sec. 34 and SW. ¼ sec. 27, T. 10 N., R. 12 W., Granite County, Mont.
>
> Modiola sp.
> Cyrena securis White.
> Corbula sp.
> Glauconia coalvillensis Meek.
> Admetopsis subfusiformis Meek.
>
> The horizon is in the Colorado group. The same association of forms occurs in the Oyster Ridge sandstone member of the Frontier formation in western Wyoming.

The lithologic and paleontologic evidence correlate the black shale and about 400 feet of the overlying beds with the Colorado beyond reasonable doubt. It is nevertheless possible that post-Colorado (Montana) beds occur in the syncline cut by Gold Creek. The pebbly sandstone that lies several hundred feet above the main intrusive sill may indicate an erosional unconformity at the base of a formation later than Colorado, but this is only a possibility, and would not justify the mapping of a distinct formation.

TERTIARY SYSTEM.

GENERAL RELATIONS OF SEDIMENTARY AND VOLCANIC ROCKS.

Only a single formation, designated "earlier gravels," is shown on the map as sedimentary and of undoubted Tertiary age. The earlier gravels are interbedded with and overlain by breccia, tuff, and ash, which may be regarded as sedimentary with respect to their mode of deposition but which, because of their volcanic origin and the intimate association of part of them with lava, are described with the igneous rocks. Both earlier gravels and volcanic rocks are overlain by terrace gravels, which are probably Tertiary in part but which are in part Quaternary and are described in another place. The general sequence of all these deposits, so far as it is known, is indicated in the columnar sections.

The gravels and associated volcanic rocks occur chiefly in the valleys. They lie with strong unconformity on the Cretaceous and older strata, and in places on the intrusive rocks, by which they are nowhere metamorphosed. The post-Cretaceous age of even the oldest deposits, which are in part the earlier gravels, is therefore certain. The age of these gravels is narrowed down to Tertiary by the strong unconformity with which they are overlain by deposits that are known to be Quaternary, but they probably comprise deposits that differ considerably in age. This probability is strongly suggested by relations observed near Anaconda, a little east of the quadrangle, where conglomerates containing many volcanic pebbles interbedded with sandstone, tuff, and shale, are overlain by a thick deposit of andesitic tuff, and all these, unconformably, by conglomerate that contains but few volcanic pebbles. Both the upper and lower conglomerates of this locality are probably represented in the earlier gravels of the quadrangle, which are distinguished as a whole from the later gravels by being more or less indurated and tilted and much eroded. It is thought probable that the deposits occurring near Rock Creek in the northwestern part of the quadrangle are chiefly coeval with the oldest gravels at Anaconda and those in the southeastern part of the quadrangle near Warm Spring Creek and Grassy Mountain with those that overlie the tuff.

EARLIER GRAVELS.

Valley of Rock Creek.—Along Rock Creek are remnants of a gravel deposit that once deeply filled an old stream channel. The surface of these remnants is in large part flat but probably not in any part the original surface of aggradation; in places it truncates the bedding of the deposit. (See Pl. VII.) It is partly covered with later gravel, not shown on the map. On the slopes of the ravines that cross the gravel area old landslides, recognized by their hummocky surface and undrained hollows, are common.

Remarkably fine exposures of these gravels may be seen on cliffs that rise steeply from Rock Creek a short distance north of the mouth of Sluice Gulch and at places west of the quadrangle. The photograph reproduced in Plate VII shows the considerable degree of induration, the thick, somewhat irregular bedding, the unconformable contact with the Newland formation on a surface that evidently once formed the sloping side of an old channel, the perceptible tilting, and the planation at the top. A characteristic feature more strikingly displayed a little east of this exposure is the erosion into spires, or "hoodoos," capped by concretions or fragments of concretionary layers.

The pebbles of this conglomerate are as a rule well rounded and the largest are about a foot in diameter. Nearly all are of whitish or dull-red quartzitic sandstone; a few are of fine-grained porphyry and of scoriaceous lava. The matrix consists chiefly of coarse quartz sand mixed with a whitish dust, apparently volcanic ash. Interbedded with and overlying the conglomerate, and mapped with it, are some dark-red and white, rather fine grained flaggy beds, essentially tuffaceous, and probably andesitic. The cattle have made "licks" in banks of the shaly red rocks. At the base of these, near the Elkhorn ranch, which is on Rock Creek just west of the quadrangle, there are blocks of red scoriaceous lava. West of Rock Creek the conglomerate is thoroughly silicified and breaks down in great angular blocks.

The conglomerate is overlain by small remnants of a lava flow. Its relation to this lava, and its intimate association with pyroclastic rocks, suggest its correlation with the older of the gravels found near Anaconda.

Valley of Warm Spring Creek.—Thick deposits of gravel occur west of Barker Creek and near the point where Warm Spring Creek leaves the quadrangle. The exposures west of Barker Creek are poor, but those at the locality farther east are somewhat better. The gravels near the eastern boundary apparently overlie tuffs. They are tilted, much eroded, and partly covered by a veneer of Quaternary terrace gravel. They are composed chiefly of well-rounded pebbles and bowlders of sandstone from the Spokane formation, the largest measuring 2 feet in diameter, and smaller ones of Newland rocks, which decompose more readily and are less conspicuous. In the Barker Creek area pebbles from the Newland formation predominate. At neither locality are the rocks forming the pebbles metamorphosed. As there are no unmetamorphosed pre-Cambrian rocks in the present drainage basin of Warm Spring Creek, the abundant pebbles of such rocks in the early gravels show clearly that the area about Georgetown Lake, was at one time drained eastward, a fact indicated also by physiographic evidence.

Southeast slope of Anaconda Range.—A large area on the southeastern flank of the Anaconda Range is underlain by somewhat consolidated gravels which should probably be correlated with those in the valley of Warm Spring Creek. The gravels on the top of Grassy Mountain lie 8,000 feet above sea level, and their thickness on the east side of the mountain appears to be at least 500 feet. The areal distribution of the gravel clearly indicates that it overlies the tuff.

The gravel area is characterized by landslides. Some of them, notably one just east of the point where Sixmile Creek leaves the quadrangle, are expressed by the contours. The eastern face of Grassy Mountain is a landslide escarpment and affords one of the best exposures of the gravels, which are here somewhat consolidated. The pebbles and bowlders, the largest 2 feet but most of them less than 1 foot in diameter, are only fairly well rounded, and not well graded as to size. They here consist mostly of Spokane and Newland rocks and various Paleozoic limestones but comprise quartzite, horny metamorphosed sedimentary rocks, and an intrusive porphyry. The general scarcity of granitoid rocks in these gravels stands in striking contrast to the predominance of such rocks in the moraines and outwash aprons and serves to distinguish the Tertiary deposits from the glacial material. Thin beds of cream-colored, pink, and brownish clay and sandstone are interstratified with the gravels.

Some of the gravel near the southern boundary of the quadrangle consists almost exclusively of bowlders of red sandstone like that which is typical of the upper part of the Spokane formation. These bowlders are in general not well rounded and the largest have diameters of as much as 5 feet. This remarkably homogeneous gravel is shown by a cutting to be at least 15 feet thick. Its source is not known but is evidently different from that of the gravel on Grassy Mountain.

TERTIARY AND QUATERNARY SYSTEMS.

TERRACE GRAVELS.

Terraces whose highest parts rise about 300 feet above the nearest streams are conspicuous in the valleys of Flint, Willow, and Warm Spring creeks. Their surfaces, as a rule, slope markedly toward the axes of the valleys, the grade being gentlest near the brink and increasing gradually toward the hillsides, so that their upper limit is indistinct. These terraces are capped by a thick layer consisting partly of stream gravel and partly of waste from adjacent bedrock slopes. Beneath the capping, in most places, there lies earlier consolidated and tilted gravel, tuff, or volcanic ash. As the ash is probably late Miocene these terrace gravels are presumably as late as Pliocene. On the other hand, they are clearly overlain at the mouth of Fred Burr Creek, north of Boulder Creek and near the head of Philipsburg Valley, by moraines of the later stage of glaciation, and groups of bowlders strewn upon them probably represent moraines of the earlier stage of glaciation. In part, then, they are certainly older than the late Pleistocene glaciation and probably older than the early Pleistocene glaciation.

The material mapped as terrace gravels, however, probably comprises some glacial or even postglacial gravel, especially that on the west side of Philipsburg Valley, where a vaguely terraced slope rising several hundred feet above the stream level merges in some places into the present flood plain, although it is truncated in other places to form a terrace escarpment. Obviously much of the gravel here mapped is much later than that which caps the higher terraces north of Marshall Creek and that of most of the terraces in the more remote parts of the quadrangle.

The material composing the terrace at Philipsburg is well exposed in many street cuttings. It is rudely stratified and consists of gravel and sand, the sand in rather large proportion. The bowlders in the gravel attain a maximum diameter of about a foot, and as a rule are not very well rounded. They consist mainly of rocks that occur in the basins of the short streams east and southeast of the town; they include a very large proportion of limestone and some decomposed granodiorite. Owing probably to the large amount of limestone they contain, certain layers are firmly cemented. Along Willow Creek the gravel consists of rather well rounded bowlders, virtually all of sandstone from the Spokane formation. It is not so much consolidated as the earlier gravel, found farther south. The capping of the terrace north of Warm Spring Creek has much the same general character as that of the Philipsburg terrace; the pebbles are subangular, derived from the rocks of the hills immediately to the north, and are distinct from the underlying gravel, which is composed of well-rounded bowlders brought many miles.

The gravel between Gird and Flint creeks is rather coarse and is composed in greater part of well-rounded bowlders of quartzite and metamorphosed Mesozoic rocks, such as occur in the Boulder Creek drainage basin. The scarcity of granite, which predominates in the moraines of this vicinity, indicates that the terrace is preglacial. The slopes in this gravel area are characterized by landslides, probably because they are underlain by soft, fine-grained Tertiary deposits. Some outcrops of clayey beds, too small to be mapped, were found north of Gird Creek. At the Kolbeck placer digging, a few miles north of the quadrangle, the gravel is underlain by light-colored volcanic ash resembling that which occurs within the quadrangle. This terrace gravel forms a very extensive capping on the earlier Tertiary deposits in the broad valley of lower Flint Creek.

QUATERNARY SYSTEM.

KINDS OF DEPOSITS.

In addition to a part of the terrace gravels, just described, the Quaternary deposits of the quadrangle comprise glacial moraine and material laid down on valley bottoms by streams and lakes. These deposits have been studied with less thoroughness and mapped with less detail than the consolidated rocks. Only two divisions of the Quaternary—moraines and alluvium—are discriminated on the map, the one comprising all material brought to its present position by ice, the other all material finally deposited by water. The greater part of the moraines is older than the greater part of the alluvium and the two classes of deposits correspond roughly to the Pleistocene and Recent series of the Quaternary system, but some of the aqueous deposits were laid down while the glaciers were active. The moraines represent at least two periods of glaciation.

MORAINES.

General features and distribution.—Because the later moraines are very much better preserved than the earlier, it is expedient to describe them first and with relative fullness. The well-developed moraines are easily recognized by their constitution, form, and occurrence. They are accumulations of loose gravel, sand, and bowlders of various sizes, indiscriminately mixed, including many huge fragments which evidently could not have been rolled by streams of water. The bowlders in this quadrangle consist mainly of granite and other intrusive rocks but contain quartzite and metamorphic hornstones. Such rocks are abundant on the highlands where the glaciers took their rise and eroded most vigorously, and they were fittest to survive the ordeal of glacier transportation. The surfaces of the moraines are commonly rough, being covered with knobs and with pits that do not drain through stream channels. Their relief amounts in places to more than 100 feet. The distribution of the moraines exhibits a highly characteristic relation to the topography. They occur in the canyons or valleys that head in the cirques described on page 21 and are thickest in the lower parts of these valleys.

Perhaps the most conspicuous of the glacial deposits are the terminal moraines that were formed when the later glaciers reached their greatest extension. Some of the lateral moraines formed at the same time are hardly less striking, but these are very unequal in prominence. In places the canyon walls were too steep to give lodgment to glacial detritus, and here the lateral moraines may be absent or represented only by scattered bowlders. The mouths of unglaciated gulches entering the glaciated canyons have pocketed much morainal material in places where the walls of the main canyons were almost bare. Moraines that have been formed at some places where the glaciers overflowed the sides of their canyons may be regarded as lateral to the main glaciers or as terminal to lobes that branched out from them. Examples are to be seen along Clear Creek and Mill Creek, in the southeast part of the quadrangle.

A great quantity of drift lies within the moraines of maximum extension, forming in many canyons a virtually continuous sheet nearly up to the cirques. This is probably in part ground moraine but consists largely of terminal and lateral moraines formed during the recession of the glaciers. In many places the outline of a glacier front during a pause in its recession or at a time of slight advance is marked by a rudely crescentic ridge, and rough terraces are formed by secondary lateral moraines. Some of the material on the valley floors that is mapped as moraine has been worked over by water.

Local features of later moraines.—The characteristic features of moraines are nowhere more strikingly displayed than on Fred Burr Creek, a short distance south of Philipsburg. At the mouth of the canyon of the creek is the terminal moraine, on which, among its irregular heaps of loose granite bowlders, there are many undrained hollows. On its west or outer side it falls abruptly to a smoother surface of preglacial terrace gravel. The lateral moraines, whose crest lines gently rise eastward, are ridges built up of loose granite bowlders on the bedrock spurs north and south of the canyon, which the glacier in places overtopped or even overflowed.

The glacier that reached the lowest level came down the valley of Boulder Creek, and seems to have pushed down the valley of Flint Creek beyond the limits of the quadrangle, or to a level of about 4,500 feet. The material mapped as moraine below the junction of the two streams consists of large bowlders, chiefly of fresh granite, whose arrangement suggests a terminal moraine modified by an impetuous stream of water. The Boulder Creek glacier was about 1,000 feet deep at a point 2 miles from the mouth of the canyon, and therefore must have dammed Flint Creek so as to form a lake in Philipsburg Valley. The withdrawal of the ice dam undoubtedly made Flint Creek, for a time, far larger and more vigorous than it now is, and the dispersion of morainic material that must have lain in the path of that stream is readily accounted for.

The middle part of Boulder Creek canyon is encumbered with a great quantity of morainal material, to which the stream owes its name. A broad terrace-like lateral moraine lies on the moderate slope southwest of the stream, but on the steep limestone slopes of the northeast side morainal material is much less abundant and most of it is lodged in gulches or on the gentler parts of the slopes.

The north lateral moraine of Racetrack Creek forms a prominent morainal bench below the North Fork, and both of the lateral moraines of this glacier jut out into Deerlodge Valley as embankments of a height that is not attained by moraines built up on level ground within the quadrangle.

The glacier of the Middle Fork of Rock Creek was the longest in the quadrangle, the distance from the head of its southeastern branch to its terminus being about 20 miles. The strong relief of its terminal moraine, whose hollows contain the ponds known as the Potato Lakes, is suggested by the contours on the map. The moraines of the East Fork are separate from those of the Middle Fork. The strong west lateral moraine of this glacier has effected a diversion of drainage and its form shows that the glacier spilled over into the basin of Meadow Creek. On the east side of the East Fork the steep cliffs carved from vertical beds of limestone afforded no lodgment for ice-borne detritus.

East of Georgetown Lake lies an extensive complex of moraines, deposited by the Warm Spring glacier system, which was by far the largest sheet of ice in the quadrangle. The distribution of its moraines shows that the glaciers forming it overflowed the divides at many places and surrounded such isolated heights as Silver Hill, the ridge east of Cable Creek, and the hill south of Browns. The moraines of this area were in large part deposited during a recession of the ice that continued until the branch glaciers had one by one shrunk away from the trunk stream and finally vanished. The intermittency of the retreat is strikingly indicated by the succession of rudely parallel moraine loops just west of Big Gulch, where the deposits are stripped of timber. This barrenness of the landscape makes it easy for the observer looking southeastward from Warm Spring Creek to Mount Haggin to obtain an instructive view of the excavation and the deposits made by the ice that occupied Gray's Gulch. At the mouth of the gulch the front of the moraine rises abruptly to a rudely semicircular crest behind which chaotic heaps and ridges of bowlders extend for several miles to a large amphitheater cut into the base of the mountain, from which most of this material was derived. The correlation between cirque and moraine is here peculiarly striking.

The south flank of the Anaconda Range is little less heavily mantled with moraines than the north flank. They are impressive in their vast bulk and chaotic roughness but have few strong outstanding lineaments except the lateral moraines along Sullivan Creek and west of Twelvemile Creek. On the sides of the deep canyon of Seymour Creek, near the south boundary of the quadrangle, successive stages of the ice front are outlined by obscure lateral moraines that arch down toward the south in nearly parallel curves.

Earlier moraines.—The fragmentary remnants of the earlier moraines are not all readily distinguished from stream deposits and later moraines. The locality at which the earlier glacial drift is most easily identifiable is at the mouth of Fred Burr Creek. At this place the later moraine appears to have covered nearly all the older one, only a little of the northwestern margin of which is left exposed. An old railway cut through both moraines reveals a striking contrast in the preservation of their materials. The bowlders of granodiorite in the later moraine are fresh and smooth; those in the earlier are rusty and defaced by scaling. The dioritic bowlders in the later moraines are but slightly weathered; those in the earlier are thoroughly softened by decay.

On Warm Spring Creek the earlier moraine seems to have been covered even more completely than on Fred Burr Creek; the terminus of the rough recent moraine is sharply defined, and the valley floor below is smooth and free from large bowlders. The later glaciers of the two large branches of Rock Creek, however, were considerably shorter than the earlier ones. For about a mile from the north end of the area mapped as morainal on the Middle Fork, there is feebly accented morainal topography, which gives way abruptly to the very much rougher topography about the Potato Lakes. Similar extension of older terminal moraines beyond the later may be observed just beyond the eastern boundary of the quadrangle, on Mill Creek, and perhaps also on Lost Creek. It is doubtful what proportion, if any, of the bowlders beyond the recent moraine of Lost Creek should be considered as old moraine rather than outwash, and similar doubt exists as to the exact limits of the terminal moraines of Grays Gulch and Big Gulch south of Warm Spring Creek.

Among the larger isolated areas of drift that apparently belong to the earlier glaciation is one about 2 miles south of Georgetown Lake. Some smaller patches not mapped may be ascribed with more or less certainty to the older drift, even though few of their bowlders consist of the granitoid rocks that are so abundant in the later moraines. Although highly resistant to attrition the granite is less resistant to weathering than the tough metamorphic rocks. It has withstood decay fairly well for the period subsequent to the last advance of the ice, but the phenomena observed at Fred Burr Creek make it seem probable that in small mounds exposed to weathering and erosion since the first advance much of it would crumble to sand and be washed away.

ALLUVIAL DEPOSITS.

The materials laid down by water in glacial and postglacial time include glacial outwash, valley alluvium, and lacustrine deposits. These have not been distinguished from each other on the map.

Outwash deposits consisting of material like that of the moraines but not so coarse are recognizable at the bases of the moraines, especially north of Mount Haggin. Those which are spread out on terraces and gentle slopes are more conspicuous than those that merge with the alluvium of the broad valleys.

The valley alluvium makes up the bottom lands along the streams, much of which, like that along lower Warm Spring Creek and near Philipsburg, is damp or even boggy meadow land and belongs to present or recent flood plains. Some of this alluvium, like that of the upper Philipsburg Valley, is drier and forms low terraces. Two terraces that differ 10 to 15 feet in height were noted on the Middle Fork of Rock Creek in gravel that laps upon morainal mounds and is clearly postglacial.

Some of the many flat meadows that lie among the glacial deposits of the large glaciated canyons were formed by the filling up of lakes that once lay in hollows among the moraines. The largest meadow that seems to have had such origin is on the East Fork of Rock Creek and is about 2 miles long. The gravel flat on Blodgett Creek evidently marks the site of a lake once formed by a dam of ice and moraine. Deposits of gravel that have a similar relation to the glacial deposits occur in some of the unglaciated gulches that are tributary to the glaciated canyons. Princeton Gulch, north of Boulder Creek, contains a deposit of this character, formed by aggradation of the stream toward the old level of the ice.

The deposits just described, though in a sense of lacustrine origin, are covered with fluviatile deposits, those of the small canyons perhaps more deeply than the others. Material that is more strictly lacustrine, deposited in lakes that were not filled up by alluviation but drained by the removal or cutting down of a dam, is probably represented by some of the fine soil in areas in Philipsburg Valley and about Georgetown Lake which were occupied by evanescent glacial lakes; but these deposits are thin, and it would probably be impracticable to separate them from the other surficial deposits.

IGNEOUS ROCKS.

All the principal classes into which igneous rocks are divided according to mode of origin are represented in the Philipsburg quadrangle. The volcanic rocks of this area, including lava and pyroclastic deposits, are confined to relatively small tracts; the intrusive rocks occupy a far greater proportion of the surface.

INTRUSIVE ROCKS.

GENERAL FEATURES.

Occurrence and age.—Intrusive igneous rocks are abundant in the eastern and southern parts of the quadrangle, where they form about half the bulk of the Flint Creek and Anaconda ranges, but they are very scarce west of Philipsburg Valley. They occur chiefly in large, irregular domelike masses, which may be briefly designated plutonic, but they occur also in dikes and sills.

As the many intrusive bodies cut one another and are affected in different degrees by shearing, a considerable length of time must have intervened between the emplacement of the earliest and that of the latest. But the intrusion of most if not all of them was effected within a period that began not earlier than the Cretaceous and ended not later than the Miocene. In stating the grounds for this conclusion, it is expedient to consider first the plutonic bodies, with which the dike rocks are probably about contemporaneous, and afterward the sills.

All the plutonic bodies except two, as is directly proved by contact phenomena, cut the pre-Tertiary strata with which they are in contact. For a mass of diorite at the middle of the east boundary of the quadrangle and for a mass of biotite granite in the southeast corner this relation is not thus directly proved. The diorite mass, however, is probably contemporaneous with similar masses in the Anaconda Range, which invade sedimentary rocks of Algonkian and Cambrian age. If similar evidence of the post-Cambrian age of the granite is lacking, the hypothesis that the rock is pre-Cambrian is utterly unsupported, and it is altogether probable that this granite, like the other plutonic rocks of the quadrangle, is post-Cambrian.

No age more definite than post-Cambrian can be assigned to the oldest of the irregular intrusive bodies solely on the evidence afforded by observation of contacts, but the farther limit of the possible period of plutonic intrusion may be drawn much closer to the present by taking account of the well-established relation between intrusion and deformation. Wherever plutonic bodies have been studied, it has been found that their emplacement has been attended or closely preceded by marked folding or faulting of the invaded strata. If, therefore, such a body be intruded into a sedimentary series, the beds deposited after the intrusion will be separated from the older beds by a marked structural unconformity; and if a succession of strata be nearly accordant in attitude their deposition has not been interrupted by intrusions of the character here considered. The application of this reasoning to the Philipsburg district is clear. All the strata up to and including the Colorado formation (of Upper Cretaceous age) that occur in this district are cut by plutonic rocks. Intrusion and deformation being related in the manner above stated, no great intrusions could have taken place during the deposition of the Paleozoic and Mesozoic strata, for the sequence of these strata is not broken by angular unconformities. If, therefore, the plutonic intrusions are all post-Cambrian they are all post-Colorado.

The minimum age of the plutonic intrusions is indicated by their relation to the Tertiary sediments and volcanic rocks. The intrusives are overlain with marked unconformity by such of these rocks as they are in contact with and are therefore presumably in general earlier; for if igneous rocks were intruded after the deposition of the earlier gravels it would be remarkable if the later intrusive bodies were nowhere in contact with Tertiary or volcanic rocks. As the earliest of these rocks are not later than Miocene, the plutonic intrusions are pre-Miocene.

That part of the foregoing argument that depends upon the relation of intrusion to deformation fails to apply to the sills. The injection of sills is not normally attended by much deformation; indeed, sills that lie at the same stratigraphic horizon throughout a large area must evidently have been injected before the strata were much disturbed. Therefore the extensive basic sills that are intercalated in the Algonkian, Cambrian, and Cretaceous strata of this quadrangle were clearly injected before the great post-Colorado deformation of the strata and are older than the plutonic rocks, whose intrusion attended or followed that deformation, and are probably pre-Tertiary. Yet even the oldest is probably post-Algonkian, for the basal conglomerate of the Cambrian, though it lies not far above the great sill of diabase in the Spokane formation, contains no pebbles of diabase. The injection of the sills was possibly contemporaneous with the volcanic outbursts that took place in areas outside this quadrangle late in Cretaceous time.

Character.—In lithologic character the intrusive rocks of the quadrangle range from aplite to diabase. None contains olivine or feldspathoids and no considerable body is without quartz. The chief sorts are quartz-bearing diorite, granodiorite, and granite, the term granite being here applied to several rocks which have the megascopic characters of granite in the strict sense but which when examined microscopically are found to contain an equal or larger amount of plagioclase than of potash feldspar.

Although not enough analyses have been made to determine fully the chemical character of the igneous rocks, the results of a few analyses and the study of many thin sections show that they have a general resemblance to the rocks of some other regions in the western United States, though they exhibit some slight but characteristic differences. Compared with the typical rocks of the Boulder batholith, those of the Philipsburg district are a little less alkaline and in part more siliceous and have a slightly smaller ratio of potash to soda. Compared with the granodiorites of the Sierra Nevada and Cascade mountains, to which they are similar, the granodiorites of the Philipsburg district are more alkaline and are richer in potash. On the other hand, they present a striking contrast with the alkaline rocks of the central Montana region.

The intrusive rocks will be described in general order of age, so far as that is known, but the relative age of some intrusions is uncertain. The order of age is nearly the order of decrease of the ratio of silica in the rocks, so far as the intrusions of primary importance are concerned. Most of the rocks that occur in dikes and some other very small intrusions, including aplites, pegmatites, lamprophyres, and porphyries generically related to the granites, have not been mapped, and only those of particular interest or importance will be described.

Igneous metamorphism.—Few districts of equal extent illustrate so fully as the Philipsburg quadrangle the phenomena of igneous metamorphism, which has there affected every common variety of sedimentary rock as well as some basic intrusives. As all the sedimentary formations are metamorphosed over considerable areas, commonly to an extent that deeply disguises their original aspect, it has been necessary, for purposes of identification, to describe the altered phase of each formation in conjunction with its unaltered phase, and the descriptions of the metamorphosed sedimentary rocks are therefore given in the preceding pages.

The chief processes taking part in the metamorphism have been recrystallization (almost the sole change in some of the purer limestones and quartzites) and reaction between the constituents, such as that between quartz and dolomite to form diopside, with liberation of carbon dioxide. Some changes, however, have depended in addition upon the transfer of material from magma to sedimentary rock. The minerals that most clearly show such transfer are those that contain elements which are not found in the unaltered sedimentary rocks but which are common in exhalations from igneous magmas. Minerals of the humite group and fluorite contain fluorine; tourmaline and ludwigite contain boron; and scapolite contains chlorine. The magnetite bodies found at the contacts of igneous rocks with limestones give equally clear evidence of transfer of material, accompanied by extensive replacement.

Of more doubtful significance are minerals whose constituents are found in the unaltered rocks but which are so abundant in the altered rocks as to suggest accession of certain constituents from the magmas. Such minerals are the magnesia-lime silicate tremolite, most abundant in the Madison, the least magnesian of the Paleozoic limestones; and the alkali feldspars which are so abundant in some of the metamorphosed calcareous sediments as to suggest that they have derived silica and alkalies from magmatic emanations. Whether igneous emanations have materially contributed to form the garnet that is so abundant in the metamorphic derivatives of the Cambrian and pre-Cambrian calcareous shales is a question to which the information now available, being deficient in chemical data, gives no definite answer. Transformation of nearly pure limestone to a mass consisting largely of lime-iron garnet has been effected thus in other districts, but nearly all the garnet of this district occurs in rocks which, unlike pure limestone, originally contained considerable amounts of all the constituents of garnet. The indubitable fact that the igneous emanations have carried iron makes it conceivable that they have contributed to the formation of garnet as well as of magnetite. It is argued in the account of the economic geology that precious metals also have been derived from the igneous magmas.

BASIC SILLS.

Sills of black to dark-gray igneous rocks are intercalated with strata of Algonkian, Cambrian, and Cretaceous age. Those between the Algonkian strata are typically diabasic, or were so originally; those higher in the geologic column are classified as dioritic.

DIABASE.

Occurrence.—Diabase intercalated with the upper part of the Spokane formation is well exposed south of Princeton, on Twin Peaks, and in the vicinity of Lost Creek. The rock at all these localities probably belongs to a continuous though possibly branching sill, whose horizontal extent is thus at least 15 miles. Diabase also forms irregular dikes that cut the Newland formation on the lower part of Lost Creek, just east of the quadrangle, and lead up to two sills (mapped as one) that are prominently exposed on the north side of the canyon.

A sill of fine-grained quartz-plagioclase-hornblende rock intruded in the Prichard formation southeast of Mount Howe is regarded as an extremely altered diabase.

Petrography.—The diabase is a heavy, compact, nearly black rock, somewhat rusty on the weathered surface, where lath-shaped feldspars can be distinguished from the dark minerals that fill the interstices. In texture it ranges from medium to fine grained.

The constituents identified microscopically in the least altered material are plagioclase, augite partly altered to amphibole, some hornblende which may be original, ilmenite or magnetite, biotite, quartz, apatite, and zircon. No olivine is found, nor any secondary mineral that suggests its former presence. The texture is ophitic. The plagioclase, which is but faintly zoned, has an average composition near andesine-labradorite, An_{50}.[1] The part of the magma that solidified last is represented by micropegmatitic intergrowths of quartz with oligoclase, probably secondary after orthoclase whose potash may have gone to form biotite.

The change of augite to amphibole, which is complete in much of the diabase, is due, at least in part, to the action of later intrusives, which have metamorphosed the diabase as well as the associated sedimentary rocks. The extreme of this alteration is shown in the rock from near Mount Howe, which has only a general resemblance to the unaltered diabase. The light and dark areas are finely crystalline aggregates, but some white areas with lath-shaped outlines evidently represent altered feldspars that formed part of an ophitic fabric. Microscopically it is found that the dark parts consist chiefly of hornblende but that they contain some biotite, and that the white parts consist of labradorite and quartz.

DIORITE.

Occurrence.—A sill near the base of the Silver Hill formation, in the southeast part of the quadrangle, and some small intrusions in the Cretaceous strata on Gold Creek consist of dark-greenish basic rocks that differ in composition from the diabase. These rocks are not uniform in texture but do not differ greatly among themselves in composition and they may all be roughly classified as diorite and diorite porphyry. The sill in the Silver Hill formation resembles one described in earlier folios as occurring at the same horizon in central Montana and as having remarkable persistence.

Petrography.—A fine-grained granular rock from a sill near Gold Creek consists mainly of almost equal parts greenish-black hornblende and dull-white feldspar but contains also considerable biotite. Porphyritic specimens collected on Gold Creek and Silver Hill are dark greenish and fine grained. They contain phenocrysts of augite, more or less completely altered to amphibole, and possibly some of original amphibole. Biotite is conspicuous in a specimen from Silver Hill, and serpentinous pseudomorphs in one from Gold Creek probably represent hypersthene phenocrysts. All these minerals recur in the groundmass, together with quartz and alkali feldspar.

Under the microscope the hornblende of a typical granular specimen from Gold Creek shows a slightly porphyritic development, yet it is allotriomorphic against plagioclase and may be uralitic. It is crowded with small flakes of biotite, which is possibly secondary, though the biotite seen with the naked eye is primary. The principal feldspar is plagioclase with cores of labradorite near An_{65} and narrow rims of oligoclase. Intergrowths of secondary sodic feldspar with quartz occur interstitially.

ACIDIC DIORITE.

General character and occurrence.—Rocks more typically dioritic than that of the sills occur somewhat abundantly in the quadrangle, both as a local facies of the bodies that consist mainly of granodiorite and as the dominant rock of fairly large masses. The largest of such independent masses of diorite are exposed in a zone that extends from Storm Lake eastward beyond Mount Haggin, in the Anaconda Range, and in an area that lies south of Racetrack Creek, in the Flint Creek Range. The rock of all these areas is a coarse-grained quartz-mica diorite consisting essentially of plagioclase, quartz, hornblende, and biotite, and it is uniform enough to be regarded as probably the product of a single episode of intrusion. It is distinct in character from the diorite of the sills and from the basic diorite described below, in both of which the dark minerals are considerably more abundant.

Although lighter than the basic diorite, the acidic diorite is conspicuously darker and more rusty than the other intrusive rocks with which it is in contact. Near the contacts with sedimentary rocks it is somewhat variable and is richer in dark minerals than elsewhere. Gneissoid banding is general in the Racetrack Creek and Mount Haggin areas and in the eastern part of the Storm Lake area. It seems to be for the most part secondary, and is clearly so at the head of Mill Creek, where it is especially well marked.

The intrusive relation of the diorite to the Cambrian and pre-Cambrian rocks is clear in the Storm Lake area. The diorite here has engulfed and intensely metamorphosed great masses of magnesian limestone resembling that of the Hasmark formation, the larger of which are mapped, and on the walls of Fourmile Basin it visibly cuts across the bedding of the pre-Cambrian rocks. In the Mount Haggin area the contact with the sediments is much obscured by talus, but at one place the intrusive relation to Cambrian beds is clear; the diorite, normal 4 feet from the contact, becomes streaky, finer grained, and more siliceous toward the contact, and the limestone for a few inches from the diorite is changed to a rock rich in garnet and epidote. The diorite of Racetrack Creek is almost certainly later than the sediments, but no clearly irruptive contact with them has been found. South of Thornton Creek, within a short distance of the limestone, the diorite shows a southward-dipping schistosity, which suggests that it has been affected by the strong thrusting which has deformed the sediments.

The diorite is older than the more siliceous intrusives with which it is in contact. Near Storm Lake it is cut by the granodiorite, and near Mount Haggin and on Racetrack Creek it is penetrated by many conspicuous light-colored dikes of aplite, pegmatite, and granite.

Petrography.—A typical specimen of the acidic diorite from the ridge east of Storm Lake is a gray medium-grained rock, at least two-thirds of which consists of feldspar and of subordinate and inconspicuous quartz, the remainder consisting chiefly of hornblende and biotite in nearly equal quantity. All the constituents form irregular individuals whose diameter attains a maximum of about 5 millimeters but averages much less. The dark minerals tend to cluster in ill-defined aggregates.

The microscope shows that plagioclase is the most abundant constituent, accompanied by hornblende, biotite, and quartz in amounts not far from equal. A little augite is intergrown with the hornblende; titanite, apatite, magnetite, zircon, and rutile are accessory. The rock contains no potash feldspar. The plagioclase, slightly zoned and conspicuously mottled, has an average composition near An_{50}.

The percentages of silica and alkalies in a sample of this rock were determined by W. T. Schaller as follows:

Partial analysis of diorite from ridge east of Storm Lake.

SiO_2	57.00
K_2O	1.55
Na_2O	2.65

According to the norm quantitative classification the rock would probably be a tonalose. The percentages are similar to those in a pyroxene-mica diorite from the Yellowstone National Park.

The diorite of Racetrack Creek resembles in general appearance the rock here described but is distinguished texturally by an obscurely porphyritic development of plagioclase and mineralogically by a somewhat smaller proportion of ferromagnesian constituents and the presence of a little microcline.

In areas southeast of Twin Lakes, toward the margin of the intrusive mass, the diorite is, on the average, finer grained and richer in dark minerals than usual, but it is streaky and irregular in composition and texture, and its plagioclase is in part porphyritic. The most extreme departure from the normal diorite is shown in a rock whose most abundant mineral is hornblende, which forms roughly equidimensional grains as much as 25 millimeters long, with lustrous cleavage facies mottled by inclusions of feldspar and other minerals.

BASIC DIORITE.

General character and occurrence.—Small areas on Foster Creek and Olson Gulch, in the east-central part of the quadrangle, and still smaller areas southwest of Georgetown Lake are occupied by basic diorite. Like the acidic diorite described above, these rocks consist mainly of plagioclase, hornblende, biotite, and quartz, but they contain also some pyroxene in places and are darker than the other diorite. They resemble somewhat the diabase of the sills, but from this they are

---

[1] The subscript figures show the percentage of the anorthite molecule in the feldspar, the percentage of the albite molecule being, of course, the difference between 100 and the figure given. Albite=An_0 to An_{10}; oligoclase=An_{10} to An_{30}; andesine=An_{30} to An_{50}; labradorite=An_{50} to An_{70}; bytownite=An_{70} to An_{90}; anorthite=An_{90} to An_{100}.

distinguished by the presence of abundant prismatic hornblende and, in most specimens, of conspicuous biotite. Their more basic parts are classifiable as gabbros.

Despite the fact that these rocks present considerable diversity of composition, it is probable that they are nearly contemporaneous; the close proximity to each other of the areas on Foster Creek and Olson Gulch makes it virtually certain that they belong to a single mass. In all its areas the basic diorite has an intrusive relation to the adjoining sedimentary rocks. Southwest of Georgetown Lake it has altered the calcareous shales of the Newland formation near its contact to diopsidic hornstones. Although the contacts of the mass in Olson Gulch are obscured by soil, its intricate boundaries and numerous inclusions, the larger of which are mapped, indicate that it is a stocklike body intruded into the Paleozoic rocks. There is no evidence that it has been affected by the complex faulting which has displaced the limestones; its intrusion seems to have occurred either at the same time as the faulting or later. It is not known to be cut by later intrusives. The diorite on Foster Creek is clearly intrusive in the Jefferson and Madison limestones and is cut by granite.

Petrography.—The most basic variety of these rocks, found on the dump of a tunnel at the forks of Olson Gulch, is a fairly coarse grained dark-gray gabbro. Its most abundant dark mineral is hornblende, which forms imperfect, stumpy prisms that attain a length of nearly a centimeter. The chief white constituent is feldspar in dull-white irregular masses, smaller than the hornblende crystals. The only other minerals easily visible to the naked eye are a little biotite and pyrite.

The microscope shows that the original constituents of the rock are hornblende, plagioclase, augite, biotite, quartz, hypersthene, magnetite, and apatite. It contains secondary bastite, chlorite, sericite, and calcite, and it is so much altered as to indicate that the pyrite is secondary. The hornblende, which carries many small inclusions of the other minerals, ranges in color from deep greenish brown to pale green. The plagioclase crystals consist in greater part of anorthite near An_{92} but, except where they are in contact with ferromagnesian minerals, they have a narrow, sharply defined rim of sodic labradorite (An_{50} to An_{55}). The order of crystallization has been, roughly, apatite and iron ores, pyroxene and cores of plagioclase, biotite, hornblende, rims of plagioclase, quartz.

A less hornblendic facies, common on Foster Creek and also found in Olson Gulch, is a dark-gray diorite of medium-fine granular texture with slightly porphyritic biotite and plagioclase in a groundmass that consists chiefly of feldspar and splintery hornblende. Poikilitic microcline can be recognized by reflections flashed from cleavage faces as much as 1 centimeter across. The presence of this potash feldspar and the absence of pyroxene constitute the chief differences between this rock and the more basic rock of Olson Gulch. Material near the northernmost contact, intermediate in composition between the two types described, contains a little scapolite, which may be original. A specimen taken southwest of Georgetown Lake contains much orthoclase but no biotite.

BASIC AND MEDIUM GRANODIORITE.

GENERAL FEATURES.

The rocks classified in this folio as basic and medium granodiorite form intrusive masses of considerable size near Philipsburg, Cable, and Storm Lake, as well as several smaller masses. They are granular in texture and consist essentially of plagioclase, quartz, orthoclase, hornblende, and biotite. Their considerable content of orthoclase chiefly distinguishes them from the acidic diorite already described, but this feldspar is subordinate in quantity to the plagioclase. The presence of hornblende and biotite in moderate and nearly equal amounts distinguishes these granodiorites from the acidic granodiorite described below, in which hornblende is relatively scarce. The only fact clearly established regarding the ages of the basic and medium granodiorites with relation to the others, from which they are for the most part isolated, is that the granodiorite at Storm Lake is later than the acidic diorite. The rock of each considerable area is distinguished by special petrographic characters, and therefore each area is described separately.

STOCK NEAR CABLE.

General character and relations.—At the south end of Cable Mountain lies a rudely circular area occupied mainly by a rather dark gray granodiorite, whose texture is somewhat finer than that of average granite and whose crystals of biotite and hornblende are comparatively regular in form and distribution. The composition of the rock is fairly uniform, but small dark dioritic-looking inclusions are distributed somewhat abundantly throughout its mass, and some parts of it near contacts are very hornblendic.

As it occurs in a tract that is not rugged and has not been glaciated, this granodiorite is poorly exposed in general, and near the flat divide between Cable and the Southern Cross mine it is so much decayed that it can be excavated with pick and shovel to the depth of several feet. Its most extensive outcrop is on the hill a mile southwest of Cable, on whose west slope a quarry has been excavated.

Sufficient proof that the granodiorite is intruded into the surrounding Algonkian and Paleozoic strata is afforded by the strong metamorphism which has affected all the sedimentary rocks along the contact. The occurrence in the contact zone of abundant scapolite and magnetite, whose constituents were contributed in part by the magma, and of ore deposits which, according to Mr. Emmons, have a similar origin, is of special interest.

The periphery of this intrusion approximately follows the strike of the adjoining strata on the southeast side, but elsewhere it generally cuts across the strike, and at many places the beds dip toward the contact. The granodiorite incloses or partly incloses a few small masses of sedimentary rock, most of which do not appear to be far removed from the positions that they occupied before the intrusion and may be "roof pendants" completely or partly isolated by erosion. The largest of these lies just north of Cable. It consists chiefly of limestone and contains the ore bodies of the Cable mine. Its slender outline on the surface and its subterranean boundaries as revealed in the mine workings show that this mass is rudely tabular in form and has nearly vertical walls. Its northern end has been brought down against Algonkian rocks by faulting which probably occurred chiefly before or at the time of the intrusion, though there is evidence of slight movement subsequent to the intrusion.

Petrography.—A typical specimen from the quarry southwest of Cable is a dark bluish-gray, evenly granular rock, somewhat finer in texture than most granites. The bulk of the dark minerals is about one-fourth that of the lighter ones. Biotite is a little more abundant than hornblende. Quartz is not conspicuous. The feldspars are not markedly different in color, but by turning the specimen about to catch reflections from cleavage faces the little subhedral plagioclase crystals can be distinguished from the larger poikilitic individuals of potash feldspar.

The original minerals revealed by the microscope are plagioclase, orthoclase, quartz, biotite, hornblende, magnetite, apatite, titanite, and zircon. The rock is fairly fresh but contains a little secondary chlorite, epidote, calcite, kaolin, sericite, and leucoxene. The texture is characterized by the development of orthoclase and quartz as relatively large individuals in which crystals of all the other minerals are evenly disseminated.

The plagioclase is conspicuously zoned and mottled. It shows a range of composition from An_{20} to An_{80} and an average near An_{45}.

Chemical composition.—A specimen representing the dominant phase of the granodiorite has been analyzed by George Steiger with the following result:

Analysis of granodiorite from quarry southwest of Cable.

	Percentage.	Molecular proportion.
SiO_2	60.19	1.003
Al_2O_3	17.39	.171
Fe_2O_3	2.04	.013
FeO	4.28	.060
MgO	2.10	.053
CaO	5.69	.102
Na_2O	3.30	.053
K_2O	2.67	.029
H_2O-	.31	
H_2O+	.89	
TiO_2	.85	.01
ZrO_2	.04	
CO_2	.21	.005
P_2O_5	.30	.002
MnO	.11	.001
S	None.	
SO_3	None.	
BaO	.08	
SrO	.02	
	100.47	

The norm, calculated to determine the position of the rock in the quantitative classification, is as follows: Quartz, 14.8; orthoclase, 16.1; albite, 27.8; anorthite, 24.7; diopside, 1.41; hypersthene, 9.5; magnetite, 3.0; ilmenite, 1.7; apatite, 0.7. This corresponds to a tonalose near harzose. This norm contains less quartz, more orthoclase, and less diopside than most granodiorites. It is poorer in both quartz and orthoclase than the harzoses of Butte. The ratio of MgO to FeO is unusually low.

Lamprophyric inclusions.—The dark inclusions, which have well-defined boundaries and subangular outlines, consist of a rock that contains the same minerals as the normal granodiorite but is much richer in ferromagnesian minerals and has a texture about half as coarse.

Marginal facies.—The bold outcrops at the contact of the granodiorite with the sedimentary rocks on the spur east of Cable show a complex mingling of light greenish-gray granular rock with dark rock rich in hornblende. Viewed microscopically, the dark rock is found to contain vestiges of decomposed plagioclase as well as an abundance of the epidotes allanite and pistacite.

Aplite and pegmatite.—Associated with this granodiorite are rocks of a type occurring in association with other granodiorites and described later as pyroxene aplite. Other siliceous rocks found near Cable are all characterized by richness in albite, which is their most abundant constituent. Small quantities of biotite, quartz, or orthoclase occur in various facies of the rock; zircon and rutile are the most characteristic accessories. The texture varies from coarse and pegmatitic to porphyritic or finely granular.

STOCK NEAR STORM LAKE.

Occurrence.—A rock somewhat resembling that of the stock at Cable occupies an area about 2 square miles in extent adjacent to Storm Lake. A few small knobs that project through the moraine north of this area are regarded as belonging to the same intrusion, but proof of the connection is not available because of the heterogeneity of the mass. Near contacts with the sediments the rock is on the whole more basic than elsewhere and is characterized by intricate mingling of more acidic and more basic portions.

The Storm Lake mass is clearly irruptive into Algonkian and Cambrian sedimentary rocks and contains abundant inclusions of those rocks. Many of the large areas are mapped and smaller areas are shown in Plate III. The granodiorite is younger than the acidic diorite described above, a relation suggested by the form of the boundary northeast of Storm Lake and clearly proved by frozen contacts of diorite of normal texture with granodiorite of especially fine texture.

Petrography.—The most typical rock of the Storm Lake mass is rather dark gray and of medium-fine grain. Its fresh glassy feldspar is not readily distinguishable from quartz, but some irregular poikilitic grains of unstriated potash feldspar can be recognized by the flashes from their basal cleavage planes. Its dark minerals are hornblende and biotite. The hornblende is in the usual grains or imperfect prisms, less than 3 millimeters in maximum diameter. The biotite is far more conspicuous; it forms ragged foils containing many inclusions, the largest nearly 1 centimeter in diameter, and pieces that are apparently separated flash together over areas 2 or 3 centimeters across. This peculiar habit of the mica constitutes the most conspicuous difference between this rock and that of the Cable intrusion.

The thin section shows that the order of abundance of the original minerals is approximately as follows: plagioclase, quartz, biotite, microcline, hornblende, augite, magnetite, apatite, zircon, and rutile. The plagioclase is considerably zoned and mottled, and has an average composition near An_{40}. Not only the biotite but the quartz and microcline are extremely poikilitic and interpenetrate with one another.

Variations.—The variations from the normal granodiorite are so multiform that only their general character can be indicated.

In places the differences from the principal kind are chiefly textural. The biotite is not everywhere poikilitic, and the rock is finer grained for a few inches from contacts than elsewhere. An apophysis from the main mass consists of granodiorite porphyry which contains many phenocrysts of andesine, pyroxene, and biotite and sporadic ones of microcline in a micrograbular groundmass consisting chiefly of quartz and microcline but including subordinate plagioclase. The biotite of this porphyry, like that of the granular rock, is extremely poikilitic.

The variations in composition are more striking than those in texture. The streakiness of the granodiorite near contacts with the sedimentary rocks, obscurely apparent in Plate III, is in places very marked. The heterogeneous marginal zone consists of nearly normal rock but comprises quartz-mica diorite without alkali feldspar. Commonly the intrusive rock is impoverished of ferromagnesian constituents for a few millimeters from the contact. Near contacts with sedimentary rocks the intrusive masses contain many inclusions, mainly of altered calcareous sediments but partly of lamprophyric material, probably formed by differentiation.

The marginal rocks differing most markedly from the normal granodiorite have the varied textures of pegmatites and aplites. The coarser grained, which are in general the more basic, are characterized by large and conspicuous crystals of pyroxene and hornblende embedded in a white feldspathic matrix. The feldspar is mostly calcic plagioclase but comprises also microcline. Titanite is a common accessory. The finer-grained rocks are rather alkaline and resemble the pyroxene aplites described on page 17. A specimen illustrating some of their features consists chiefly of sugary feldspar and quartz but contains a small amount of hornblende and pale-green diopside. The feldspar is microcline but includes subordinate amounts of albite and oligoclase.

THE PHILIPSBURG BATHOLITH.

General character and occurrence.—A granodiorite of lighter color and coarser texture than that of Cable or of Storm Lake forms a large mass, of roughly elliptical ground plan, in the mountains just east of Philipsburg. There is a small outlier in the southeastern part of the town, and other masses, southeast of Rumsey Mountain, on Boulder Creek, and in the northwestern part of the quadrangle, may belong to the same intrusion.

The main part of the mass is fairly uniform, although it contains lamprophyric inclusions and is rather more hornblendic near contacts. The normal granodiorite near Rumsey Mountain apparently grades into a highly hornblendic diorite. Aplite forms numerous small dikes but is not so abundant as in the more siliceous granitoid rocks.

The fresh rock is well exposed in the high glaciated plateau about Fred Burr Lake and at the heads of the canyons that descend from the plateau. The general tint of the little-weathered outcrops, which show regular jointing, is pure light gray. About Granite, beyond the limit of glaciation, the rock is deeply weathered, its surface being strewn with great subangular bowlders of disintegration, among which shattered knobs rise here and there. On lower slopes the granodiorite is mostly covered with deep soil.

The granodiorite is in contact with all the sedimentary formations from the Newland to the Madison limestone. The irruptive nature of the rock at the periphery of the mass is abundantly proved by phenomena strikingly displayed in the immediate vicinity of Philipsburg. Here the Silver Hill formation is metamorphosed to coarsely crystalline rocks, which are penetrated by dikelets of porphyry related in composition to the rock of the batholith. Special features of the contact zone are iron ores (some containing the rare boron mineral ludwigite) at contacts with calcareous sediments near Philipsburg, and abundant scapolite in calcareous metamorphosed rocks near Philipsburg and northeast of Rumsey Mountain.

The upper surface of the mass, as is evident from the outline of the area of outcrop, is rudely domelike. The contact follows closely the bedding of the adjacent sedimentary rocks at many places, especially near Twin Peaks, but throughout fully half of its circumference it cuts across the bedding.

Petrography.—The character of the prevailing rock is well illustrated by typical specimens taken from the gulch east of Copper Creek, about a mile from the contact. The general tint of the rock is a rather light warm gray. It is granular, without conspicuous porphyritic development of any of the constituents, and is of medium grain. More than half the rock consists of feldspar, two varieties of which are readily distinguished—unstriated potash feldspar, having a pale flesh tint and forming large individuals, and the grayish-white striated plagioclase. Both species have rude crystal form. Quartz is abundant. Biotite is slightly more abundant than hornblende; both together form a relatively small part of the rock.

The complete list of original constituents visible under the microscope, named nearly in the order of their relative abundance, is as follows: Plagioclase, quartz, potash, feldspar, biotite, hornblende, magnetite, apatite, zircon, and allanite. The secondary constituents are chlorite, epidote, calcite, kaolin, and sericite.

The plagioclase, which is rather conspicuously zoned and mottled, averages about An_{40}. The potash feldspar is a slightly perthitic orthoclase.

The following percentages were determined by W. T. Schaller:

Partial analyses of rock of Philipsburg batholith.

SiO_2	68.21
Na_2O	3.22
K_2O	3.56

These figures, together with the mineral composition, indicate roughly the position of the rock in the quantitative classification. Similar percentages of silica and alkalies occur in the subrang amiatose; but the high ratio of soda to potash indicates an affinity to yellowstonose.

Lamprophyric inclusions.—The dark, sharply bounded inclusions that characterize the granodiorite of the Philipsburg batholith, especially in the neighborhood of contacts, consist of the same minerals as the parent rock but are of finer texture and in part obscurely porphyritic. Hornblende, biotite, titanite, magnetite, and apatite are more abundant and orthoclase and quartz are less abundant than in the granodiorite. The strongly zoned and mottled crystals of plagioclase are more calcic than those of the normal rock, some of their centers containing bytownite near An_{80}.

Variations.—Independently of conspicuous differences in composition, the granodiorite varies in texture. The orthoclase is in places poikilitic; elsewhere the plagioclase, or both plagioclase and orthoclase, is obscurely porphyritic. The most noteworthy unevenness of composition consists in the less siliceous character which the rock usually though not invariably assumes near contacts. Here, as a rule, the granodiorite grades into a quartz diorite containing larger and more perfect crystals of hornblende, a somewhat more calcic plagioclase, and less orthoclase. Rock of this type, which occurs on the divide between Fred Burr Creek and Summer Gulch, is apparently transitional to a more basic diorite found in Summer Gulch.

DIORITE OF SUMMER GULCH.

The diorite of Summer Gulch differs from the normal granodiorite, and in the same way as the quartz-mica diorites above described, but in greater degree. It resembles somewhat the diorite of Foster Creek. Its dominant phase is a very dark gray, medium fine grained rock, in which plagioclase, hornblende, and biotite are conspicuous. The small grains of ferromagnesian minerals here and there are clustered, producing an obscurely dappled appearance.

Under the microscope its mineral constitution is found to be plagioclase, quartz, hornblende, biotite, orthoclase, magnetite, apatite, titanite, zircon, and allanite. The plagioclase is stongly mottled and zoned; ragged cores of calcic bytownite near An_{85} are enveloped in shells ranging from labradorite to calcic oligoclase.

A still more basic phase is characterized by a porphyritic development of hornblende in crystals that attain a length of about 1 centimeter.

The minerals detected microscopically are the same as those in the rock just described but include also scapolite, which may be original. The plagioclase crystals have sharply defined cores of anorthite (near An_{95}) and rims of andesine (An_{50} to An_{30}).

INTRUSIVE GRANITOID ROCK IN OLSON GULCH.

Occurrence.—In the lower part of Olson Gulch there is about 1½ square miles of granitoid rock that bears some resemblance to that of the Philipsburg batholith but contains very little hornblende. It is poorly exposed and its relation to the adjacent sediments is not evident. No metamorphic effect assignable with certainty to this body, unless it be the deposit of iron ore that lies west of the gulch, can be disentangled from the general metamorphism that appears in all the sedimentary rocks in this part of the quadrangle. However, the form of the eastern boundary of the granodiorite suggests an intrusive relation to the adjoining rocks, evidence of any other relation is lacking, and there is no reason to doubt that the contacts of the mass are chiefly irruptive.

Petrography.—This rock is very uniform. A typical specimen shows a brownish-gray tint and a rather fine granitic texture; its visible constituents are feldspar, biotite, quartz, and hornblende. The greater part of the feldspar is a dull greenish-white subhedral plagioclase, readily distinguished from the flesh-colored poikilitic potash feldspar. Quartz is inconspicuous; biotite is rather plentiful, but hornblende is so scarce that it is not readily found.

The relative abundance of the minerals, as shown by the microscope, may be roughly indicated as follows: Plagioclase, quartz, orthoclase, biotite, hornblende, magnetite, apatite, titanite, zircon, tourmaline, and rutile. The plagioclase is built up of zones that range from labradorite-bytownite to oligoclase. Texturally the rock, like that at Cable, is characterized by more or less perfect crystals of plagioclase and ferromagnesian constituents bound together by comparatively large allotriomorphic grains of quartz and orthoclase.

SMALLER INTRUSIONS.

Two small stocks of porphyry east of Red Hill, north of Philipsburg, and some dikes between Willow Creek and Henderson Mountain have been mapped as granodiorite, but they are all so much decomposed that their composition could not be determined satisfactorily. Those near Philipsburg have a contact zone of garnet rock. The dikes in the northwest part of the quadrangle are small but are regarded as worthy of mapping because they are almost the only igneous rocks in a large area; many similar dikes that occur in areas where other igneous rocks are abundant are unmapped. Small areas of granodiorite occur on Boulder Creek, in Henderson Gulch, along Willow Creek and Sluice Gluch, near the western edge of the quadrangle, and southeast of Rumsey Mountain. The character of these rocks may be sufficiently indicated by comparing them with the granodiorites already described.

The mass on Boulder Creek, probably a mere outlier of the Philipsburg batholith, is intrusive in Devonian and Carboniferous limestones. It consists of a dark-gray granular rock, finer grained and richer in hornblende, magnetite, and titanite than the granodiorite of the Philipsburg batholith.

The small mass on Willow Creek, which is intrusive in the pre-Cambrian, resembles the granodiorite of Storm Lake. The rock contains less quartz and orthoclase than that of the Philipsburg batholith and a little augite.

The very small mass intrusive in the Newland formation southeast of Rumsey Mountain consists of a dark-gray rock like the granodiorite of the Philipsburg batholith but finer grained, poorer in hornblende and orthoclase and richer in biotite.

The igneous rock in Henderson Gulch is poorly exposed, but strong metamorphism near its contact shows that it is intrusive in the Newland formation. The contact zone is characterized by abundance of garnet and epidote. The metamorphism extends over a remarkably wide area, and the metamorphic shell has probably protected from denudation an intrusive mass of far greater extent than the surface exposure. The rock is porphyritic, but the coarsest part of it appears granular because the groundmass is relatively coarse. The largest phenocrysts are of flesh-colored potash feldspar, some of which are as much as 1.5 centimeters long. There are many smaller phenocrysts of plagioclase, quartz, and biotite, and a few of potash feldspar.

NONPORPHYRITIC BIOTITE GRANITES.

VARIETIES.

The rocks mapped as nonporphyritic biotite granite include three varieties. These are readily distinguishable with the aid of a microscope, but megascopically two of them, which occur near Lost Creek and in the Anaconda Range, respectively, are very similar, and the third variety, the principal exposure of which is in the northeast part of the quadrangle, might not easily be distinguished from these by an untrained observer. On the map all of these rocks are represented by one pattern, but are distinguished by numbers following the general letter symbol.

THE ROYAL BATHOLITH OR LACCOLITH.

General character and occurrence.—A rock of granitoid texture composed chiefly of quartz, plagioclase, potash feldspar, and biotite forms a large intrusive mass that occupies the region about the headwaters of Rock, South Gold, and Pikes Peak creeks, in the northeastern part of the quadrangle and extends outside the quadrangle. It is named for the Royal mine, of which it forms the country rock. A small mass of rock of the same type lies at the head of Boulder Creek, adjacent to the Philipsburg batholith. Its boundaries as shown on the map are only approximate.

The general appearance of the rock in the field is somewhat similar to that of the granodiorite of the Philipsburg batholith, but it is lighter in tone. It is darker than the adjacent porphyritic granite, but, unlike the biotite granite of the Anaconda Range, it nowhere has a tawny hue. The mass is on the whole very uniform in composition but near the margins it is rather more biotitic and has a slight schistosity parallel to the contact.

About most of its periphery the mass is in irruptive contact with sedimentary rocks, the most striking evidence of this relation being the metamorphism produced in the sediments. Although the latest beds in actual contact with the granite are Lower Cretaceous, the metamorphism strongly affects the Upper Cretaceous beds north of Rose Mountain, nearly a mile from the contact.

The upper surface of the intrusive mass slopes in general away from the center, and, more markedly than in any similar mass in the quadrangle, the contact tends to follow the bedding of the adjacent sedimentary rocks. The comparatively thin Quadrant formation is in contact with the granite throughout the greater part of the periphery of the granite. It is therefore possible that the mass, instead of being a batholith extending downward indefinitely, as shown in structure section B–B, is a laccolith — a blister-shaped body injected between the strata and having a floor composed of the beds that lie stratigraphically just beneath the Quadrant formation.

In Rock Creek basin this granite is apparently intruded by the porphyritic muscovite-biotite granite. Contact phenomena proving this relation have not been observed, but the porphyritic granite is not gneissoid, whereas that of the Royal batholith is greatly sheared outside the quadrangle on the east.

Petrography.—The petrographic character of the dominant phase of the granite of the Royal batholith is well illustrated by material gathered from the dump of the Royal mine. The general color of this rock is very light gray. Feldspar constitutes much more than half of its bulk; the mineral next most abundant is quartz; and the remaining essential constituent, very subordinate in quantity, is black mica, which forms rather small irregular foils. A few particles of white mica and of titanite are visible but not conspicuous. The feldspar is of two kinds, distinct in habit. One kind forms many individuals, rarely more than 2 or 3 millimeters in length, which are striated and are therefore plagioclase. The other kind, which shows no striations and is therefore potash feldspar, occurs in much larger individuals. Those which are about a centimeter or less in length possess rude crystal form. The larger ones are more irregular in form and are so thickly crowded with grains of all the other constituents that their crystalline continuity is shown only by the reflections that flash from their cleavage planes when the specimen is turned about in a bright light. The largest crystal observed was a Carlsbad twin about 5 centimeters (2 inches) long.

The original minerals visible under the microscope are plagioclase, quartz, potash feldspar, biotite, muscovite, apatite, magnetite, zircon, titanite, and allanite. The order of crystallization is, roughly, zircon, magnetite, apatite, magnetite, muscovite, plagioclase, biotite, potash feldspar, and quartz. The feldspar is fairly fresh, the biotite considerably chloritized. The plagioclase is conspicuously zoned. The most calcic portions of the crystals are near andesine-labradorite (An_{50}); the most sodic are oligoclase. The average composition is estimated optically as An_{40}. Some of the potash feldspar shows microcline twinning and is perthitically intergrown with a small amount of albite.

This rock was analyzed chemically by George Steiger, with the following result:

Analyses of biotite granite from Royal mine.

	Per cent.	Molecular proportions.
SiO_2	68.40	1.140
Al_2O_3	16.34	.160
Fe_2O_3	.17	.001
FeO	1.56	.022
MgO	.64	.016
CaO	3.77	.067
Na_2O	3.39	.055
K_2O	3.91	.041
H_2O-	.29	
H_2O+	.55	
TiO_2	.29	.004
ZrO_2	None.	
CO_2	None.	
P_2O_5	.22	.002
MnO	.07	.001
BaO	.15	.001
SrO		
S	None.	
SO_3	None.	
	99.80	

To classify the rock in the quantitative system, the norm was calculated and found to be as follows: Quartz, 24.7; orthoclase, 22.8; albite, 28.8; anorthite, 16.7; corundum, 0.1; hypersthene, 3.8; ilmenite, 0.6; magnetite, 0.2;

apatite, 2.4. The rock is amiatose, near toscanose, which is more alkalic. Of the varieties of amiatose tabulated by Washington, the two that most resemble the granite of the Royal mine are a granodiorite from Silver Lake House, Eldorado County, Cal., and a biotite granite from the North Fork of Tuolumne River, Cal. The varieties of amiatose from Butte contain much more iron and magnesia.

The marginal parts of the batholith are more or less distinctly gneissoid and in places are obscurely porphyritic. They are somewhat richer in biotite than the rock in the main body of the batholith, and their plagioclase is commonly more calcic than that in the specimen from the Royal mine. The unstriated feldspar is less conspicuous than in the dominant phase. Microscopically, the minerals show less evidence of deformation than might be expected from their megascopic appearance, and the foliation is probably primary.

Intense foliation independent of contacts is developed in this granite east of the limits of the quadrangle along a north-south shear zone, which affects various other intrusives in the vicinity of Danielsville. On Rock Creek about 2 miles beyond the boundary of the quadrangle the granite has been changed to a readily cleavable gneiss, in which the biotite forms discontinuous films along the cleavage faces. Some of the larger crystals of feldspar have been rounded off to form thick lenses or "eyes," whose longer diameters lie parallel to the planes of schistosity.

MINOR INTRUSIONS.

Small masses of granitoid rocks more like that of the Royal batholith than that of any other large intrusion occur on Foster Creek, Warm Spring Creek, and north of the quarries on Warm Spring Creek. All except a hornblende-bearing variant of the largest mass, contain the same minerals as the Royal batholith, but the several masses are markedly different in texture.

Granite of Foster Creek.—The most extensive of these minor intrusions occupies an area of about 2 square miles on Foster Creek and several smaller areas. Its apophyses cut diorite and Devonian and Carboniferous limestone.

The rock in most of this area is a light-gray medium-grained biotite granite resembling that of the Royal batholith in texture, color, and constitution but characterized by the development of biotite in very thin and broad ragged flakes, appearing in cross section as sharp black lines.

The microscope shows that the essential constituents of the rock are perthitic microcline, quartz, plagioclase, biotite, muscovite, magnetite, apatite, zircon, and titanite. Alkali feldspar is more abundant than in the granite of the Royal mine. The plagioclase is strikingly zoned, with cores of andesine, labradorite, or even sodic bytownite, shading into rims of oligoclase and albite. Magnetite and apatite are rather abundant.

In the northeastern part of the area, this rock apparently grades into rocks that are considerably richer in biotite and contain hornblende. Microcline bears about the same proportion to plagioclase as in the rock previously described. The plagioclase is more calcic than in that rock.

Granite porphyry on upper Warm Spring Creek.—Warm Spring Creek, northeast of Cable, crosses a rock mass that cuts the Madison limestone, the contact in part lying parallel to the bedding. It forms a talus on the east side of Warm Spring Creek canyon but occurs in no prominent outcrops.

The mass is fairly uniform; a typical specimen is light brownish-gray, has a fine, apparently granular texture, consists chiefly of feldspar and quartz, and contains a sprinkling of biotite.

The microscope shows the texture to be in reality porphyritic, although the groundmass is coarse by comparison with the size of the phenocrysts, which are of plagioclase, quartz, and mica, the mica being chiefly biotite but including some intergrown muscovite. In the groundmass, besides a second generation of these same minerals, there is considerable microcline. The plagioclase crystals are built up of distinct zones, which range in composition from about An_{40} to about An_{15}.

Microgranite north of lower Warm Spring Creek.—About 1¼ miles nearly due north of bench mark 5605, on lower Warm Spring Creek, there is a very small area of fine-grained granite, which is intrusive in Cambrian strata, and others, considered too small to map, lie in the same vicinity. A similar rock, also unmapped, forms a dike in coarser granites at the head of Clear Creek.

The rock is a "pepper and salt" gray and has a texture like that of typical granite but finer. The minerals visible to the naked eye are feldspar, quartz, and biotite.

The microscope shows that the chief constituents of the rock are plagioclase, quartz, potash feldspar, and greenish biotite. It contains a little muscovite. Magnetite, apatite, titanite, zircon, and allanite occur as rather abundant accessories, and tourmaline occurs sporadically. There is some apparently secondary epidote, and a little chlorite, sericite, etc., but the rock is comparatively fresh. There is some epidote with allanite cores, which appears to be primary. The plagioclase is zoned, with a range from An_{20} to An_{50}.

Aplite north of lower Warm Spring Creek.—About a mile north of the great lime quarry on Warm Spring Creek a small mass of fine-grained rock is intruded into Madison limestone. The rock resembles in general tint that just described but is of finer, more sugary texture and is dappled with ill-defined greenish clusters of mica about 5 millimeters in diameter. It contains sparsely scattered small flakes of biotite and muscovite. The microscope shows that the rock is similar in mineral constitution to the granite porphyry farther up the creek.

NONPORPHYRITIC BIOTITE GRANITE NEAR MILL CREEK.

General character and occurrence.—Near the southeast corner of the quadrangle, between Tenmile and Mill creeks, is a large area of rather coarsely granular rock consisting essentially of quartz, oligoclase, potash feldspar, and biotite. This biotite granite is well exposed on the precipitous glaciated walls of the canyons of Mill Creek and Clear Creek, but on gentle slopes it is covered with a mantle of coarse sand and partly disintegrated fragments. Although light gray when fresh, it is discolored by weathering to a pale tawny hue, which, in the exposures along Mill Creek, for example, contrasts with the darker, vaguely greenish tint of the granodiorite.

Relations.—This granite is not in irruptive contact with any sedimentary rock unless it be the mass of quartzite north of Mill Creek, which is assigned only tentatively to the Flathead quartzite, and whose contact with the granite is not well exposed. The contact with the Madison limestone south of Mill Creek is due to a fault. The force that produced this rupture has also sheared the granite, which on Mill Creek, near the east boundary of the quadrangle, is transformed to a dark gneiss that splits into thin, smooth plates.

The igneous rocks with which the biotite granite is in contact are the acidic granodiorite, porphyritic biotite granite, and nonporphyritic muscovite-biotite granite. The granodiorite has intruded this granite and is clearly later. Direct evidence as to the relative age of the porphyritic and nonporphyritic biotite granites was not obtained, but as the porphyritic granite is later than the granodiorite it must be later than the nonporphyritic biotite granite. The relative ages of this rock and the nonporphyritic muscovite-biotite granite on the north was not determined.

Petrography.—The general tone of the freshest specimens of this granite is a light warm gray, resulting from the blended tints of the cream-white feldspar, the slightly brownish quartz, and the small quantity of black biotite. The quartz occurs in very irregular ill-defined masses about 3 millimeters in average diameter. The feldspar forms some fairly well developed crystals about 1 centimeter long, but most of it is in grains not over 2 or 3 millimeters across. The large crystals, which the microscope shows to be of microcline, are sporadic, irregularly distributed, and not conspicuous enough to make the rock porphyritic.

The microscope shows that the feldspar comprises nearly equal amounts of perthitic microcline and oligoclase. Quartz is about equal to each of these in amount, brown biotite is subordinate, and magnetite, apatite, and zircon are accessory. There is a minute quantity of muscovite, apparently original. The perthitic intergrowth, in contrast to that in the alkaline granite of Lost Creek, contains albite in very subordinate proportion. The plagioclase is but faintly zoned; its average composition is near An_{20}.

ALKALINE BIOTITE GRANITE NEAR LOST CREEK.

General character and occurrence.—The granite that occupies several square miles on lower Lost Creek and the hills farther south, near the east edge of the quadrangle, is composed chiefly of orthoclase, albite, quartz, and biotite, and contains fluorite. The presence of fluorite and the character of the feldspar differentiate the rock from the nonporphyritic biotite granite of the Anaconda Range, but these distinctive features are recognizable only by the aid of the microscope, the two rocks being very similar in megascopic appearance.

The most accessible outcrops of this granite are barren weathered knobs that rise 10 to 50 feet above a waste-covered surface on the slopes north of Warm Spring Creek near the eastern border of the quadrangle. They are too small to be mapped. Better exposures occur in Lost Creek canyon. Here the rock appears whitish in places where it is least weathered, but it is nearly all stained dull yellow or orange with iron oxide. The relatively fresh granite exposed on the steep glaciated canyon walls shows few joints, but the more weathered granite above is much jointed. In both places a large proportion of the joints are curved nearly parallel to the surface, and are apparently due to exfoliation. The sheeting is evidently of the same origin.

Relations.—The intrusive relation of this granite to the Newland formation is notably displayed on the north wall of Lost Creek canyon. The westward-dipping surface of the intrusive mass there cuts across the bedding at an acute angle. Dikes of the granite or of pegmatite penetrate both the Newland formation and the diabase by which it is intruded. On the hill south of Lost Creek the Algonkian rocks are cut by many dikes of tourmaline-bearing aplite and pegmatite that are probably related to biotite granite. The contact of this granite with Carboniferous rocks on the slope north of Warm Spring Creek is probably due to faulting.

Petrography.—The tint of the fresh rock is very light warm gray, and its texture is granitic and moderately coarse to rather fine. The constituents visible to the naked eye are feldspar, quartz, and biotite. The quartz has a smoky tint and presents a sharp contrast to the dull cream-white of the feldspar, which is about twice as abundant. Biotite is rather scarce. A very faint greenish tint observed in places may be due to the fluorite, which, however, is not conspicuous.

The microscope shows that the feldspar consists of microcline and nearly pure albite. These form comparatively coarse perthitic intergrowths, which contain nearly equal amounts of the two varieties; and albite, which is in excess, occurs also in separate crystals. Quartz is about equal to microcline in amount; greenish biotite and fluorite are distinctly subordinate; magnetite, apatite, zircon, and rutile are scarce accessories. The biotite is bordered partly by colorless mica in parallel intergrowth, but not altered to chlorite or epidote. In all specimens fluorite forms irregular grains less than 1 millimeter in diameter between the feldspars or inclosed within them. There is no evidence that it is secondary.

The pegmatite and aplite are composed chiefly of quartz, white microcline, subordinate muscovite and albite, and conspicuous black prisms of tourmaline. These rocks grade into others composed essentially of quartz and tourmaline, with little or no feldspar.

NONPORPHYRITIC MUSCOVITE-BIOTITE GRANITE.

General character and occurrence.—Granite in which muscovite as well as biotite is essential, and which contains no large and prominent feldspar crystals, is one of the chief rocks in the eastern part of the Anaconda Range, where it occupies several areas aligned from northeast to southwest. One area lies south of Mount Howe; one is at the head of Twelvemile Creek; another, divided on the surface by moraines, is at the head of Mill Creek; and still another, the largest, lies northeast of Mount Haggin. The general tint of the granite, as seen in the field, is very like that of the biotite granite, though it is somewhat lighter and less yellowish. Much pegmatite and aplite is associated with this granite, particularly near its margins.

Relations.—This granite is clearly intrusive into Algonkian strata in all the areas but the largest. Even in this area it is in contact with Devonian and Mississippian limestones, and the contacts are probably intrusive, though not definitely proved to be so.

The intrusive rocks with which this nonporphyritic muscovite-biotite granite is in contact are acidic granodiorite of the Carp Lake type, nonporphyritic biotite granite, porphyritic muscovite-biotite granite, and diorite. If all the masses of this granite were intruded contemporaneously they are older than any of the other rocks named except the diorite and, possibly, the biotite granite, to which their relation in age was not determined. The relation to the diorite is strikingly shown on the north face of Mount Haggin, where the dark rock of the summit is cut by white dikes of the granite and related pegmatite. The granite is itself cut by apophyses of acidic granodiorite northeast of Mount Haggin and south of Mount Howe, and at its contact with the porphyritic muscovite-biotite granite, near the head of Twelvemile Creek, the nonporphyritic granite is uniform in composition and texture, but the porphyritic granite varies in respect to these features, as intrusives commonly do at their contact with older rocks.

Petrography.—Material from the talus south of Hearst Lake is very light gray and has a rather coarse granitic texture. Feldspar constitutes nearly two-thirds of the rock, quartz the greater part of the remainder; the other minerals visible to the naked eye are muscovite and biotite in small and nearly equal quantity. The potash and soda-lime feldspars alike are almost pure white. The largest crystals, about 1 centimeter long, are of unstriated feldspar, but as the size dwindles from this by gradations the aspect of the granite becomes less porphyritic. The quartz is grayish, not smoky as in much of the biotite granite. Of the micas, muscovite forms the larger and more conspicuous flakes, some being as much as 5 millimeters in diameter.

The microscope shows that the feldspar consists of perthitic microcline and plagioclase in nearly equal amount, the alkali feldspar possibly in slight excess. The soda-lime feldspar is rather faintly zoned oligoclase and its range of composition is approximately from An_{20} to An_{10}, the estimated average composition being An_{15}. Accessory constituents are magnetite, zircon, and little apatite. The effect of dynamic stress appears in the curved and broken twin lamellæ of the plagioclase and in marked bending of the flakes of mica.

Material from areas south of Mount Howe is slightly less siliceous. It contains a little more biotite; the thin section shows perceptibly less alkali feldspar than plagioclase, and the plagioclase is more calcic, averaging about An_{20} or An_{25}. The mass at the head of Twelvemile Creek is of similar composition but is still finer in texture.

ACIDIC GRANODIORITE.

General character and occurrence.—In the Anaconda Range there are several bodies of a granitoid rock which is composed chiefly of plagioclase, quartz, orthoclase, and biotite but contains in places a little hornblende. The quartz is abundant and the orthoclase is very subordinate to the plagioclase. Unlike the other granular rocks of this district, this rock fingers out into many large dikes, which are of porphyritic texture. The areas of this granodiorite all fall within a relatively narrow zone extending east-northeast from the southwest corner of the quadrangle to the head of Clear Creek.

The fresh rock is light gray but not so light as the more potassic granites with which it is associated. In the area southeast of the Carp mine its contact with the porphyritic biotite granite can be recognized at a distance because the granodiorite is darker, more thoroughly jointed, and rusty on the weathered surface. This rustiness is not so marked elsewhere and may be due to a local secondary development of pyrite.

In the easternmost area intense shearing has developed abundant chlorite, which makes the rock darker and more greenish than where it is unaltered, and on the precipitous walls of Mill Creek canyon it can readily be distinguished at a distance from the lighter, more tawny-hued granites on either side. Another effect of the stresses that the rock has undergone has been the formation of shear zones along which erosion is relatively easy. To this cause is due the highly serrate character of part of the divide between Mill and Tenmile creeks, illustrated in Plate I.

The apophysal dikes of granodiorite porphyry are most abundant and conspicuous about Mounts Howe and Evans. Their light-gray tint stands in strong contrast with the dark rusty red of the Prichard formation (see Pl. II), and the dikes are readily traced on rocky slopes, but they are concealed in places by talus or by rock waste. On the other hand, the porphyry dikes at the head of Barker Creek and those east of Mount Haggin are darker than the rocks that they penetrate.

Relations.—The intrusive relation of this granodiorite to the adjacent sediments is clear. Its apophyses penetrate Algonkian and Cambrian rocks. The contact with the Newland formation near the peak 9,814 feet high is parallel to the bedding. Of the other intrusive rocks the two nonporphyritic granites east of Mount Haggin and the diorite north of Mount Howe are older than this granodiorite and are cut by its apophyses. The porphyritic biotite granite, on the other hand, is evidently later (see next column) as is probably also the porphyritic muscovite-biotite granite. The relations are not, indeed, clear at the contact of this rock with the acid granodiorite in the Anaconda Range, but in the Flint Creek Range, where both porphyritic granites are represented, the one with both micas is later than the one with biotite alone. So far, therefore, as the petrographic identity of the granites in the two ranges is evidence of their identity in age, it is evidence that the porphyritic muscovite granite is later than the siliceous granodiorite. The relation of the siliceous granodiorite to the granodiorite of Storm Lake at their contact is obscured by talus.

Petrography.—A representative specimen from a point about a mile south-southeast of peak "9814," in the west part of the Anaconda Range, is pure light gray, with typical granitic texture. The constituents recognizable with the naked eye are feldspar, quartz, biotite, hornblende, titanite, and secondary pyrite in scattered grains along obscure joint fissures. The dark minerals are present in relatively small quantity. Two varieties of feldspar can be distinguished. The more abundant variety, plagioclase, is somewhat the less transparent. The other variety, orthoclase, is the more glassy and occurs in larger individuals containing many inclusions. Quartz, obviously abundant, appears chiefly in irregular sugary grayish masses about 3 millimeters in diameter. Hornblende and biotite form evenly sprinkled particles, most of them less than 1 millimeter in diameter. A considerable portion of these constituents, however, is segregated into clusters approximately 5 millimeters in average diameter, about six of which appear on the face of an ordinary hand specimen. The granodiorite is further characterized by larger dark blotches whose presence constitutes one of the obvious differences between this rock and the contiguous granites. These blotches, the largest of which are about 6 inches in diameter and most of which are roundish or oval, are of the same nature as those in the other granodiorites and differ from the parent rock chiefly by finer texture and greater richness in ferromagnesian constituents.

The relative abundance of the chief constituents in the light-colored part of the rock, as determined microscopically, is nearly indicated by the order, plagioclase, quartz, orthoclase, biotite, and hornblende. Accessory constituents are titanite, apatite, zircon, allanite, and magnetite. The rock is fairly fresh. The plagioclase is rather strongly zoned and mottled; its composition ranges approximately from An_{40} to An_{10} and averages about An_{30}. The orthoclase is slightly perthitic.

The rock has been analyzed by George Steiger with the following result:

Analysis of siliceous granodiorite 1 mile south-southeast of peak "9814."

SiO_2	70.05
Al_2O_3	15.04
Fe_2O_3	.70
FeO	1.32
MgO	1.04
CaO	2.46
Na_2O	4.03
K_2O	3.33
H_2O-	.70
H_2O+	1.12
TiO_2	.36
ZrO_2	.02
P_2O_5	.08
MnO	.03
BaO	.10
Li_2O	.05
	100.43

No SO_3, S, or CO_2 found.

The norm calculated to fix the place of the rock in the quantitative classification is as follows: Quartz, 26.64; orthoclase, 19.46; albite, 34.06; anorthite, 12.23; corundum, 0.41; hypersthene, 3.79; ilmenite, 0.76; magnetite, 0.93; apatite, 0.34. The rock is lassenose, near toscanose, which is more alkalic.

Variations.—Some of the rock mapped with that described is perceptibly more basic and much is somewhat less so. The specimens from the Mount Howe area and those taken farther east contain little or no hornblende, and have a slightly more sodic plagioclase and more potash feldspar than the analyzed rock. These differences might seem to justify a distinction in the mapping, but they become manifest only by careful comparison of specimens, aided by microscopic study. In the field one is rather struck by the resemblances in tone, in the habit of the feldspars, and in the characteristic segregations of the ferromagnesian constituents.

Granodiorite porphyry of apophyses.—A typical specimen of the granodiorite porphyry collected on the west slope of Mount Howe appears very similar to the granular phase, though it is slightly darker. The porphyritic texture is obscure because the gray microcrystalline groundmass is not much different in tone from the largest and most abundant phenocrysts, which consist of plagioclase (andesine and oligoclase). There are many smaller phenocrysts of quartz and biotite, and some of hornblende. The ferromagnesian constituents cluster as they do in the granular rock. Some of the dikes are free from hornblende, some of them contain orthoclase phenocrysts, and others contain a little augite.

The groundmass consists of abundant quartz and potash feldspar, subordinate plagioclase, and a little biotite.

PORPHYRITIC BIOTITE GRANITE.

General character and occurrence. — Porphyritic biotite granite, containing large phenocrysts of microcline in a coarse granular groundmass of quartz, plagioclase, microcline, and biotite, occurs in both the Anaconda and the Flint Creek ranges.

In the Anaconda Range, where it is one of the most abundant rocks, it occupies a zone lying south of the granodiorite and extending about east-northeast from Carp Lake to Clear Creek. In the Flint Creek Range it is confined to comparatively small areas on Racetrack Creek, near the point where that stream leaves the quadrangle.

Viewed from a distance, the porphyritic biotite granite, like the nonporphyritic, appears light gray to tawny. In areas north of Mill Creek it has been somewhat sheared, and owing to the consequent disguise of its characteristic features, it is difficult to draw its boundaries accurately. In part of the Racetrack Creek area it has been rendered very schistose by dynamic action.

Relations.—In the Flint Creek Range the rock is intrusive into Cambrian and Algonkian strata and the siliceous diorite and is cut by the muscovite-biotite porphyritic granite. In the Anaconda Range it cuts the Algonkian and is later than any other granular intrusive except the muscovite-biotite porphyritic granite.

Its relative age in the Anaconda Range is fixed by its relation to the granodiorite of the Carp Lake type. This relation is clearly shown about 2½ miles east of Carp Lake, where two apophyses from the granite cut the granodiorite, as represented somewhat diagrammatically on the geologic map. In Mill Creek canyon, again, the greater age of the granodiorite is shown by the fact that at the contact this rock is normal and uniform, whereas the biotite granite is variable, being partly pegmatitic and partly more biotitic than the normal type. The contact with the muscovite-biotite porphyritic granite on Tenmile Creek is not well exposed, and the relation between the two rocks is obscure.

The relations in the Flint Creek Range are clear. Contacts with diorite are shown south of Racetrack Creek, where the diorite is uniform and the granite varies in texture and in abundance of feldspar phenocrysts and biotite. It is older than the muscovite-biotite granite, as is shown by similar evidence and by the fact that that rock is not schistose.

Petrography.—The porphyritic biotite granite in the Anaconda Range and that in the Flint Creek Range are sensibly identical in character. The general tint is pinkish gray. The phenocrysts, which constitute about half the bulk of the rock are most prominent on weathered surfaces. They are rarely more than 2 centimeters and average about 1 centimeter in diameter. They contain small inclusions, which are especially abundant near their margins. A small proportion are Carlsbad twins. The matrix of the phenocrysts has the texture of rather coarse granite and its visible constituents are quartz, feldspar, and biotite. The quartz, which constitutes about half the groundmass, forms irregular patches about 3 millimeters in diameter. It has a smoky hue, contrasting with the whitish tint of the feldspar. Biotite is rather abundant in irregular flakes about 1 or 2 millimeters in diameter.

The microscope shows that the phenocrysts are perthitic microcline. This alkalic feldspar occurs in the groundmass as irregular grains in amount inferior to that of the soda-lime feldspar. The plagioclase, unlike that of the nonporphyritic biotite granite, is characterized by rather marked zonal banding. The range of composition in successive zones is sometimes as wide as from andesine near An_{40} to oligoclase-albite (An_{10}); the average composition is probably that of a calcic oligoclase (An_{20} to An_{30}). Accessory constituents are muscovite, magnetite, apatite, titanite, zircon, rutile, and relatively abundant allanite.

The porphyritic biotite granite on Racetrack Creek has been converted by shearing into an augen gneiss, which is of a darker, more bluish gray, than the unsheared rock, the feldspar being pure white and the quartz not smoky. The lines of schistosity curve about the phenocrysts, which have been affected but little by crushing. Much of the feldspar and quartz in the groundmass has been finely crushed, the large masses of quartz have been drawn out into lenses, and the distribution of the biotite has become streaky.

Pegmatite and aplite cutting this granite are well exposed near the head of Sullivan Creek. The aplite is the more abundant. It is cut by pegmatite veins and also passes by gradations to fairly coarse pegmatite and to the normal granite. The essential constituents of the typical aplite and pegmatite are perthitic microcline, albite, quartz, and muscovite; a little red garnet occurs in small crystals.

PORPHYRITIC MUSCOVITE-BIOTITE GRANITE.

Character and distribution.—In both the Flint Creek and Anaconda ranges there are bodies of granite containing large porphyritic crystals of alkali feldspar in a coarse groundmass containing both muscovite and biotite. The largest mass of this porphyritic muscovite-biotite granite overlaps the eastern border of the quadrangle and extends from Lost Creek to Rock Creek. It embraces the top of Mount Powell, a lofty peak a short distance east of the quadrangle, and may be called the Mount Powell batholith. In the Anaconda Range a considerably smaller mass, which may be called the Twelvemile batholith, is exposed about the heads of Twelvemile and Tenmile creeks.

Relations.—The Twelvemile batholith cuts the Prichard and Neihart formations, an irregular irruptive contact with the former being well exposed at the head of Tenmile Creek. The Mount Powell batholith has been observed in contact with strata of pre-Cambrian to early Cretaceous age. It sends apophyses into Cretaceous rocks east of Twin Peaks. The contact metamorphism produced by this intrusion is everywhere very marked, but most striking, perhaps, in the Cambrian rocks south of Thornton Creek.

The relation of the porphyritic muscovite-biotite granite to other intrusives in the Anaconda Range has not been directly determined except with respect to the nonporphyritic muscovite-biotite granite. At the head of Tenmile Creek a good exposure shows that the porphyritic granite is the later; its porphyritic texture disappears about 3 feet from the contact, still closer to which it becomes finer grained and grades into aplite. The other rock shows no variation related to the contact.

In the Flint Creek Range, the porphyritic muscovite-biotite granite is later than the other granitoid rocks whose relation to it is known. Its exemption from the shearing that affected the rock of the Royal batholith and the porphyritic biotite granite indicates that it is later than either. More direct evidence of its relation to the biotite granite is seen at the contact north of Racetrack Creek, where that rock is uniform and the muscovite-biotite granite is variable in texture and composition. The schistosity of the diorite south of Racetrack Creek proves its greater age, and it is also cut by the aplite and pegmatite of the muscovite-biotite granite south of Thornton Creek. The contact with the granite intrusive south of Lost Creek is ill-exposed and the relative ages of the two rocks are not known.

Petrography.—The porphyritic muscovite-biotite granite of the Anaconda Range is essentially identical in character with that of the Flint Creek Range. The tint of the prevailing rock in mass is very light pure gray. At least a fourth of its volume consists of snow-white feldspar phenocrysts about an inch long—distinctly larger on the average than those of the biotite granite—embedded in a rather coarse grained granitic groundmass. About half of this groundmass consists of white feldspar in grains less than 0.5 centimeter in diameter, some of which are visibly striated; the remainder is chiefly grayish quartz in irregular masses but comprises moderate and nearly equal amounts of muscovite and biotite.

The microscope shows that the phenocrysts are perthitic microcline containing numerous inclusions of plagioclase and some (chiefly near the margin) of quartz and biotite. In the groundmass quartz and plagioclase are more abundant than microcline and orthoclase. The plagioclase is slightly zoned. Its range of composition is approximately from An_{25} to An_{10}, the average about An_{15} or An_{20}. Accessories are magnetite, apatite, and zircon.

The following determinations of the silica and alkalies in a fairly fresh specimen from the Anaconda Range were made by W. T. Schaller:

Partial analysis of porphyritic granite 1 mile southeast of Mount Evans.

SiO_2	72.50
Na_2O	3.97
K_2O	4.06

These percentages are similar to those in the granite of the Bitterroot Mountains, described by Lindgren. In that rock they are 72.07, 4.02, and 4.09 respectively. According to the quantitative classification the rock from the Anaconda Range would probably be a toscanose.

The variations from this type are chiefly textural. The phenocrysts are commonly larger than in the normal type described, the largest having a length of 3 inches. Their abundance also varies; at some places they are crowded closely together; at others they are so scarce that the porphyritic texture is not conspicuous. The rock is notably even grained in the western part of the Mount Powell batholith north of Racetrack Creek, where it is possible that a separate intrusion of nonporphyritic granite occurs, but if so its areal extent is relatively small. The porphyritic texture is commonly lacking for a few inches or even a few feet from contacts with older rocks

The chief constituents of the pegmatites and aplites associated with this granite are quartz, microcline, and albite, which are accompanied in all places by considerable muscovite, and in some by red garnet, and here and there by a little biotite.

PYROXENE APLITE.

Occurrence and distribution.—The most unusual intrusives in the Philipsburg quadrangle are fine-textured greenish-gray aplitic rocks whose chief constituents are plagioclase, alkali feldspar, quartz, and diopsidic pyroxene. Some contain also primary scapolite, which rarely occurs in igneous rocks.

These pyroxene aplites bear much the same relation to the granodiorites that the ordinary aplites and pegmatites, which are composed essentially of alkali feldspar, quartz, and mica, bear to the granites. They occur like ordinary aplites, forming dikes or small stocklike intrusions and being irregularly mingled with basic material in marginal zones. In one significant respect, however, their occurrence differs from that of the ordinary aplites; they have not been found in the central parts of batholiths but invariably, so far as observed, near contacts with calcareous sediments.

The pyroxene aplite has not been mapped except as parts of the granodiorite masses. One of the most accessible intrusive masses is a small dike in the granodiorite near the contact with Madison limestone south of the Bimetallic mill, near Philipsburg. A large dikelike mass is finely exposed on the lower part of Granite Creek east of Princeton. Another comparatively large mass lies about 1½ miles northeast of Rumsey Mountain. A very small dike, about a foot thick and traced for about 50 feet, cuts Devonian limestone east of Foster Creek somewhat less than a mile north of the county boundary. A marginal intrusive mass lies at the base of the cliff below the dike just mentioned, where the granodiorite is separated from the limestone by a few feet of the pyroxene aplite into which it appears to grade. At the contact of the Cable batholith with calcareous shales and limestones pyroxene aplite and hornblendic rock are intricately mingled, and similar conditions occur in the marginal part of the Storm Lake batholith.

Petrography.—Although the pyroxene aplites exhibit considerable differences they have many features in common. In color they range from greenish white to dark greenish gray; in texture, from fine to moderately coarse. Plagioclase and alkali feldspar, commonly distinguished by difference of habit, are present in roughly equal quantity and constitute half of the rock or more. The other essential minerals constantly present are quartz and pyroxene, neither of which is conspicuous. The pyroxene is of a pale variety, and where it is not intergrown with hornblende its presence is manifested only by the greenish tinge it gives the rock. Amphibole occurs in nearly all specimens, and biotite in a few, and both minerals are relatively conspicuous because of their dark tone.

Accessories revealed by the microscope are titanite, apatite, magnetite, and zircon, titanite being almost abundant enough to rank as an essential constituent. The plagioclase crystals are strongly zoned and have cores as calcic as bytownite near An_{75}. The greater part of each crystal is commonly andesine near An_{40}, which is about the average composition. Most crystals have narrow, ragged borders of oligoclase-albite. The alkali feldspar forms much larger poikilitic individuals. In some specimens it is potassic, in others it is of a sodic variety which is described more fully below. The pyroxene is diopsidic; the amphibole, pale to moderately deep grass green, is partly but not wholly secondary. The general order of crystallization has been: Zircon and apatite, plagioclase, titanite and ferromagnesian minerals, quartz, and alkali feldspar.

The features worthy of further notice are the alkali feldspar and the occurrence of scapolite. The alkali feldspar of some of the aplites is orthoclase or microcline; some is but slightly perthitic, some rather markedly so. In about half the specimens, however, the feldspar is of a peculiar sodic variety. This feldspar resembles microcline in its interstitial relations to other minerals and the fine cross-hatching that appears in sections nearly normal to the *a* axis; but optical and chemical tests indicate that the feldspar is albite or anorthoclase very rich in soda. It has probably been formed by replacement of microcline.

Scapolite is most abundant in the pyroxene aplite of Foster Creek. This rock has the general features above described; the alkali feldspar is microcline; it contains some hornblende, partly secondary and partly primary, and quartz in moderate amount.

The scapolite is remarkably poikilitic. In the hand specimen the flashes from its cleavage faces show that it forms individuals as much as 2 centimeters across, crowded with inclusions. The microscope shows that it not only incloses all the other constituents but interpenetrates with all but quartz. The proportion of scapolite in the rock has been estimated at about 25 per cent. Its double refraction is about .020, which corresponds to a combination in which there are somewhat more of calcic than of sodic molecules.

Although the pyroxene and lime-rich feldspar are a little altered, the rock is on the whole more than ordinarily fresh. This fact, together with the textural relations and abundance of the scapolite, make it impossible to regard that mineral as other than primary.

Another pyroxene aplite containing scapolite occurs about a mile northeast of Rumsey Mountain. Here the scapolite is far less abundant than in the other rock, but its relation to the other minerals is really the same. It appears microscopically in lacelike patches intergrown with both soda-lime feldspar and alkali feldspar.

Chemical composition.—Specimens of these two types of scapolite-bearing rock have been analyzed by W. F. Hillebrand with the results shown below.

Analyses of scapolite-bearing pyroxene aplites.

	1	2
SiO_2	68.00	57.98
TiO_2	.43	.66
ZrO_2	.02	.04
Al_2O_3	16.33	19.32
Cr_2O_3	None.	None.
Fe_2O_3	.26	.44
FeO	.70	.83
MnO	.02	.07
CaO	5.90	8.87
SrO	.03	.05
BaO	.03	.12
MgO	1.41	1.93
K_2O	.38	4.01
Na_2O	6.20	3.62
Li_2O	None.	Faint trace.
H_2O-	.06	.57
H_2O+	.25	.67
P_2O_5	.22	.17
CO	None.	.53
S	.01	.01
Cl	.13	.17
F	^{a}.07	^{a}.07
	100.45	100.13
Less O for Cl and F	.06	.07
	100.39	100.06

^{a} Apparently high.

1. Pyroxene aplite with a little scapolite, from place about 1½ miles northeast of Rumsey Mountain.

2. Pyroxene aplite with much scapolite from dike on east wall of Foster Creek Canyon a mile north of boundary between Granite and Deer Lodge counties.

The norms, calculated in order to determine their position in the quantitative classification, serve to emphasize some of the chemical peculiarities of the rocks. They are as follows:

1. Pyroxene aplite northeast of Rumsey Mountain: Quartz, 19.98; orthoclase, 2.22; albite, 50.30; anorthite, 16.68; halite, 0.47; diopside, 7.75; hypersthene, 1.76; magnetite, 0.46; apatite, 0.67; ilmenite, 0.61; fluorite, 0.16. The rock is a madorose (I.4.3.5).

2. Pyroxene aplite east of Foster Creek. Quartz, 4.56; orthoclase, 23.91; albite, 27.77; anorthite, 25.85; halite, 0.59; diopside, 12.67; wollastonite, 1.39; magnetite, 0.70; ilmenite, 1.22; apatite, 0.34; fluorite, 0.11. The rock is a monzonose (II.5.2.3) not far from shoshonose, which is less alkalic.

The greatest chemical difference between the rocks is in the proportion of the alkalies. The aplite of Rumsey Mountain is very poor in potash, but it contains about twice as much soda as the other, the total molecular proportion of alkalies being nearly the same in the two specimens. This fact is one of those which indicates that the peculiar alkali feldspar of the rock of Rumsey Mountain was formed by substitution of soda for the potash of microcline. The most striking similarity of the two chemical analyses is great richness in lime opposed to comparative poverty in iron and magnesia. In both, also, chlorine is rather high.

Genesis.—The richness of the rock in lime is indicated by its abundant calcic plagioclase and diopside, the presence of which has perhaps been one of the conditions essential to the formation of scapolite, which may, however, have been determined by the retention of chlorine in the magma during solidification. That abundant chlorine was given forth by the Philipsburg and Cable intrusive rocks is shown by the abundance of scapolite in their contact zones. Although little or none of this gas was fixed in the granodiorites, considerable was retained in the aplites, owing to conditions that are not fully understood but among which abundance of lime should probably be counted. The abnormally large proportion of lime is ascribed to the absorption of limestone in siliceous alkaline magmas resembling those of normal aplites. The only other known occurrence of primary scapolite is in Canadian nepheline syenites, described by Adams, who believes them to have formed from a magma which had absorbed limestone.

VOLCANIC ROCKS.

GENERAL RELATIONS.

The volcanic rocks of the quadrangle consist of andesitic breccia and tuff, confined to the southeastern part of the area; andesitic lava, found chiefly in the northwestern part; and volcanic ash, found in the larger valleys of the western part. All these rocks are somewhat intimately associated with the Tertiary gravels and, like them, are separated from the pre-Tertiary sedimentary and intrusive rocks by a strong unconformity. Their precise age and their relations to each other are not clear. Evidence observed in and near the quadrangle indicates that the ash is later than the lava and the coarser pyroclastics. In its composition and its horizontal attitude the ash resembles the beds in the lower valley of Flint Creek identified by Douglass by their vertebrate fossils as Miocene, but the deposit in this quadrangle has yielded no fossils.

LAVA, BRECCIA, AND TUFF.

Areas near Rock and Willow creeks.—A pink andesitic lava occupies several small areas in the valley of Willow Creek near near the western boundary of the quadrangle. It lies in a depression, probably part of an old valley, in the Spokane formation. About half a mile south of Antelope Gulch two small masses of lava overlie the old gravel. Although these are so fine grained that their composition can not be determined well enough to establish their correlation with the masses farther north, they are probably of the same age, and if so, they indicate the relative age of the andesite and the gravel. Another small cap of andesite lies on the Newland formation near the place where the East Fork of Rock Creek leaves the quadrangle. All these remnants of andesite lie at a comparatively low altitude, as if they were parts of an eruptive mass that flowed out on the floor of an ancient valley.

The rock on Willow Creek is a typical biotite andesite, containing dull-white crystals of feldspar, most of them about 1 or 2 millimeters in diameter, and somewhat smaller black flakes of biotite rather thickly sprinkled in a pink groundmass. The mass on the East Fork of Rock Creek is essentially similar but has a drab color. The small masses overlying the gravels are apparently flow breccias composed of rusty drab lithoidal lava without phenocrysts.

The microscope shows that the plagioclase of the porphyritic andesite occurs in three fairly distinct generations, the last consisting of the slender microlites that make up the greater part of the groundmass. The crystals of the first generation, which are somewhat zoned, consist mainly of andesine near An_{40}; those of the second and third generations are chiefly oligoclase near An_{20}. The groundmass contains weakly birefringent poikilitic individuals of orthoclase or quartz or both.

Area near Warm Spring Creek.—The volcanic rocks north and south of Warm Spring Creek, near the eastern edge of the quadrangle, are chiefly light-colored, medium-textured andesitic tuff but include one or two small patches of lava. The tuff north of Warm Spring Creek rests on Carboniferous strata and on granite with strong unconformity and overlap and contains fragments of quartzite and limestone near its base. It is apparently overlain by heavy deposits of stream gravel.

Upon the outcrops of tuff rest also a few great blocks of granitoid rock whose large size virtually excludes the possibility that they were rolled by currents of water and whose composition differs from that of any rocks found in place to the west, where the stream gravels of this locality originated. Their difference from any rock of the Anaconda and Flint Creek ranges renders untenable the supposition that they are morainic. They are identical in petrographic character with the quartz monzonite at Butte and were evidently derived from the Boulder batholith, from which they must have been transported to their present place, in a direction opposite to the general course of stream and glacier currents, by one of two uncommon agencies. They may conceivably have been dropped from icebergs floating in a glacial lake, but although a vast ice-dammed lake once filled a large part of the Clark Fork basin, its highest level was lower than these bowlders. It is regarded as more probable that they were torn from the sides of volcanic vents and cast abroad with the andesitic fragments that make up the tuffaceous deposits.

The prevailing rocks in the area near Warm Spring Creek are dull olive-green and gray to cream-colored tuffs without distinct stratification but with an obscure flaggy parting in places. They are largely composed of fine-grained white or grayish, more or less compact fragments of andesite, containing small phenocrysts of feldspar, biotite, and a little quartz and hornblende. These fragments are embedded in an ashy matrix composed of smaller crystals and rock fragments.

South of Warm Spring Creek is some whitish decomposed biotite andesite. A rock apparently constituting a small remnant of a flow just north of the road at the eastern boundary of the quadrangle is a more basic dark-red porphyritic andesite, with conspicuous phenocrysts of andesine and inconspicuous ones of biotite, hornblende, and pyroxene.

Area south of Grassy Mountain.—The volcanic rocks near the southeast corner of the quadrangle are chiefly tuff-breccia of coarser texture than those exposed farther north. The surface here is strewn with blocks of light-colored lava, the largest 10 feet in diameter, and although at first sight these seem to be remnants of a flow they are more probably weathered-out fragments from an accumulation of material blown with great explosive force from some ancient crater not far distant. In the landslide just east of Sixmile Creek there are great blocks of tuff-breccia composed of angular fragments of gray and red andesite, the largest 3 feet in diameter, and also fine-grained tuff like that in the more northerly areas.

In composition the rocks of this area range from rhyolite-dacite to hornblende-hypersthene andesite.

The rhyolite-dacite, which forms the very large blocks already mentioned, is an irregularly fractured pale drab rock containing numerous rather large phenocrysts of quartz and feldspar and smaller comparatively inconspicuous ones of biotite. Its many irregular amygdaloidal cavities are more or less completely filled with chalcedony, quartz, and opal.

The microscope shows that most of the feldspar phenocrysts consist of andesine, but the largest consist of sanidine. The presence of sanidine and of quartz distinguishes this rock from the biotite andesite, which it somewhat resembles and with which it may have some genetic relation.

The coarse breccia is of hornblende-hypersthene andesite. Megascopically the rock composing most of the fragments shows conspicuous phenocrysts of glassy feldspar, the largest 5 millimeters in diameter, and small prisms of hornblende and pyroxene in a dark-gray resinous-looking groundmass.

The microscope shows that the feldspar phenocrysts are zoned plagioclase with average composition near andesine-labradorite (An_{50}). The other phenocrysts comprise much brown hornblende and hypersthene, and sporadic biotite.

VOLCANIC ASH.

Occurrence.—Soft, pale-tinted, obscurely stratified volcanic ash, presumably of Miocene age, occurs (1) at the northern boundary of the quadrangle west of Flint Creek, (2) on Willow Creek, near the western border of the quadrangle, and (3) in Philipsburg Valley and its southern continuation across the East Fork of Rock Creek.

This formation is perhaps the least resistant to erosion and the most poorly exposed in the quadrangle, being rarely uncovered except on steep slopes below the brinks of terraces capped by protecting gravel. Among the better exposures are some about 3 miles northwest of Philipsburg, whose whitish tint makes them visible from the town, and another in a gully about a mile north of Quinlan's ranch, at the head of Philipsburg Valley. Most of the large area mapped along Trout Creek is covered by a thin veneer of gravel and rock waste, but the presence of ash beds beneath the surficial deposits is shown by small outcrops in gullies and fragments of white silt on the dumps of badger holes. The ash probably underlies the terrace north of Philipsburg and that between Gird and Flint creeks, but even if it does the thickness of the gravel deposits at these localities would entitle them to be shown on the map.

Petrography.—The typical rock of this formation has a buff color grading to greenish or pale reddish, a fine-grained, homogeneous texture, and a slightly indurated, almost earthy consistency. It differs from dried clay in being noticeably lighter and in feeling harsh rather than unctuous to the touch. Bedding is but obscurely visible in outcrops and is rarely visible at all in hand specimens. At some places near its base the ash contains little angular fragments of older rocks, but it is associated with no true sandstones or conglomerates. When powdered and examined under the microscope the rock is found to consist essentially of minute angular fragments of volcanic glass. A tuffaceous nature is more evident in a coarser-grained specimen from the northern edge of the quadrangle, in which white particles of pumice are visible to the naked eye.

STRUCTURE.

CLASSIFICATION OF STRUCTURAL FEATURES.

The fact that a great unconformity divides the Tertiary volcanic and sedimentary rocks from the Cretaceous and older strata may be stated in terms of structure by saying that in general the deformation of the pre-Tertiary strata is far greater than that of the post-Cretaceous rocks. The contrast in structure between the strata beneath the unconformity and those above it is such as to suggest at once a twofold division of the structural features according to age. The other unconformities should logically form the basis of further subdivisions, but it can readily be shown that their structural significance is relatively so slight that for the present purpose they may be disregarded.

The quantitative significance of the unconformity between the Algonkian and Cambrian strata may be estimated by restoring in imagination the original horizontality of the basal beds of the Cambrian series. When the Cambrian strata were horizontal the Algonkian strata undulated and, as the Spokane formation thickens toward the west, their general dip was westward. Their inclination was as much as 40° in some places; but in most places it was very much less, and throughout considerable areas the beds must have lain nearly flat. The deformation that affected the Algonkian rocks before the deposition of the Flathead formation was in fact so much gentler than the vigorous folding and faulting that much later affected all the pre-Tertiary strata that the general appearance of the structure sections would not be materially different if the Cambrian overlay the Algonkian conformably. The unconformities in the Cenozoic series are as subordinate in magnitude to the great unconformity as that at the base of the Cambrian and afford even less basis for systematic division of structural features, inasmuch as they have been less continuously traced.

The folds and faults that affect the pre-Tertiary strata will therefore be described first, and the structure of the Tertiary rocks afterward without attempt to discriminate the results of minor disturbances. No attention will be given to the Quaternary rocks, because they are not visibly disturbed.

The intrusive sills and the tuffs and lavas, which form relatively thin layers that were originally horizontal, require no discussion apart from the sedimentary strata together with which they have been folded and faulted. The plutonic intrusive bodies, on the other hand, require separate consideration from two points of view. In connection with the structure of the pre-Tertiary strata, the causal relations that may exist between plutonic intrusion and deformation must be considered. The shearing or other deformation undergone by the plutonic masses, most or all of which are probably Tertiary, will be considered together with that of the other Tertiary rocks.

STRUCTURE OF PRE-TERTIARY ROCKS.

ORDER OF DESCRIPTION.

The folds and faults in the pre-Tertiary rocks are represented as fully as the scale permits by the geologic map and the structure sections. This graphic record obviates in large measure the need for mere description, but a record so complex is not readily understood without some verbal comment. The general character of the faults and folds will therefore be indicated and some noteworthy examples of both will be described; the relations of these structural features to the intrusive rocks will next be considered; and, finally, the chief results of crustal deformation will be summarized. As the faults are more easily traceable on the map than the folds, it is desirable to describe them first, even though most of them are probably later in origin than the folds. In order to clarify the discussion the diagram forming figure 4 has been prepared. This figure shows the major structural features, including most of those to which extended reference will be made, disencumbered from the multitude of details and from igneous and surficial rocks.

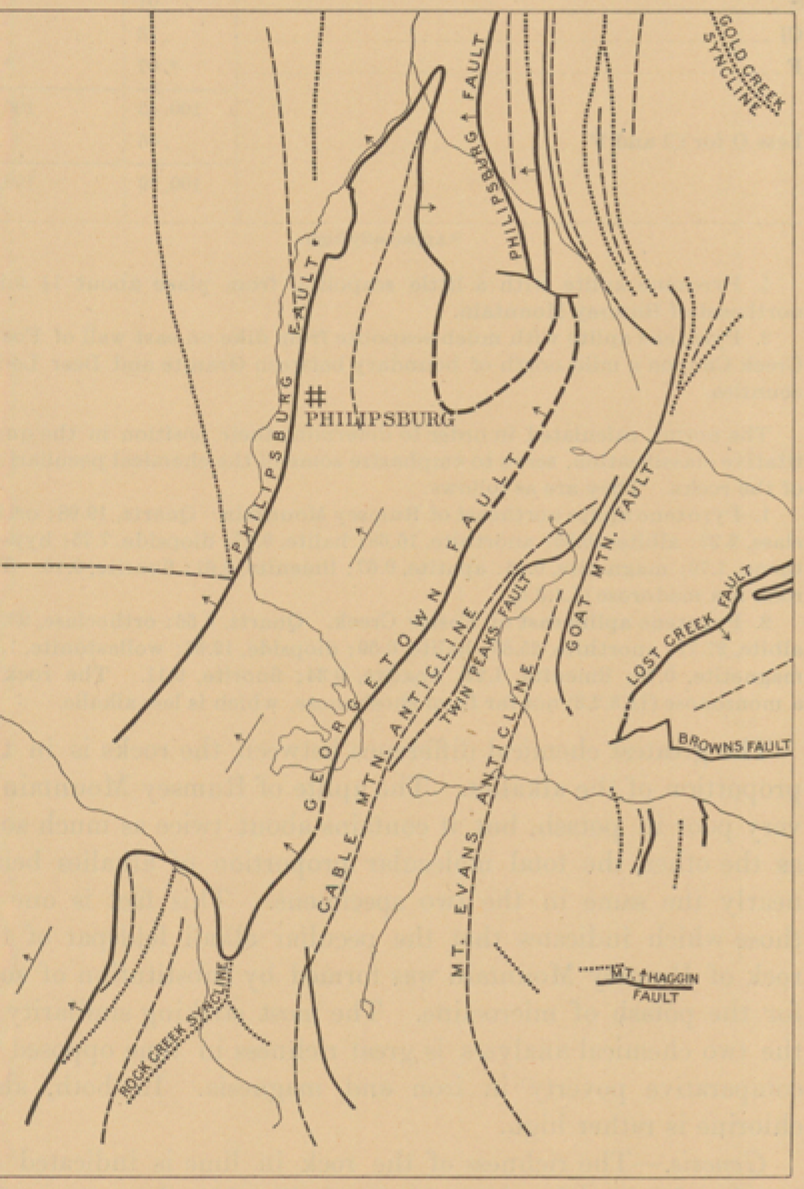


FIGURE 4.—Diagram showing the main structural features in the Philipsburg quadrangle.

Heavy lines are overthrust faults, whose dips are indicated by arrows. Lighter lines are large normal faults; dashed light lines, major anticlines; dotted lines, major synclines; short light lines with arrow, monoclines.

FAULTS.

GENERAL FEATURES.

The strike of the faults, like that of the folds, is prevailingly northeastward throughout the central and southern parts of the quadrangle and more directly northward in the northern part, but it is very irregular in the southeastern part of the quadrangle, where the structure in general is chaotic. In respect of characters other than strike—of dip, amount and direction of throw, and deformation or lack of deformation of the fault planes—the faults are extremely diverse.

Typical overthrust faults of low dip are represented by several examples. Two of these, of which the most westerly is called the Philipsburg and the most easterly the Georgetown overthrust, traverse the quadrangle longitudinally. They effect a far greater displacement than any of the other faults, their throw being measurable in miles, and they are further remarkable for having been folded and faulted. It is these great thrust faults whose possible identity with similar dislocations far to the north and south was pointed out in the introductory account of the regional geology (p. 2). Other flat overthrusts, one of which is folded, occur in the southeastern part of the quadrangle, where there are also minor thrusts of moderate dip that are dislocated by normal faults. The movement on the Philipsburg and Georgetown faults was an overthrust toward the east; the other overthrust masses moved in various directions, overthrusts toward the east, west, and south having taken place within a few miles of each other in the southeastern part of the quadrangle.

The majority of the faults have steep dips, and probably most of the steep faults here as elsewhere are normal. But it can not be assumed that all of those whose dip is unknown are normal, for the quadrangle contains reversed faults that are not very far from vertical. Nor are all the normal faults steep; at least one, the Browns fault, has a very low dip.

Of those faults chosen for special description because of the aptness with which they illustrate the types mentioned above, or because they are strong and persistent lineaments in the geologic structure, the thrust faults of low or moderate dip will be described first, the steep reversed faults next, then the steep faults whose direction of dip is unknown, and lastly the faults known to be normal. This order is not strictly chronologic, for the ages of the faults are not certainly known, but it is certain that the thrust faults that have been deformed are older than most of the faults of steep dip. The greater thrust faults will therefore be described first, not only because they are older but because of their magnitude and of the interesting deformation they have undergone.

GEORGETOWN OVERTHRUST.

The best exposure of the Georgetown fault and the strongest evidence of the deformation to which it has been subjected is afforded by the section along the large branch that enters the East Fork of Rock Creek near the hill marked "7781" on the map (section E–E). The structure exposed along the steep slope north of that branch might, after a cursory examination, be regarded as a simple syncline in essentially conformable strata, but this interpretation is precluded by the results of thorough study. The rocks in the trough of the syncline are identified by their lithologic character and by their areal relations with the Newland formation, which is of Algonkian age, and they overlie the Quadrant formation, which is Pennsylvanian, and the Ellis formation, which is Jurassic. They are crumpled and brecciated near the base and have evidently been brought to their present position by an eastward overthrust of the great Algonkian mass and a subsequent local depression of the thrust plane. The depression was probably formed by folding. It is believed that the thrust occurred before the strata had been much folded, that the thrust movement was nearly parallel to the bedding planes at the particular place considered, and that the beds thus superimposed were folded together. This interpretation is congruous with facts observed elsewhere in the quadrangle and especially with the indirect course of the fault farther south. The nose of an anticline which, like the syncline, pitches northward is supposed to be covered by the moraine of the East Fork. The fault is traceable southward on the west limb of this fold to another great moraine just within the quadrangle. On the east branch of Meadow Creek its plane dips westward at a moderate angle and it is accompanied by a complex of subsidiary faults.

The fault may readily be traced northward for several miles. Just south of Georgetown Lake its trace is jogged by several cross faults, most readily detected where they offset the well-defined boundary between the Madison limestone and the Quadrant formation. It continues beyond the lake along upper Flint Creek.

The fault is cut off by the granodiorite of the Philipsburg batholith, and its identification north of that intrusive mass, which is 6 miles in breadth, is somewhat conjectural. Its continuation is believed to be a fault that passes just east of Princeton and that is jogged by a cross fault 3 miles south of that place. Objection may be made to this identification because the throw of the supposed northernmost section of the Georgetown overthrust is small, but this objection is weakened by the fact that the throw of the main fault apparently diminishes northward from the lake. The parallel Georgetown and Philipsburg faults seem to bear a complementary relation. Both are evidently the work of a single thrust, and on any cross section the total movement on both appears to have been roughly constant. The movement on the Georgetown fault was greatest in the southern part of the quadrangle, where that on the Philipsburg fault was least, and in the latitude of Princeton, where the Georgetown fault begins to die out, the throw of the Philipsburg fault is large.

PHILIPSBURG OVERTHRUST.

The most accessible exposure of the Philipsburg overthrust is about 3 miles south of Philipsburg, on the west slope of the hill opposite the mouth of Fred Burr Creek, where the Newland formation (Algonkian) has been brought into contact with Pennsylvanian rocks. A southward continuation of this fault under the surficial deposits of Philipsburg Valley is indicated by the relations of the rocks on either side of that depression. The base of the Spokane formation on the west side of the valley is nearly in line with the top of that formation on the east side. In a locality where the Spokane formation has a thickness of thousands of feet, these areal relations imply a fault whose throw is considerable, though less than it is farther north.

The fault emerges from beneath the later deposits at the north end of Philipsburg Valley. On the east side of the canyon of Flint Creek, about 6 miles north of Philipsburg, the fault plane has a westward dip of 20° to 30°. Its sharp bend near bench mark 5005 is regarded as due to a small fold in the fault plane, and the relations where the overthrust reaches Flint Creek indicate that it has been jogged by a transverse fault.

Northeast of Flint the overthrust again disappears beneath surficial deposits, which conceal the nose of the northward-pitching anticline into which the thrust plane is believed to have been folded. (See structure section A–A.) This belief has been reached partly by eliminating other hypotheses. One of those rejected is that the eastward-dipping fault plane that crosses Wyman Gulch represents a separate overthrust from the east. No continuation of such an overthrust appears on the south side of the Philipsburg batholith, and this plane is therefore regarded as the continuation of the Philipsburg fault on the east limb of an anticline.

The thrust plane thus downfolded is supposed to reemerge on the east side of a syncline as the conspicuous fault that crosses Swamp Gulch just west of its mouth. This fault is peculiar in that, although in most places the older rocks are on the west or upthrust side, the condition is locally reversed. Such independence of minor antecedent structures would be quite possible in a major fault and not inconsistent with the parallelism between the fault and the bedding of the underlying rocks seen on the north part of the ridge west of Wyman Gulch (section A–A) as well as in the syncline near Rock Creek.

It is only after both the Georgetown and the Philipsburg faults have been discussed that the congruity of the hypothetic elements of their interpretation can be pointed out. This congruity is shown in figure 5, according to which they have been deformed alike, both having been thrown into an anticline and a syncline. Both these folds, like most of the folds in the strata, pitch northward. Owing to this northward pitch, the Philipsburg fault is too high at the south to appear in section E–E, and the Georgetown fault is too low to appear in section A–A.

LOST CREEK OVERTHRUST.

A thrust fault of northeasterly strike that crosses Lost Creek about 3 miles from the eastern edge of the quadrangle is noteworthy because its movement is opposed in direction to the Philipsburg and Georgetown overthrusts, and because it has been folded even more sharply than these. (See fig. 5.) It is well exposed in the cliff south of Thornton Creek, where the northwestward overthrusting has brought schists of the Spokane formation upon overturned Cambrian rocks. At this place the fault has a dip of about 35° SE., which, if it persisted, would carry the fault plane well beneath the bottom of the next canyon to the south. Yet on the south side of this canyon there is a fault contact of similar attitude and character, which is regarded as a part of the Lost Creek fault. The fault plane bends abruptly down along the axis of the canyon, at whose head the down-bent segment is remarkably well exposed. Green metamorphosed flaggy beds of the Spokane formation on the north and whitish magnesian limestone of the Hasmark on the south are here in contact along a surface that is approximately vertical in general but sinuous in detail. The contact is nearly free from gouge; and the rocks on both sides, though somewhat brecciated, are fairly firm, giving the impression of having been welded together by tremendous pressure exerted after the sliding movement had ended. The throw of this fault must be much greater than the distance—about a mile—between its northernmost exposure and the exposure along the south side of the canyon mentioned.

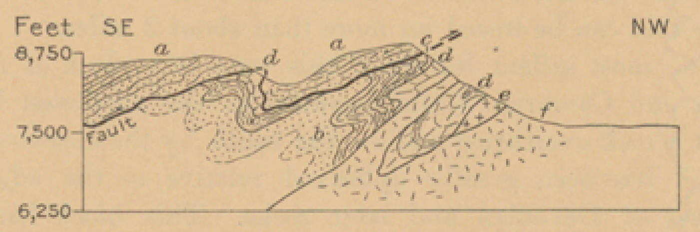


FIGURE 5.—Section across folded Lost Creek overthrust fault, south of Thornton Creek.

The overthrust was from the southeast and the fault plane was later folded with the rocks. *a*, Spokane formation (Algonkian); *b*, Flathead quartzite (Cambrian); *c*, Silver Hill formation (Cambrian); *d*. Hasmark formation (Cambrian); *e*, Acidic diorite (Tertiary); *f*, Porphyritic muscovite-biotite granite (Tertiary).

The southward continuation of the fault seems to dip eastward but much less gently than the part near Lost Creek, and it may have been steepened by deformation.

OTHER OVERTHRUSTS.

A thrust fault that strikes east-west and dips about 30° N. emerges along the south slope of the ridge that culminates in Mount Haggin. Where the stratigraphic throw of the fault is greatest the Newland formation (Algonkian) has been superposed upon the Hasmark formation (Cambrian). The Newland strata have an anticlinal structure along the westernmost part of the slope, but toward the east the fault cuts away the south limb of the anticline, and beneath Mount Haggin the fault plane is nearly parallel to the bedding of the rocks both above and below. (See fig. 6.) The parallelism of the fault and the strata make it difficult to estimate the throw of this fault, but it amounts to several hundreds or even some thousands of feet.

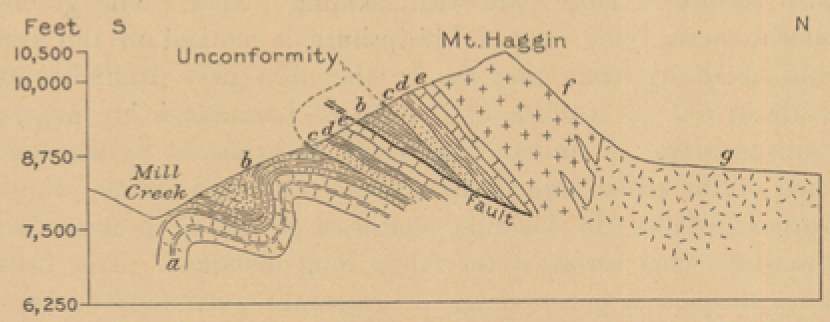


FIGURE 6.—North-south section through Mount Haggin, showing overthrust fault.

The Spokane formation (*b*) is thrust over on the Hasmark formation (*e*). The unconformity between the Flathead quartzite and the Spokane formation is also shown. *a*, Newland formation (Algonkian); *b*, Spokane formation (Algonkian); *c*, Flathead quartzite (Cambrian); *d*, Silver Hill formation (Cambrian); *e*, Hasmark formation (Cambrian); *f*, Acidic diorite (Tertiary); *g*, Nonporphyritic muscovite-biotite granite (Tertiary).

Reversed faults of steeper dip and of less throw than those described above have displaced the rocks that form the hill south of Browns. As appears in structure section D–D, one of these faults has brought the Madison limestone (Carboniferous) in contact with the Colorado formation (Cretaceous) and has been affected by a normal fault.

STEEP REVERSED FAULTS NEAR MOUNT TINY.

The faults south and west of Mount Tiny are not especially large or conspicuous. The one of greatest throw, which is at the head of Blodgett Creek, brings Hasmark rocks against Newland. The chief interest of these faults consists in the fact that although they have a steep dip, and therefore might be assumed to be normal, the ones whose direction of dip is known are reversed. This condition can be observed along a short fault north of "10068," at the head of Seymour Creek, and another about a mile northwest, both of which dip about 75°. There is little breccia along both faults.

GOAT MOUNTAIN FAULT.

The fault that is traceable for 7 miles south of Indian Meadows is probably a continuation of the one that crosses Finley Basin west of Goat Mountain, although this continuity, not having been definitely proved, is not represented on the map. If the continuity exists the Goat Mountain fault is one of the longest in the district; but it is not one of those with greatest throw. Along most of its course it brings Madison limestone on the west against Quadrant, Ellis, and Kootenai rocks on the east, though near the south end it brings the limestone of the Hasmark formation against the Madison limestone.

The fault is well exposed in a notch southeast of Racetrack Lake, but not so well, in general, farther south, the contact with the Madison limestone being largely concealed by fragments of quartzite of the Quadrant formation and the tough metamorphosed Mesozoic sediments. Its dip in this vicinity is steep but of unknown direction. The existence of the fault in Finley Basin is shown most clearly on the slope north of the basin, where the quartzite of the Quadrant formation dips toward the Madison limestone. The trace of the fault as drawn and the aspect of the exposures as seen from the south indicate that the fault is reversed and has a steep westerly dip.

TWIN PEAKS FAULT.

A fault having great throw a length of many miles extends from the notch northeast of Twin Peaks to the granodiorite batholith near Cable and apparently continues even beyond that intrusive mass. For most of its length it separates the Spokane formation from the Madison limestone, and it is therefore one of the most conspicuous geologic boundaries. Its dip is not certainly known, but it apparently dips eastward and is therefore normal.

BROWNS FAULT.

One or two miles north of Warm Spring Creek, near Browns, there is a fault that is especially conspicuous among the multitude of faults there developed, because it forms the boundary between the Madison limestone and strata of Cambrian and Algonkian age. This fault is unusual in combining normal displacement with a low dip. It apparently has been offset a long distance by a later transverse fault.

GROUPS OF SMALL FAULTS.

West of Cable Mountain.—The Paleozoic rocks on the west flank of Cable Mountain are dislocated by a large number of comparatively small faults, some nearly parallel to the strike of the bedding, some transverse to it. Those most readily discernible in the field are the transverse faults near the south end of the mountain, detected by following the very characteristic purple bed at the base of the limestone of the Red Lion formation, which is repeatedly offset. More faults were found here than could be represented on the scale of the map. The transverse faults farther north are shown, less clearly, by jogs in the Flathead quartzite and Red Lion and Maywood formations. The planes of all the transverse faults are apparently of steep dip. The principal strike fault is one at the head of the creek whose downthrow is in the same direction as that of the Georgetown overthrust just west, to which it may be subsidiary; its dip, however, is not known.

South of Lost Creek.—The most persistent fractures in that veritable mosaic from which the ridge south of Lost Creek is carved are a series of step faults whose downthrow is on the southeast side and whose effect is expressed in the skyline of the ridge as viewed from the vicinity of the mouth of Barker Creek. Erosion along the summit of this ridge has been arrested at the surface of the Flathead quartzite, which forms three broad and nearly level steps. A numerous group of divergent faults is well exposed in a gulch directly north of bench mark 5605. Most of these can be traced by the contacts between the pale-greenish beds of metamorphosed Newland and the darker, more rusty beds of the Spokane. The mapping of these faults on the top of the plateau is based on many laborious traverses, but exposures here, as on the similar plateau north of Lost Creek, are poor, and it is very possible that errors have been made in interpreting the few outcrops.

FOLDS.

GENERAL FEATURES.

The major folds of the quadrangle strike from northeast to north-northwest, their axes being in general convex toward the east. Most of the folds in the quadrangle are rather persistent, the most striking exceptions being in the southeastern part. As the structure sections show, they present the greatest diversity of character. Some are broad and open, others appressed and overturned; and in places the rocks have undergone intricate contortion, which it is impossible to show on structure sections. The axial planes of most of the folds in the northern and central parts of the quadrangle dip eastward; those of most of the folds in the western part of the Anaconda Range dip westward. A few prominent folds are selected for special description in order to illustrate the several types just mentioned and to trace as far as possible the more persistent folds, many of which are obscured by minor plications or are interrupted by faults and intrusive bodies.

MARSHALL CREEK SYNCLINE.

The largest continuous area of the Spokane formation shown on the map lies northwest of Philipsburg. The plotted dips within and about this area and the form of its boundary show that it lies in a northward-pitching syncline, which may be named for Marshall Creek, the stream that drains most of the area. This fold is the most extensive within the quadrangle, and the most gentle. Throughout a large area near its axis the rocks are nearly horizontal. Its cross section is asymmetric, the maximum dips on its west limb being about 25° and those on the east limb about 60°. The axial plane thus has an eastward dip.

At first glance this syncline would appear to end at Philipsburg Valley, but it originally extended much farther southward. Its eastern limb is represented by the zone of Algonkian rocks that extends from Rumsey Mountain to the crest of the Anaconda Range; its western limb was upheaved by the Philipsburg fault and has been eroded away.

CABLE MOUNTAIN ANTICLINE.

One of the most persistent anticlines in the quadrangle is clearly developed on Cable Mountain, after which it has been named. It terminates at the north against the Twin Peaks fault, into which its axis gradually converges. The northern part of the fold is strongly asymmetric, its axial plane having a low eastward dip. The overturning becomes gradually less pronounced toward the south until, at the southern end of Cable Mountain, the fold is nearly symmetrical. Here it shows a southward pitch. It is interrupted by the granodiorite batholith described on pages 13 and 14, but, though it is broken by faults and has a more or less undulating crest, it can be traced to the Continental Divide, where it has a strong northward pitch.

MOUNT EVANS ANTICLINE.

The next extensive anticline east of the Cable Mountain anticline is one of the largest structural features of the Anaconda Range, but it is so much obscured by moraines, intrusive rocks, and minor structural features that it can not be readily traced. It is obscurely expressed by the areal distribution of the rocks, which shows that it pitches northward. The Neihart quartzite, the oldest formation in the quadrangle, is exposed on the axis of the fold on Sullivan Creek. Areas of the Prichard formation lie east, north, and west of the Neihart area. West and north of these lie areas of the Ravalli formation, which, however, does not appear on the east, where it has been depressed by folding and faulting. Still farther north lie successive ill-defined zones of later Algonkian and Cambrian strata. The dips plotted on the map, even though somewhat generalized, show the great complexity of this fold.

PHILIPSBURG ANTICLINE.

The most conspicuous structural feature in the immediate vicinity of Philipsburg is a nearly symmetrical northward-pitching anticline, expressed on the map by curved concentric bands representing the Paleozoic formations. The mapping can readily be verified by following certain of these strata, particularly the Flathead quartzite, the Red Lion formation, and the quartzite of the Quadrant formation.

The approximate parallelism of the strata in this anticline to the arched Philipsburg overthrust, already described, shows that the folding of the strata here resulted in part from the same movement that deformed the fault plane.

SYNCLINE SOUTHEAST OF GOAT MOUNTAIN.

The structure of the area of Pennsylvanian and Mesozoic rocks southeast of Goat Mountain is not very obvious either on the map or on the ground, but its interpretation is illustrated in the eastern part of section B–B. The structure in this area finds expression in the outcrop of the beds on the walls of glacial amphitheaters and particularly in the wall that may be seen by one looking southeastward from Goat Peak. (See fig. 7.) The strata at this locality are distinctly banded and the bands are sharply bent so as to form a sort of chevron with the points toward the east. This appearance suggests at first an angular unconformity, but the clue to the interpretation is given by a view along the face of the cliff illustrated in figure 7, *a*, which shows that the structural feature here is a strongly overturned syncline.

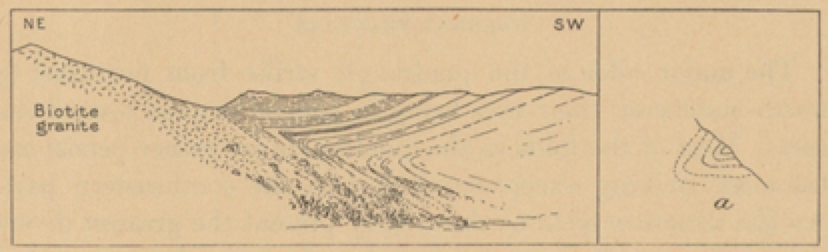


FIGURE 7.—Recumbent syncline of Carboniferous and Mesozoic sedimentary rocks as seen looking southeast from top of Goat Mountain.

Intrusive granite contact is nearly parallel to the bedding. *a*, Cross-section of the syncline seen in looking southwestward along the face of the cliff.

FOLDS NEAR LOST CREEK.

In the vicinity of Lost Creek, closely associated in origin with the Lost Creek overthrust (see p. 19), there is folding of somewhat the same character as that seen from Goat Mountain but still more intricate. A detail of the folding seen in the Cambrian rocks beneath this overthrust on the cliff south of Thornton Creek is illustrated in figure 8. South of Lost Creek the deformation is even more extreme. At one point in this neighborhood the Cambrian limestone shows a close fold, which is not only recumbent toward the west but whose crest curled over like that of a breaking wave.

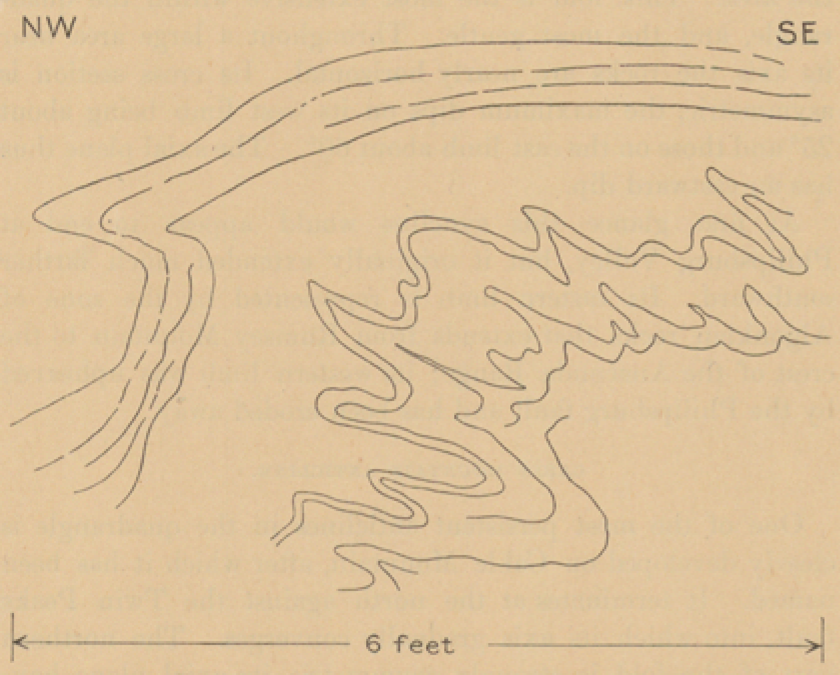


FIGURE 8.—Detail of folding in Cambrian rocks on the cliff south of Thornton Creek.

The folding was caused by the overriding of strata in an overthrust fault block from the southeast.

RELATIONS OF STRUCTURE TO PLUTONIC INTRUSION.

Some evidence concerning the extent to which plutonic intrusion has caused or accompanied deformation of the strata, concerning the influence of passive resistance by great masses of congealed magma upon the yielding of the strata to later stresses, and concerning the chronologic sequence of intrusion and deformation may be derived from the relations between the forms of the intrusive bodies and the attitudes of the strata adjoining them. A glance at the map will show that these relations are various; that the peripheries of igneous masses in part accord with bedding planes or the prolongations of fault fissures but in part transgress the strike of beds and faults. Not only the planes of bedding or faulting but also the axes of folding betray significant relations to the intrusive bodies.

Coincidence of the irruptive contact with a plane of stratification is most persistent in the periphery of the Royal intrusive body, a large part of which is in contact with the comparatively thin Quadrant formation. The sides of the great mass of porphyritic granite crossed by Racetrack Creek also accord in large part with bedding planes. The granodiorite mass lying east of Philipsburg is flanked on the east and north by strata that lie for the most part parallel to its surface; but its western and southern boundaries are mostly transgressive. A similar complexity is displayed by the contacts of the acidic granodiorite in the Anaconda Range, whose surface follows the bedding southeast of the Carp mine but elsewhere cuts across it for fairly long distances. The beds are crumpled in places along the accordant portion of the contact. The diorite of Mount Haggin also appears to overlie the sedimentary rocks and is possibly the remnant of a laccolith. The contact here dips gently under the intrusive mass instead of being steep or dipping away from the center of the mass like most of the other contacts. Northeast of Storm Lake, however, the same rock cuts across the strata along a steep and irregular surface. The peripheries of some other masses, notably that of the Cable stock, are chiefly transgressive.

The plutonic masses are cut by fissures, along some of which there has been considerable faulting, but discussion of these is deferred to a later section. To the fissures that do not cut them, these masses stand in three sorts of relations: they transgress some fault fissures, their peripheries coincide in part with others, and into other fissures the magmas have been injected to form dikes.

The most conspicuous faults that are cut across by igneous rocks are the Georgetown and Mount Haggin overthrusts and the reversed Goat Mountain fault, all of which one would expect on general considerations to be among the earliest. The apparently normal fault east of Twin Peaks and a few others not known to be reversed also appear to be older than the plutonic masses, parts of whose boundaries are in line with the faults.

The most prominent system of dikes is constituted by the apophyses of the mass of acidic granodiorite in the Anaconda Range. These dikes occupy fissures along which little or no faulting has occurred. On the other hand, a granitic rock was injected either during or after the movement along the northernmost fault that crosses Foster Creek.

The bearing of these diverse relations upon the mechanism of the plutonic intrusions can hardly be discussed thoroughly without unduly entering upon speculative ground but may be touched on briefly. The frequency of accordant contacts dipping outward suggests that many rising masses of magma exerted upward pressure. The abundance of dikes branching from the main mass of acidic granodiorite also suggests that this magma pressed upward in such a way as to distend and crack its roof. On the other hand, the frequency of transgressive contacts and of inclusions in some intrusive bodies would seem to indicate that bodily unheaval or pushing aside of the older rocks was not the sole method of emplacement but may have been aided by stoping. Even accordance of contact with bedding or fissures might be effected locally by stoping if the process were arrested at the contact of a relatively coherent rock with one more readily shattered.

Whatever its degree, the pressure between the magmas and the older rocks was not necessarily of great effect in deforming the strata; both deformation and the forcing upward of magma may have been due to a common compressive stress. At any rate the period of intrusion was clearly comprised within the period of deformation. The transgression of faults and folds by irruptive contacts is sufficient proof that much deformation had been accomplished before plutonic intrusion was at an end. Some faulting evidently occurred after the intrusion. Evidence that folding persisted after the solidification of some plutonic bodies is afforded by the relations of structural axes to such bodies.

A harmony between the trend of folds and that of irruptive contacts is most evident in the northeast quarter of the quadrangle. The axes of the more persistent folds in this locality describe a gentle sigmoid flexure, of which the northern part is concave toward the Royal intrusive body, the southern part concave toward the intrusive body east of Philipsburg. The crests of the overturned folds north and south of the Royal mass plunge downward away from that mass, and the folding is progressively more acute in proportion to the distance from the mass in either direction. These conditions must be the result of a pressure from the east that acted after the plutonic bodies mentioned were congealed and that was resisted by those two great bosses of comparatively rigid crystalline rock. Less striking phenomena of similar import are to be seen in the Anaconda Range. The crests of the folds rise southward toward the backbone of this range, which is stiffened by igneous masses, and the folds open out toward the south.

GENERAL RESULTS OF DEFORMATION.

The larger facts that first detach themselves from the multitude of structural details are (1) the northward pitch of most of the folds, and (2) the divisibility of the quadrangle into three zones, each characterized by the prevalence of certain types of structure and to a less extent by the prevalence of certain sedimentary formations.

Western zone.—The westernmost zone is occupied by an overthrust mass of Algonkian rocks. It is definitely bounded south of the Philipsburg batholith by the Georgetown overthrust. Its boundary north of that batholith is not so simple, owing partly to the fact that the overthrust mass has been cut through by erosion along the crest of the Philipsburg anticline, and partly to the dying out of the Georgetown overthrust in this direction. This western zone is characterized as a whole by open folds of northward pitch. The folds become less open toward the northeast and faults are numerous and prominent near Flint.

Middle zone.—The middle zone, extending roughly from the west half of the southern boundary to the east half of the northern boundary of the quadrangle is characterized by fairly regular and close folding. Its western boundary is determined mainly by the Philipsburg and Georgetown overthrusts; its eastern boundary may be regarded as coincident with the contacts of the Royal and Mount Powell batholiths north of Racetrack Creek and with the Goat Mountain fault south of that stream. It is almost completely cut in two by the Philipsburg batholith, about whose eastern margin the axes of folding bend in a sweeping curve balanced by a somewhat gentler curve about the Royal batholith. The area north of the Philipsburg batholith (section A–A) is occupied by many north-south folds, most of which can be traced by following the bold outcrops of the quartzite of the Quadrant formation. The most westerly folds are nearly symmetrical, but those farther east are more and more overturned. The openness and the northward pitch of the syncline north of the Royal batholith presents a decided contrast to the closely appressed character and southward pitch of those farther south.

The principal faults in this area, apart from the Philipsburg and Georgetown overthrusts, are strike faults, the most important of which are one passing through Princeton and one already described as the Goat Peak fault.

The part of the central zone lying south of the Philipsburg batholith is the more complex. Most but not all of its folds have a northward pitch, and the prevalent strike is northeasterly. The Cable Mountain anticline, the only fold that is well defined throughout the length of this division, shows at its northern end the same westward overturning that prevails in the northeastern part of the quadrangle but straightens up farther south. This torsion of the axial plane is typical for the central zone of folding as a whole, and eastward rather than westward overturning prevails in the western part of the Anaconda Range. Of the many faults in the southern division of the central zone, the only one of the first magnitude is the Twin Peaks fault. The minor faults are not systematic in direction or downthrow, and their aggregate effect can hardly be generalized.

Eastern zone.—The eastern zone, lying south of the Mount Powell batholith, is especially characterized by complex faulting. Almost its only regularity consists in the feeble prevalence of a northeasterly structural trend. The strata and the faults of the area strike in all directions, however, and no complete fold can be traced for more than about 2 miles.

The most salient feature of this zone is a block of Algonkian and Cambrian strata, bounded on the northwest by the Lost Creek overthrust and on the south by the Browns fault, which has been greatly upheaved relative to the adjoining masses of Devonian and later rocks. This block has been carved from an anticline, striking northeastward, whose axis projects into the quadrangle from the point where Lost Creek leaves it. The southeast limb, almost destroyed by faulting and intrusion, has a low dip. The northwest limb is contorted and in general strongly overturned, the overturn being obviously related to the Lost Creek overthrust. The folded mass is affected by a multitude of presumably normal faults, most of which cause downthrow toward the east or southeast.

In the mass overridden by the Lost Creek overthrust the structure, as shown in section C–C, is extremely complex and irregular. The most striking exposure of structural detail in this area is on the cliff east of Foster Creek near the county line. (See Pl. VIII.) The strongly overturned folding there shown is near the end of a southward-pitching syncline, which is the most persistent fold in this drainage basin. The same view shows a normal fault of notably low dip, followed for some distance by a dike.

The structure immediately south of the Browns fault is obscurely anticlinal but is complicated to the utmost by faults and minor folds. The hill south of Browns and part of the spur across Big Gulch show a complex but comparatively legible structure, represented by cross section D–D. The discordance in structure between the two sides of the valley of Warm Spring Creek in this neighborhood suggests the existence of faults beneath the Quaternary deposits in the valley.

Faults and intrusions separate the area just discussed from the strip of sedimentary rock extending eastward toward Mount Haggin. The structure of this strip is illustrated by the section forming figure 6.

STRUCTURE OF THE TERTIARY ROCKS.

EASTERN PART OF FLINT CREEK RANGE.

Deformation of intrusive rocks.—Near the eastern boundary of the quadrangle, on Racetrack and Rock creeks, the biotite granite of the Royal intrusive and the porphyritic biotite granite and quartz diorite exposed farther to the south are very schistose. The planes of schistosity in the diorite between Racetrack and Thornton creeks strike about northeast and dip 30° SE., or about parallel to the thrust fault south of Thornton Creek.

The juxtaposition of the alkaline biotite granite south of Lost Creek with the Madison limestone, though ill exposed, is apparently due to a fault, for the limestone is not much metamorphosed and is brecciated in places along the contact, which dips rather gently eastward. At places north of Lost Creek and a little east of the quadrangle the evidence of faulting is more conspicuous, the granite having been much brecciated and chloritized in a gulch eroded along the contact.

Deformation of tuffs and gravels.—Along Warm Spring Creek and Lost Creek just east of the quadrangle the tuff and underlying gravel are thrown into open folds and are cut by faults. The prevailing dip is eastward and in the tuff, at the place where Lost Creek enters Deerlodge Valley, it amounts to 70°. Not only is the tuff much deformed, but the gravel that overlies it unconformably is gently tilted. The dip at some places amounts to 20° and the beds are dislocated by both normal and steep reversed faults with throws of about 5 feet. Some small exposures of the gravel that lie north of lower Warm Spring Creek show rather strong dips.

EASTERN PART OF ANACONDA RANGE.

Tilting of gravel.—The great altitude of the gravel on Grassy Mountain, where it lies much higher than elsewhere, indicates in itself a considerable deformation by tilting. The bedding on the summit, however, is nearly horizontal, and a pronounced inclination has been detected only on Sevenmile Creek, where sandy layers dip 15° upstream. As the direction of dip is away from the general direction of tilting, some folding as well as general tilting must have occurred.

Faulting of intrusive rocks.—At the head of Mill Creek brecciated limestone is in contact with diorite that has an east-west and vertical schistosity. The two rocks are probably faulted together, but there is no means of knowing the throw of the fault. Shearing in the granites and granodiorite is general all along Mill Creek but is not expressed by very definite schistosity except in the lower part of the canyon. Near the eastern boundary of the quadrangle, however, an exposure in the stream channel reveals very marked and regular schistosity in the biotite granite, striking N. 70° E. and dipping 23° S., which is doubtless related to a fault between the granite and the Madison limestone. The evidence for this fault is very clear on the south side of Mill Creek canyon about a mile from the boundary of the quadrangle, where, within a hundred feet of each other, there are exposures of limestone breccia and sheared and chloritized granite. (See fig. 9.)

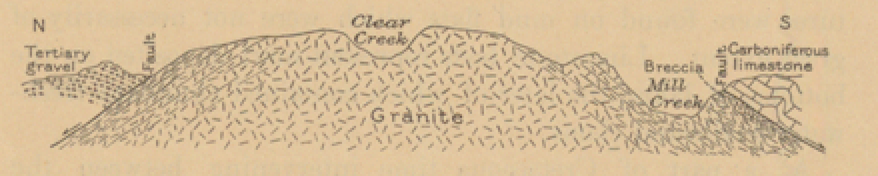


FIGURE 9.—Diagrammatic section across Mill and Clear creeks, showing schistosity in granite parallel to fault planes on its borders.

There is a fault breccia at the limestone contact on the south and a fault facet on the granite slope on the north.

North of Mill Creek the schistosity becomes less definite but beyond Clear Creek it is again distinct and dips about 30° N. The contact with the tilted Tertiary gravel at the foot of the mountain follows a remarkably straight, smooth facet, which bevels the gentle slope above and dips about parallel to the schistosity in the granite. This contact is taken to be a fault. There is a striking analogy between the phenomena at this place and those along the great Bitterroot fault, described by Lindgren. The interpretation of the facts above described is illustrated somewhat diagrammatically in figure 9.

FLINT CREEK AND ROCK CREEK BASINS.

Tilting of Tertiary deposits.—Deformation of the earlier gravel on Rock Creek is clearly shown in Plate VII. In the exposure of which this is a view the dip is about 25° E. The dip has not been measured at other places.

In exposures of the volcanic ash in Philipsburg Valley and near Willow Creek the obscure bedding of the material is horizontal.

The terraces about Philipsburg have a distinct inclination, but this is chiefly due to aggradation. A strong suggestion, however, that there has been warping of at least the older part of the terrace gravel is given by the position of the remnant near the pass at the head of Trail Creek.

PHYSIOGRAPHY.

EFFECTS OF PRESENT CONDITIONS.

Many characters in the physiography of any region can easily be explained as the result of normal erosion influenced by various conditions now existent, the most obvious of which is the different resistance of different rocks to erosion. The wide range of hardness in the rocks of the Philipsburg quadrangle has entailed a corresponding variety in the character of sculptural details. Among the larger effects of differential degradation is the contrast in altitude and form between the Flint Creek and Anaconda ranges on the one hand and the hills in the western part of the quadrangle on the other. The low, rounded western hills, a part of the Sapphire Mountains, are carved from the Algonkian strata, which, except the sandstone of the Spokane formation and the hornstones formed by local igneous metamorphism of the Newland formation, are relatively soft and homogeneous. The high and rugged Anaconda and Flint Creek ranges are carved, for the most part, from a relatively hard and heterogeneous complex of igneous rocks and variously metamorphosed sedimentary strata. The location of the Philipsburg Valley and its prolongations, which coincide with a fault zone, may have been determined in part by differential erosion in crushed rocks, and the eastern part, at least, of that other major depression that separates the Anaconda from the Flint Creek Range is also eroded along a zone of faulting. Differences of situation as well as of material increase the variety of sculpture; rugged forms, for example, are most common on the heights where steep declivities directly increase the effectiveness of the streams and of talus creep in removing material, where frost is active in disintegrating the rocks, and where there is little vegetation to retard erosion.

EFFECTS OF PAST CONDITIONS.

Of greater geologic interest than the topographic features that can be explained as the result of present conditions are the features explainable only as the result of past conditions, and that consequently throw light upon the erosional history of the region. Of the features in the Philipsburg quadrangle that possess this historical interest, the most important groups, enumerated in general order of age, are (1) high remnants of old erosion surfaces, (2) valleys of existing streams, (3) glacial features.

REMNANTS OF OLD EROSION SURFACES.

In regions of complex geologic structure, like that surrounding Philipsburg, an extensive surface of low relief can be produced only by very long continued erosion. A surface partly leveled by this agency may contain prominent residual hills, but its flatter parts will descend to the major streams by gradual declivities. If, therefore, flat erosion surfaces are found at a great elevation above streams to which they are near, it is evident that they belong to an earlier cycle separated from the present by some uplift or other event that has caused the streams to intrench themselves more deeply.

The Philipsburg quadrangle is occupied in large part by surfaces of low relief that stand at elevations of 6,000 to 8,500 feet above sea level and consequently as much as 2,000 feet above the nearest large streams, from which they are separated by steep or moderate slopes. From moderately elevated points near Philipsburg, for example, the hilltops to the west and north appear as remnants of an elevated erosion surface whose essential flatness is only emphasized by the prominence of Henderson Mountain, which is due to local induration of the rocks by metamorphism. Other flat upland surfaces lying east of Philipsburg Valley and south of Georgetown Lake, and perhaps also the high glaciated plateau in the Flint Creek Range above Fred Burr Lake, are likewise remnants of an old topography.

In the eastern part of the quadrangle no very extensive old erosion surfaces are preserved, but areas that stand at an elevation of about 8,500 feet on both sides of Lost Creek are remarkable for their flatness and for the fact that they cut indifferently across the bedding of crumpled and faulted rocks, which differ widely in hardness.

The surfaces that are flat enough to suggest plateaus pass into others whose relief is considerable yet too gentle to accord with their high altitude. Areas having such topography surround Georgetown and Echo lakes. Some of the high but gentle slopes are evidently parts of old valleys. The appearance of a dissected valley parallel to and 2 miles south of the Silver Lake and Warm Spring Creek valley, at an elevation of 7,500 feet above sea level, is presented to the observer at points from which he may look along its axis. Many of the higher summits probably represent hills that stood above the old erosion surfaces and have been defaced by the destructive agencies to which they are especially exposed.

The remnants of old topography can not be regarded as parts of a single rolling surface. For example, two flat surfaces near the head of Lost Creek and Foster Creek, which differ in altitude by 1,000 feet, are separated by comparatively steep slopes; and the highlands south of Georgetown Lake rise toward the crest of the Anaconda Range by a series of steps that range from about 6,500 to about 8,500 feet above sea level. This rudely terraced character is probably to be regarded as evidence that the upland surfaces are the work of several stages of erosion, for it can not be explained as due in any great measure to faulting and folding. Some deformation of the old erosion surfaces, however, is indicated by topographic as well as stratigraphic evidence. The eastward slope of the plateaus near Lost Creek, for example, is so marked as to suggest that they have been tilted.

VALLEYS OF PRESENT STREAMS.

Virtually all the stream valleys in the quadrangle may readily be assigned to one or the other of two classes—open valleys and canyons. The open valleys, which contain parts of Rock, Willow, Flint, and Warm Spring creeks, present a rather sharp contrast to the canyons in which most of the streams are flowing.

These open valleys are bordered by gentle slopes, the lower parts of which are terraced. Remnants of one especially broad terrace with decided streamward slope are conspicuous in each basin and are well shown by the map contours north of Philipsburg and on Willow, Rock, and Warm Spring creeks.

The relatively great age of the open valleys is indicated by the fact that they are partly filled with Tertiary deposits, and by the great disproportion that exists in places between the breadth of the valleys and the volume of the streams that occupy them. This is illustrated by the upper part of Philipsburg Valley, which is 2 miles broad yet contains no stream of appreciable eroding power. The broad valley can not be entirely the work of the present streams.

The canyons are as a rule proportionate in size to the streams by which they are occupied. Most of them are modified by glacial features which will be described later, but comparison of the glaciated with the unglaciated canyons indicates that preglacial stream erosion has been about equal to glacial erosion in the canyons where both have been active. The few long canyons that have not been glaciated have the moderately steep unterraced slopes, the narrow bottoms, and the V-shaped cross section that are the result of long-continued but still vigorous stream erosion.

A canyon of exceptional character is that of Flint Creek between Georgetown Lake and the power house, which has a very steep gradient and precipitous rocky sides. This canyon is the result of exceptionally rapid erosion, due to glacial diversion, in glacial and postglacial time. Narrow trenches have been cut in the bottoms of some of the glaciated canyons, one on Boulder Creek, attaining a depth of more than 100 feet. The peculiar course of Blodgett Creek south of Georgetown Lake is also due to glacial diversion, and the middle part of its canyon has a youthful, trenchlike character.

GLACIAL FEATURES.

Vanished glaciers have left their characteristic sculpture on the sides of all the peaks and ridges in the quadrangle that exceed 8,000 feet in height. They eroded most vigorously along their upper parts and deposited most heavily along their lowest parts. The deposits they formed are described on pages 10 and 11; their erosional effects will be briefly indicated here.

The most striking effect of erosion by these vanished alpine glaciers is the formation of cirques—flat-bottomed basins that are open on one side and surrounded on the other by steep, rocky slopes. Their form is conspicuously shown by the contours on the topographic map, and the type is exemplified in almost ideal simplicity by Finley Basin, at the head of Boulder Creek. Some of the cirques are narrower than this basin and less distinct from the heads of unglaciated stream canyons. Others, chiefly in the Anaconda Range, show extreme development of the characteristic broad, flat floor and high, steep walls, evidently a result of especially long and vigorous glaciation.

The canyons down which the glaciers moved have some features like those of the cirques. Their floors are flatter and their sides steeper than those of normal stream-carved canyons; their cross profile and the contours that delineate them are U-shaped rather than V-shaped. These features are very strongly marked in the canyon of the middle fork of Barker Creek, in the Anaconda Range, which is virtually a prolongation of the cirque at its head. A glaciated canyon near Philipsburg is that of Fred Burr Creek. Abrupt discontinuity with slopes produced by prolonged stream erosion is common to most of the glaciated canyons, as is illustrated by the sharp contrast between the gentle slopes about Echo Lake and the steep slopes of Flint Creek canyon to the east.

Characteristic "hanging" minor canyons, due to the greater glaciation of the main canyon, occur along Boulder Creek, several of whose tributaries plunge abruptly to the main stream from valleys several hundred feet higher. Swamp Creek, for example, drops 600 feet in the last half mile of its course, a height as great as its fall in the 3 miles above the point where its grade begins to steepen. Carp Lake, in the Anaconda Range, occupies another typical hanging valley.

Details of glacial sculpture too small to be shown on the map are no less characteristic than those delineated by the contours. The floors of the cirques and the upper parts of the glaciated canyons are in large part surfaced with barren rock, the harder kinds of which retain the polish and scratches produced by moving ice; and the projections of the glaciated bedrock surfaces have been rounded off by the grinding action of the glaciers. Such evidence of glaciation is well displayed on the high flat ground about Fred Burr Lake, showing that this area was covered by a sheet of ice from which glaciers extended in several directions.

GEOLOGIC HISTORY.

PROTEROZOIC ERA.

ALGONKIAN PERIOD.

The earliest geologic event recorded in the Philipsburg quadrangle was the deposition of the sands that have since been consolidated as the Neihart quartzite. The almost purely siliceous character of this formation shows that the sands were worked over so thoroughly that nearly all the softer and less durable minerals were washed away and the resistant quartz left behind. This work could hardly have been done so completely except by the beating of waves on a sea beach. In the Neihart epoch, therefore, the region including the Philipsburg quadrangle was presumably submerged by a sea a part of whose shore remained within or near the quadrangle during the long period that was necessary for the accumulation of a layer of sand at least 1,000 feet thick. It is probable that the earth's crust here subsided considerably while the sands were accumulating.

Most of the rocks of the Prichard formation were originally dark-bluish muds, whose regular banding and fine texture, persisting throughout a great area in Montana and Idaho, indicate that they were deposited in a body of water that was fairly deep and extensive, perhaps sufficiently so to be called a sea. The transition from the Neihart to the Prichard formation is therefore the record of continued subsidence of the land and a consequent deepening of the sea over this area and a shifting of the shore line to a considerable distance from the quadrangle, and the great thickness and the uniform character of the Prichard sediments indicate that gradual subsidence continued during most of the time that they represent. The presence of quartzitic beds at several horizons shows that the water was never very deep.

The sand of the Ravalli formation, being much less purely quartzose than that of the Neihart quartzite, could not have been subjected to so much attrition. It was deposited in shallow water which, as is shown by the presence of cross bedding in some of the sandstone, was agitated in places by currents. Such conditions might exist off the shore of a sea or a large lake or in an estuary. Similar beds in Idaho and western Montana that are supposed to be contemporaneous with those of the Ravalli formation are marked with abundant ripple marks and mud cracks, indicating that they were deposited on mud flats that must have lain close to dry land and suggesting deposition in an estuary. The corresponding strata in the Philipsburg quadrangle appear to be a seaward though perhaps not strictly marine extension of these beds. The increase in the proportion of muddy material contributed to the higher beds of the formation may have been due to excess of subsidence over sedimentation, but the increase was so gradual that it might be explained as the result of diminished erosional activity of the streams owing to a wearing down of the land surface.

The Newland formation combines a calcareous composition, which is most common in sediments deposited in water of considerable depth, with features that are plainly due to shallow-water and even subaerial deposition. Its muds and sands were laid down in a vast basin, never deeply submerged as a whole, a part of which might be covered by water in one year and exposed to the air in the next by evaporation or the shifting of a stream. The rivers that carried in the sediment probably drained an old land surface from which erosion was much in arrears at its task of removing the products of subaerial decay, among which carbonates were abundant. The rivers would therefore be abundantly charged with various salts and might deposit a large part of their less soluble load, such as the carbonates of lime, magnesia, and iron, in a broad, shallow basin from which there was abundant evaporation. The absence of gypsum or rock salt from the Newland formation might be explained by supposing that the basin had an outlet, and that the relation between outflow and evaporation was such as to produce a degree of concentration which resulted in the precipitation of carbonates of calcium, iron, and magnesium, but not in that of relatively soluble substances. An alternative or supplementary cause of precipitation might be the decay of low aquatic organisms, which is capable of precipitating insoluble carbonates from the dissolved sulphates.

The Spokane formation has in common with the Newland, though in still more striking development, the features that indicate deposition in shallow water or on dry land. On the other hand, its differences from the Newland indicate corresponding differences in conditions of deposition.

The virtual absence of lime from the later formation might be the result of continuous drainage toward the ocean. It is probable, however, that the rivers of Spokane time were less heavily charged with carbonates than those of the preceding period. The progressive coarsening of the material deposited during the Spokane epoch indicates that the land was being elevated and that as erosion more and more nearly kept pace with decay, carbonates were formed less and less abundantly. An arid climate entailing scarcity of vegetation would further decrease the rate of carbonation and account for the low hydration of the abundant red iron oxide in the Spokane formation. The sandstones, which are most abundant in the upper part, bear strong marks of current action, indicating deposition in flowing rather than stagnant water.

The formation can be most satisfactorily explained as a deposit laid down by the shifting current of a muddy river on a vast subsiding delta plain. At any given time a large part of such a plain would be dotted with shallow lagoons and other parts would be wholly dry, and the beds of newly desiccated ponds would be covered with upcurled flakes of smooth red mud. Small fragments of this mud, made brittle by the sun, would become loosened and mingle with the wind-blown sand to form a peculiar sandstone, such as is described on page 5.

PALEOZOIC ERA.

The unconformity between the Algonkian and Cambrian strata, which is general throughout the Rocky Mountain region and especially distinct in the Philipsburg quadrangle, records earth movement and erosion that probably occurred in early Cambrian time. The deposition of the Belt series was terminated by extensive upheaval and warping of the crust. A vast area was thus exposed to erosion, gradually stripped of a layer of rock whose thickness amounted in places to several thousand feet, and finally reduced to rather low relief.

This long period of erosion was followed in Middle Cambrian time by an invasion of the sea, due to a gradual subsidence of the land that seems to have begun at the east and to have moved westward. At first the sea was shallow, and its earliest deposits were beach sands represented by the Flathead quartzite. The waves were in places vigorous enough to pluck fairly large fragments of Algonkian sandstone from the shore and shape them into pebbles and cobbles.

As the sea became deeper, glauconitic greensands, represented by the lower part of the Silver Hill formation, and limy muds, represented by its upper part, were successively deposited. They in turn were covered with limy ooze, almost free from earthy material, represented by the lower member of the Hasmark formation, which must have been deposited in fairly deep water at considerable distance from shore. Similar conditions existed during most of the remainder of Cambrian time, but they were not continuous. The shale beds that alternate with the Cambrian limestone are probably due to upheavals that stimulated erosion on the land and brought the shore line nearer to the site of deposition, so that the waters occupying the Philipsburg region were muddy. A somewhat greater upheaval in late Cambrian or post-Cambrian time is indicated by the sandy character of the lower part of the Maywood formation, whose ferruginous and sandy limestones are such as might have been laid down in a shallow inland sea.

It is uncertain whether or not the Philipsburg quadrangle became a land area between the deposition of the Red Lion formation and that of the Maywood. But the absence of strata between the Maywood, which may be Upper Cambrian, and the Devonian Jefferson limestone, and, still more definitely, the local conglomerate at the base of the Jefferson, indicate that during some part of the interval between the Cambrian and Devonian periods the Philipsburg region stood above sea level and underwent erosion. Its elevation was not accompanied by tilting, for no angular unconformity has been produced.

Early in Devonian time the land was depressed, apparently with some rapidity, so that deep-sea conditions soon supervened, and they persisted long enough to allow the accumulation of about 1,000 feet of limestone containing marine fossils. No clear local evidence indicates any complete interruption of sedimentation prior to the beginning of Mississippian time, but the absence of any beds demonstrably corresponding to the Threeforks formation, which represents the Upper Devonian in central Montana, suggests the possibility that the area included within the quadrangle was land in late Devonian time.

The Mississippian epoch was the last in which the oceanic conditions requisite to the deposition of relatively pure limestone were long maintained. About 1,500 feet of this material, rich in corals and shells of the mollusks and brachiopods which abounded in the waters of the Mississippian sea, was deposited.

The sharp lithologic distinction between the Madison limestone and the basal part of the Pennsylvanian Quadrant formation is evidence that they were deposited under very different conditions, and that the change was rather sudden. The inequalities in the thickness of the Madison limestone and of the lower member of the Quadrant make it even appear probable that there was an interval of erosion between the two formations. The red shales and impure limestones of the lower member of the Quadrant have yielded marine organic remains; but these forms were probably not oceanic. Their lithologic character suggests that the beds were laid down in some inland sea subject to much evaporation, a hypothesis confirmed by the finding of gypsum beds and molds of salt crystals in the similar rocks of the Quadrant formation in the Great Falls region.

The quartzites of the upper part of the Quadrant are probably beach deposits, superposed upon the fine-grained rocks of the lower member after an interval of erosion, for continuous deposition would have been recorded by a gradual instead of an absolutely abrupt lithologic transition. It therefore may be supposed that the inland sea of early Quadrant time was filled or upheaved and its bed, after a brief period of erosion, again invaded by the sea, whose advancing margin gradually covered the surface with a layer of beach sands. An interlude in these conditions is represented by the calcareous and phosphatic beds between the quartzite strata. The carbonate and the oolitic phosphate of lime are presumably chemical precipitates and are most likely to have been formed in a shallow inclosed sea. The wide expanse and the unbroken continuity of the phosphate beds in this region indicates that the sea extended continuously over a large part of Montana, Idaho, Utah, and Wyoming.

MESOZOIC ERA.

About the close of Paleozoic time, or in the early part of the Mesozoic era, the sea bottom was again upheaved and exposed to erosion. The absence of Triassic deposits from the Philipsburg area may mean that it was a land surface during the Triassic period or that Triassic deposits were laid down and afterward removed. The local absence of the upper quartzitic stratum at the Rock Creek locality may be due to this post-Carboniferous erosion, which accounts, at any rate, for the presence of chert pebbles in the Ellis formation. During the part of Jurassic time represented by this formation the region was covered by sea water of rather slight depth. That the shore can not have been remote is attested by the conglomeratic nature of some of the beds and the presence of much earthy matter even in the limestone.

The sea bottom upon which the Ellis formation—and possibly some later deposits that have since been removed—had been laid down became a land area in early Cretaceous time and then became the site of fresh-water deposition. The large area in Montana and the adjoining part of Canada which was overlain by the Kootenai formation was perhaps never covered by one continuous lake but appears to have been a great interior basin, occupied partly by lakes and partly by marshes and river flood plains. In the marshes peat was formed which later solidified into beds of coal that are characteristic of the formation in many areas, though not, so far as known, in the Philipsburg quadrangle. The mud breccias and related features were found on mud flats which were not necessarily of great extent. Limestone beds represent marl deposited on the bottoms of lakes, the later of which contained abundant fresh-water snails and clams.

As a part of Cretaceous time intervening between the Kootenai and Colorado epochs is not represented in the Philipsburg quadrangle, the region must have been upheaved and eroded within that interval. After having thus become land, the region was once more submerged beneath the sea, whose first deposits consisted of black mud which has solidified as the shaly lower member of the Colorado formation. The sediments contained much carbonaceous matter, which in places outside the quadrangle formed layers of sufficient purity to constitute coal beds. The coarseness of the later beds mapped as Colorado in this area indicates a shallowing of the sea by sedimentation or upheaval.

CENOZOIC ERA.

TERTIARY PERIOD.

NATURE OF RECORD.

The pre-Tertiary history of the region, a relatively monotonous story of sedimentation occasionally interrupted by upheaval, erosion, and resubmergence, must be read almost wholly from a succession of stratified rocks. The history of the comparatively brief time embraced in the Tertiary period was far more eventful and its record far more complex. The earth's crust, which had been comparatively stable during Algonkian, Paleozoic, and Mesozoic time, was repeatedly crumpled, broken, or tilted in the Tertiary, and the record of these events is found in the geologic structure. In Tertiary and Quaternary time the region was chiefly land exposed to erosion, which is recorded in sculpture as well as in deposits. Igneous activities, which had been almost wholly dormant before, became vigorously active during a large part of the Tertiary period and are recorded by bodies of intrusive rock, lava flows, and pyroclastic deposits.

This varied record is capable of yielding a fuller knowledge of the later history than can be attained concerning the earlier, but it is hardly feasible in default of special studies not yet made to narrate the Cenozoic events in chronologic sequence nor fully to decipher the interrelations of igneous, orogenic, and sculptural agencies. It is therefore convenient to employ a topical division of the general subject, and to discuss in turn (1) deformation, (2) igneous intrusion, (3) volcanic eruptions, (4) physiographic development. It is necessary, however, in discussing each agency, to make some reference to others which it influenced or by which it was influenced.

DEFORMATION.

The great upheavals that gave birth to the Rocky Mountains started near the beginning of the Tertiary period. The strata were then thrown into folds, and at the same time the surface was probably upheaved as a whole, but the upheaval was greater in the western part of the Rockies than in the eastern part of the Great Plains. The margin of the more elevated area was subject to strain, which finally produced extensive north-south fissures with a gentle westward dip. These fissures afforded a means of relieving lateral pressure, by the thrusting of the more elevated western mass over the lower mass on the east. Thus the Philipsburg thrust zone, the Lewis overthrust near the international boundary, the Bannock overthrust in southeastern Idaho, and other connecting links and continuations not yet found, were probably formed almost simultaneously. Thrusts in other directions, exemplified on Mount Haggin and near Lost Creek, probably occurred at about the same time.

Thrust faulting, however, did not fully satisfy the compressive forces that had come into play. It was possibly brought to an end by warping of the thrust planes with consequent increase of friction. At any rate, folding was renewed, and strongly affected the overthrusts as well as the strata; the thrust planes were bent into well defined folds, and even overturned in places.

Simultaneously with the great thrust faults and the folds, minor thrust faults and probably even normal faults were formed, but most of the normal faults, which were probably the result of tension, were subsequent to the features that are clearly the result of compression.

After the great deformation was accomplished there occurred some feebler crustal movements, attested by shearing and faulting of intrusive rocks, minor faulting and folding of the earlier gravels, and tilting of the peneplain surfaces and some of the later gravels. The earliest of these deformations were undoubtedly those that principally affected the intrusive rocks. The tilting of early gravels and peneplain surfaces came somewhat later, and a tilting of some of the terrace gravels was probably the latest crustal movement of which there is a legible record. There are indications that the broad depressions are in part the result of downwarping of the crust. Among these indications are the coincidence of these valleys with axes of folding, their lack of branches coordinate with them in size, and incongruities of drainage with relief that will be touched on later.

INTRUSION.

With the exception of a few basic sills, injected prior to any strong folding, the intrusive rocks that form so large a part of the Anaconda and Flint Creek ranges were intruded either during the period of strong deformation or just after its close. Evidence observed within the quadrangle (see pp. 11 and 12) shows pretty conclusively that all the batholithic intrusions were post-Colorado and pre-Miocene, but the period of intrusion may have extended over much of late Cretaceous and early Tertiary time. That the period was long is indicated by the great difference in the amount of shearing that has been undergone by adjoining intrusive bodies and by the rather numerous sequence of intrusions observed in some places. Even more definite proof is found in the northeastern part of the quadrangle. The structural relations of the Royal batholith indicate that it was intruded long before the folding was complete and that it was strongly sheared after solidification; the Mount Powell batholith, on the other hand, has not been sheared and presumably solidified after most of the deformation of the pre-Tertiary rocks had been accomplished.

The order in which the several kinds of magma were intruded is not fully known. Observations in the Anaconda and Flint Creek ranges have virtually proved the following sequence: (1) Diabase and other basic sills, (2) acidic diorite of Mount Haggin and other places, (3) nonporphyritic muscovite-biotite granite, (4) acidic granodiorite, (5) porphyritic biotite granite, (6) porphyritic muscovite-biotite granite. Of the position of the medium and basic granodiorites that are so abundant nothing is known except that the granodiorite of Storm Lake is later than the acidic diorite. So much is probably true of all the granodiorites, and it may even be conjectured that all but the most acidic are nearly contemporaneous, for although the range of composition shown by the rocks mapped in the same color as the granodiorite of Storm Lake is wide it is not more so than that which is commonly found in a single intrusion of this rather variable species. It may be conjectured for the same ground that these granodiorites are closely related in genesis to the Boulder batholith. Another large intrusive mass of doubtful age is the Royal batholith. It is evidently among the oldest. The relative age of many of the minor intrusions is indeterminable.

The intrusion of large masses of magma caused extensive alterations in the sedimentary rocks. Heat was conducted to these directly and conveyed by fluids given off by the magmas, and any water originally contained in the sediments at the time of intrusion was heated and set in vigorous circulation. The gases given off by the magmas certainly included much chlorine, some fluorine and boron, and probably water vapor. The heating and solvent action of the circulating water and the chemical activity of magmatic gases caused the original constituents of the rocks to form new combinations. The rocks assumed crystalline textures and as a rule became much harder. Less conspicuous alterations were produced in the oldest basic igneous rocks.

VOLCANIC ERUPTIONS.

Most of the volcanic eruptions whose products are found in the Philipsburg quadrangle occurred in the Miocene epoch, though the earliest may have occurred in the Eocene. They appear to have been considerably later than any of the important intrusions, none of which probably reached the surface. The lavas welled up in comparatively quiet fashion, but the tuffs and volcanic ash are the product of explosive eruptions, whose vigor may be appreciated from the large size of the blocks found in the tuffs of the southeastern part of the quadrangle.

The situation of the Tertiary volcanoes that gave forth these materials is somewhat conjectural, but it is certain that some stood near Anaconda. This fact is indicated by the abundance and coarseness of the fragmental volcanic rocks in the southeastern part of the quadrangle, which can not have been blown so far from their source as the much finer volcanic ash that lies in the Philipsburg and Rock Creek valleys. Moreover, volcanic pipes filled with solidified lava may actually be seen just east of the quadrangle, near the Washoe smelter. Erosion and deposition were active during and between the eruptions, which must have been somewhat intermittent and largely determined the present form of the volcanic deposits. Showers of tuff were spread over hills and valleys in sheets of nearly even thickness, but winds and waters must soon have concentrated most of the finer material in the depressions, where some of it undoubtedly was deposited in a dry condition, some was arranged by streams and some settled in lakes. The coarsest material must have been the least subject to redistribution, but the abundance of andesitic gravel near Anaconda indicates that much coarse tuff was transported for some distance by streams.

PHYSIOGRAPHIC DEVELOPMENT.

Ever since the Tertiary upheaval parts of the quadrangle have been undergoing erosion. The thickness of rock thus removed must amount to at least 20,000 feet where the oldest strata are exposed, and the average for the quadrangle as a whole can hardly be less than 10,000 feet. Most of the products of this erosion were evidently carried far away, and the oldest surfaces now extant were carved after the greater part of it had been accomplished. They are later than the intrusive rocks but are older than the volcanic rocks.

The older sculptural features are the flat upland surfaces, which, for the sake of simplicity, may be regarded as one, and the bedrock slopes of the broader valleys. The relative age of these two topographic types, which are of regional development, may conceivably be explained according to either of the following hypotheses:

(1) A rugged topography was produced by erosion in early Tertiary time. The entire surface was then brought near to a common level partly by erosion of the uplands and partly by filling of depressions with detrital and pyroclastic deposits. The bedrock valleys, which, according to this hypothesis, would be older than the peneplain, have been largely cleared of their soft filling, whereas the harder upland surfaces have been much less reduced.

(2) The region was reduced to low relief early in the Tertiary period; erosion was then invigorated by upheaval or otherwise, and broad valleys were sunk in the upland surface or peneplain. The valleys were subsequently filled wholly or in part with gravel, volcanic ash, etc. The valleys would thus be younger than the plateau-like remnants of the old flat surface.

The second hypothesis appears to be best supported. The course of Tertiary erosion and deposition may, then, be tentatively outlined as follows:

The land upheaved by the Tertiary revolution was vigorously attacked by streams. It was carved into a bold topography, of which all traces have been obliterated, for erosion proceeded until the mountains were reduced to a rolling plain dotted with hills. While the uplands were being reduced the products of erosion were being deposited in the broadening valleys. Some of the highest flat surfaces and some of the earlier gravels doubtless belong to this period.

Then followed the deformation and upheaval recorded in the tilted attitude of the earlier gravels and the warped peneplain surfaces. The broad valleys were probably formed at this time, in part perhaps by down-warping but certainly in part by erosion, which was stimulated by the upheaval.

In Oligocene and Miocene time the depressions were partly or completely filled with lava, tuff, volcanic ash, and detrital material. The basins were probably occupied in part by lakes, for some ponding of drainage must inevitably have attended the outpouring of volcanic material.

It was after the basins were thus filled that most of the erosion of the mountain canyons was accomplished. Mere cessation of volcanic eruptions of tuff, which formed a protective blanket, renewed at intervals, would have sufficed to make erosion more effective, but erosion was also stimulated by deformation. Slow rising of mountain ridges against streams of established course may be one of the reasons why many streams in this region emerge from basin valleys through deep gorges rather than through more open passes. Thus Philipsburg Valley drains northward through a canyon instead of southward through the lowest part of its bedrock rim; and Henderson Gulch, cutting eastward through a bold ridge, takes part of the drainage of an old valley whose natural outlet would appear to be northward. These phenomena may be due, however, to another cause. From basins that were completely filled with sediments the streams might escape through any gap in the rim, coincident or not with the old exit, that was no higher than the level to which the sediments had accumulated, and as they in the process sank they would cut narrow gorges in the hard rocks and wide valleys in the soft materials.

In any case, a broad layer of the volcanic ash was removed from the valleys by post-Miocene erosion. In a comparatively short time, however, the valleys became areas of deposition, while vigorous erosion continued in the mountains, and a part of the gravel was spread out over the valley floors, remnants of which now form the higher terraces.

Even these terraces, probably of Pliocene age, appear to have been deformed. Their general dip toward the axis of the valleys is due partly, of course, to the fact that the small streams and rills deposit most heavily at their first emergence into the broad valleys, but the position of the patch of gravel 7 miles west by north of Philipsburg seems best explained as the result of warping, which must once more have accelerated erosion in the uplands.

QUATERNARY PERIOD.

In early Quaternary time, when the relief in its larger features was similar to what it is now and the mountains were somewhat higher, the climate became much colder and the precipitation heavier than it had been before. Both topographic and climatic conditions were very similar to those that now exist in the Canadian Rockies, and resulted in the formation of glaciers resembling those now found in that region. From a hundred sources on the lofty peaks and ridges the ice flowed down the canyons eroded by preglacial streams, and many joined each other to form trunk glaciers. These melted more and more rapidly as they descended into warmer air and terminated in the broad valleys, where they had so little protection from the sun’s rays that the rate of melting balanced the rate of supply from the cold uplands. A copious stream of water, milky with ground rock, issued from the foot of each glacier and spread mud and gravel upon the valley floors below.

The climate then grew warmer, causing the glaciers gradually to shrink and finally to vanish, so that conditions were similar to those of to-day. Stream erosion and the agents of disintegration and decay softened the old glacial sculpture, and in large part removed its moraines. But glacial conditions were to come and to vanish at least once more, perhaps several times, though positive evidence of more than two glaciations has not been found in this quadrangle. The moraines and sculpture of the later glaciation, which was probably somewhat less extensive than the greatest of the earlier, are almost intact, and the great disparity in preservation between the earlier and later deposits makes it appear that much more time intervened between the two—or the last two—glacial stages than has elapsed since the last glaciers were at their maximum. This later period was largely occupied by the slow, vacillating retreat of the glaciers, remnants of which may have lingered in the shady cirques until a comparatively recent date.

A collateral effect of glaciation in both periods was the ponding and diversion of drainage. While the glaciers were largest, ice dams retained extensive lakes in Philipsburg Valley and the basin now occupied by the Georgetown reservoir. Philipsburg Valley drained through its former outlet when the ice dam was withdrawn, but the glacial Georgetown Lake had made itself a new outlet before this occurred, and the drainage which had so long been barred from its natural egress toward the east was transferred to the western slope of the Flint Creek Range. The history illustrated by these two examples was paralleled by that of small streams that drained into canyons usurped by glaciers.

The relatively small amount of erosion that has taken place in the region since the final disappearance of the glaciers is indicated by the slight extent to which the records of the last glaciation are defaced: the moraines in general show little erosion, and large areas of glaciated bedrock retain their glacial polish. The most conspicuous postglacial change in the cirques has been the accumulation of talus, composed chiefly of blocks riven by frost from cliffs of jointed rock. Lower down the streams have in places sharply intrenched the floors of the glaciated canyons. Still lower, in parts of the valleys encumbered with moraines that have impounded the streams, alluviation has been more active than erosion and has begun to fill the hollows among the moraines. Long after the withdrawal of the ice these hollows must have been thickly studded with small lakes, a few of which still remain. Alluviation has been active in the valleys beyond the moraines, in postglacial as well as glacial time. The early Quaternary stream gravels, however, have been intrenched and form terraces.

METALLIFEROUS MINERAL RESOURCES.

By W. H. Emmons.

The ore deposits of the Philipsburg quadrangle are treated fully in Professional Paper 78 of the United States Geological Survey. In this folio the nature and occurrence of the ores are discussed briefly and the conclusions regarding their genesis are summarized. The detailed descriptions of mining districts and of mines in Professional Paper 78 are not repeated, and much descriptive matter upon which conclusions are based is either omitted or briefly outlined.

HISTORY.

The first workable placers discovered in Montana were found on Gold Creek, a few miles north of this quadrangle, by James and Granville Stuart, who, in 1862, built sluice boxes and took out a small amount of gold near the present site of Pioneer. A year later the deposits of Alder Gulch, 100 miles southeast, were discovered and this led to the founding of Virginia City. Stimulated by success at Alder Gulch many parties were organized for prospecting. In the few years following lodes were discovered in a majority of the mining districts which subsequently proved important sources of the metals. The first lode discovered in the Philipsburg quadrangle was that of the Hope mine, found by Horton in 1864. Soon afterward the Trout, Algonkian, and other lodes were located. The Cable mine was discovered in 1866. The Hope mill, one of the oldest in Montana and still in operation, was built in 1867. Placer deposits were worked at Henderson (Emmettsburg), Cable, Gold Creek, and Georgetown but were much less productive than the lode deposits. The Granite Mountain mine, financed by C. D. McLure and associates, was opened in the early eighties and for several years paid about $2,000,000 dividends annually. The Bimetallic mine, located on the same lode and controlled largely by the same interests, was opened soon after the Granite Mountain and was in successful operation for several years. The two mines were consolidated in 1898 as the Granite-Bimetallic Consolidated Mining Co. These camps reached the zenith of their prosperity from 1881 to 1893, when the larger ore shoots of the Granite-Bimetallic, Hope, Combination, Pyrenees, and Cable mines were uncovered. At this time Philipsburg was one of the most important silver camps of the United States. With the completion of the Northern Pacific Railway in 1883 and the Philipsburg branch in 1887 mining costs were greatly reduced and the companies were enabled to pay a larger percentage of their receipts to the stockholders. The total production of the mines of the quadrangle, as nearly as can be estimated, is $50,000,000, of which about 80 per cent is silver and nearly all the remainder gold. Most of this metal has been won from the ores by roasting with salt and by pan amalgamation.

THE ORES.

Some of the ores carry, besides gold and silver, small amounts of copper and lead. Amalgamating methods do not save the copper and lead, but some part of these metals is recovered from such ore as is shipped to smelters. Low-grade ore of the Cable mine recently smelted at Anaconda was more valuable for copper than for gold. The deposits of magnetic iron have been utilized for flux at several Montana smelters and a few hundred tons are still shipped annually.

The manganese deposits in the area east of Philipsburg, which in part at least are the gossans of rhodochrosite deposits, have been mined for flux, and a few cars have been shipped to steel manufacturers. Portions of the silver-gold lodes near Philipsburg carry considerable zinc blende, which is not at present utilized.

OCCURRENCE AND DISTRIBUTION OF THE ORES.

Metalliferous deposits are distributed over a large part of the quadrangle but are most numerous in the northern and northeastern portions. The Flint Creek mining district, which includes the Granite-Bimetallic, Hope, and other mines, is the most important, but the Georgetown (Cable), Black Pine (Combination), and the Boulder Creek districts have each yielded considerable gold or silver. In the Anaconda Range, in the southeastern part of the quadrangle, there are small quartz veins, but no profitable deposits have been found.

The quadrangle is an area of sedimentary rocks intricately folded, faulted, and intruded by granitic rocks. The deposits occur in both sedimentary and igneous rocks. Most of those in sedimentary rocks are confined to the vicinity of igneous intrusions. The most productive deposits are not more than a mile from such contacts. Since all of the consolidated sedimentary rocks are older than the intrusive rocks and older than the deposits, the latter may at favorable places be found in any of the Paleozoic or Mesozoic formations.

The Philipsburg batholith, which is of granodiorite and one of the largest bodies of intrusive rock in this area, is bounded nearly everywhere by sedimentary rocks, which at places near the contact are greatly metamorphosed. The granodiorite and the sedimentary rocks near by are cut by fissure veins and on Hope Hill valuable bedding-plane deposits are developed in the limestones. In the Red Lion district north of Georgetown gold-bearing veins cut the limestone near the granodiorite. Except some replacement deposits of magnetite, no contact metamorphic deposits are developed near this batholith. The Cable batholith is somewhat similar in lithologic character to the Philipsburg batholith but is smaller. Valuable gold deposits are found in limestones near the contacts. Of these the Cable ores are intergrown with calcite, magnetite, pyrrhotite, and other minerals, and are presumed to be of contact-metamorphic origin. The ores of the Southern Cross and other mines near by are replacement veins in limestone. In the northeast corner of the quadrangle there is another large area of granitic rock which, like the intruded sediments near by, is cut by numerous gold and silver veins. The Queen and Bunker Hill mines, in the northern part of the quadrangle, are in limestone near intruding granite. The Combination mine in quartzite, some 3 or 4 miles southwest, is about a mile from a dike of quartz porphyry.

THE FISSURES.

The fissures which cut the rocks of the quadrangle are believed to have been formed by relief from compressive stresses. They may be divided into two groups—those which were formed before the ore was deposited and which therefore may contain veins, and those were formed after the ores were deposited and which may brecciate or cut across and displace veins. A large number of fissures are not mineralized and these include faults of great throw. Four of the vein deposits fill fault fissures on which the movement was considerable, but none of these deposits that have been yet exploited are of great value, and most of the ore-bearing fissures have no measurable displacement. The mineralized fissures of the quadrangle strike toward all points of the compass and taken all together do not fall into well-defined coordinate groups, but there is a marked parallelism for the fissures of restricted areas, as in the mineralized area east of Philipsburg. At a number of places, notably at the Hope, Combination, and Headlight mines, the deposits are crossed by fissures and have been faulted since they were formed, but in general the throw of these faults is not great. At least 90 per cent of the postmineral faults are of the normal type, implying a downthrow of the hanging wall.

CLASSES OF DEPOSITS.

Types discriminated.—The ore deposits of the quadrangle are:

A. Deposits filling fissures.
   1. Silver-bearing veins in granite.
   2. Gold-bearing veins in granite.
   3. Silver-bearing veins in quartzite.
   4. Gold-bearing veins and sheeted zones in quartzites.

B. Replacement deposits related to fissures or to bedding planes.
   5. Silver-bearing replacement veins in sedimentary rocks.
   6. Silver deposits in bedding planes of calcareous rocks.
   7. Gold-bearing replacement veins in sedimentary rocks.

C. Replacement deposits of contact-metamorphic origin.
   8. Gold-copper deposits.
   9. Magnetite deposits.

D. Gold placers.

Fissure veins.—The silver-bearing veins in granite include the deposits of the Granite-Bimetallic, Hobo, Silver Chief, Mitchell, and other mines. The outcrops of these deposits are usually lean, but some siliceous rock stained with iron and manganese oxides, horn silver, and silver-bearing lead carbonate may form in the gossan. The upper parts of these lodes contain very little gold. Some of these deposits, notably the Granite-Bimetallic lode, have been greatly fractured since they were deposited and show unmistakable evidence of downward enrichment. The upper zone of the Granite-Bimetallic lode, extending from the outcrop to a depth of 10 feet to about 400 feet below the surface, is leached of much of its valuable content and below this zone to a depth of about 800 feet lies a zone of rich oxidized and rich sulphide ore. The rich sulphide ore is composed of primary low-grade sulphide ore cut by numerous veinlets which are filled with ruby silver and other minerals. Below this zone the primary sulphide ore is relatively low grade. The most favorable depth for prospecting these lodes is from 200 to 500 feet below the surface for veins which are highly fractured.

The gold-bearing veins in granite include the Royal, Sunday, Pyrenees, Luxemburg, and other lodes. The outcrops are siliceous iron-stained rocks, generally carrying little or no manganese. Some of these are simple fissure fillings and some are composed of several small, closely spaced veins which form sheeted zones. There is no clear evidence of enrichment of these deposits except residually, through oxidation, by which the upper zones of the veins become proportionally richer through the removal of sulphur and part of the iron of the primary ore. Some of the ore shoots are related to intersections of veins. The most favorable places to prospect the gold veins are at intersections and in the upper zones of veins at a depth from 10 to 200 feet below the surface.

The silver-bearing veins in quartzite include the deposits of the Combination, Albion, and Powell mines. The Combination vein fills a fissure in quartzite of the Spokane formation and is oriented approximately with the bedding. These deposits are highly siliceous and therefore weather slowly, and their apices are likely to be indicated by outcropping quartz or by loose quartz débris, but the outcrops seldom form reefs above the surrounding country. The ore is of low grade except where it has been shattered and enriched by secondary processes. Some of these deposits have been faulted since they were formed and generally the downthrow is on the hanging-wall side.

The gold-bearing veins in quartzite are numerous, but their production has been small. Some of them are sheeted zones. As a rule the ore is quartz and pyrite, but at the Golden Eagle mine free gold with tourmaline gangue fills thin joint fissures in quartzite.

Replacement veins.—The silver-bearing replacement veins in sedimentary rocks include the deposits of the Trout, Blackmail, Headlight, and other mines. These veins fill the same set of fissures as those which were filled by the silver-bearing veins in granite and the ore is closely similar. In the calcareous rocks, however, the veins are of the replacement type and are much less regular in shape than those of the silver veins in granite. The silver veins of both these groups have been opened since they were formed and waters rich in manganese carbonate have deposited much rhodochrosite in fractures and around the fragments of more siliceous ore. Where the country rock was limestone it has been extensively replaced by manganese carbonate.

The silver deposits in bedding planes of calcareous rocks include the ore bodies of Hope Hill and several smaller deposits in the valley of Warm Spring Creek. The deposits are highly siliceous and as they occur in soluble rocks they may have conspicuous outcrops. The ore shoots are related to fissures, to bedding planes, to thin beds of intercalated shale, and to saddles or minor anticlines. The extent to which these deposits have been enriched by secondary process is not fully understood, but where horn silver is present it appears to have been formed most extensively within 200 feet of the surface.

The gold-bearing replacement veins include the Southern Cross, Red Lion, Hannah, and other deposits, principally in the Cambrian dolomites. They usually outcrop as soft ferruginous iron-stained rock which carries considerable quartz. These deposits are similar in their general features to the silver-bearing replacement veins, but the tabular form is not so evident in most of them. Many are oriented approximately with the bedding planes of the country rocks. Some of the largest ore bodies occur at intersections of fissures, and such places should be regarded as favorable ones for prospecting. Most of the deposits of the group have been disturbed and fissured since deposition, and surface waters have had free access to them. Most of the richest ore lies at a depth of 10 to 100 feet below the surface and at some places extends at least 250 feet below the surface. Some of these veins contain pyrrhotite, magnetite, and specularite, and this group of minerals indicates that such veins were formed under considerable pressure or at high temperature.

Contact deposits. — The contact-metamorphic gold-copper deposits are in highly metamorphosed calcareous rocks near their contact with the granite of the Cable batholith. The ore is composed of calcite, quartz, sericite, chlorite, pyrite, chalcopyrite, magnetite, pyrrhotite, and other minerals, with which free gold is intimately associated. During the metamorphism of the country rock the gold was deposited presumably by the aqueous solutions which were given off from the igneous rock.

Contact-metamorphic deposits of magnetic iron are found at a number of places near Philipsburg, Cable, and in Olson Gulch. These ores are associated with calcite, diopside, scapolite, forsterite, garnet, actinolite, and other minerals of contact-metamorphic origin. The magnetite was deposited through replacement of limestone by solutions given off by cooling igneous rocks near by. These deposits are primary and are not to be regarded as the gossans of sulphide deposits.

GENESIS OF THE ORES.

As shown in the account of the geologic history a long period of sedimentation began in pre-Cambrian time and extended through the Mesozoic era. After the Mesozoic rocks were deposited igneous intrusions broke through the sedimentary rocks and formed the great batholiths. The sedimentary rocks were metamorphosed by the intruding igneous rocks and at some places garnet, tremolite, actinolite, and other contact-metamorphic minerals were formed. At this time the gold-copper contact-metamorphic ores of the Cable mine and large bodies of magnetite were deposited by solutions emanating from the cooling intrusions. Some of the gold-bearing replacement veins were formed at about the same time. After the granite had solidified, compressive stresses were set up and fissures were formed in the intrusive masses and in the sedimentary rocks near by. These were filled by metalliferous solutions that carried an excess of silica, alkaline carbonates, and sulphides. Sericite, calcite, pyrite, and other minerals were deposited in the wall rock by processes of hydrothermal metamorphism. The solutions were ascending. The deposits they formed were very extensive vertically and where the country rock was limestone and this was gently flexed the anticlinal folds were the most extensively replaced by ore; where shale beds were interstratified with limestone the ore was in some places deposited below the bed of shale, but not above it. In the Granite mine there is evidence that the richest ore shoots are related to junctions of fissures, where presumably the mingling of solutions was a favorable factor. The greatest enrichment is above approximately horizontal junctions. Approximately vertical junctions do not seem to have been influential in the process of enrichment. Such relations of the enriched portions of the lodes suggest ascending waters and give additional weight to the evidence afforded by the relation of ore shoots to beds of shale and other structural features. The ore deposits are more numerous in the igneous rocks and in the sedimentary rocks near igneous contacts than at a distance from such contacts, and the important bodies of ore so far as known are limited to such positions. This distribution indicates that the ore deposits are conditioned upon the presence of the igneous rock and suggests the probability that the ascending waters were solutions given off from the intrusives which are exposed, or from deeper unexposed igneous rocks.

AGE.

Since the intrusive rocks to which the ores are genetically related cut late Cretaceous strata, the ores are younger than these beds. They were therefore formed in very late Cretaceous or in Tertiary time. It has been shown that some of the deposits were probably formed 7,000 feet below the surface at the time of deposition, consequently there must have been considerable erosion since the ores were deposited. The Miocene beds, which are generally flat-lying, are, as shown on preceding pages, later than the period of profound fissuring and eruptive activity and later therefore than the ore deposits. These facts show that the deposits were formed not later than early Tertiary (Eocene), and as there was much erosion before the Miocene beds were laid down the ores were probably deposited not later than the earlier part of the Eocene.

PLACER DEPOSITS.

The placer deposits of this quadrangle have not been highly productive. As nearly as they can be estimated they have yielded less than $2,000,000. The silver-gold lodes at Philipsburg, Combination, and other deposits, predominantly argentiferous, have not yielded placers; the auriferous lodes at Henderson, Cable, Georgetown, and in the drainage basins of Boulder and Gold creeks, have supplied workable gravels. At present not more than a few thousand dollars worth of gold is obtained annually from placers, and in the summer of 1907 about a score of men were engaged in washing. The methods employed are groundsluicing and hydraulicking. At some places drifts are run along the bedrock. The deposits are stream gravels and glacial gravels. As a rule the material is so coarse that it is expensive to remove and the profits of operation are small. It is possible, however, if the depth to bedrock does not prohibit operations, that certain deposits near Henderson and Cable may be worked by cheaper methods.

NONMETALLIFEROUS RESOURCES.

By F. C. Calkins.

Although not comparable with the ores in economic importance, some nonmetalliferous mineral resources deserve brief mention. These are water, limestone, silica, phosphate, and building stone.

Water. — Water is utilized not only for the ordinary domestic uses, but in small measure for irrigation and in larger measure for power. Wells sunk in the valleys reach water at moderate depths and among the hills the many streams render wells unnecessary. Although irrigation is practiced on a small scale by farmers in Philipsburg Valley, no important system of ditches has been constructed, and the demand is far from overtaxing the supply.

At the time of survey water power was used in only one large plant—that of the Anaconda Copper Mining Co., on Flint Creek between Philipsburg Valley and Georgetown Lake, which is utilized as a reservoir. This development takes advantage of a remarkable combination of natural conditions, which seem first to have been recognized by the late Paul A. Fusz. Not many years ago, the site of Georgetown Lake was merely a broad meadow with no more standing water than sufficed to make a part of it marshy. It received however, the waters of a large drainage basin, and emptied through a gorge of remarkably steep gradient—about 600 feet in the first mile—which ended in a broad flat valley that afforded site for a power house. A very small dam at the head of the gorge sufficed to convert the basin into a lake, which now has an area of about 6 square miles. The water is conveyed by a flume to a point directly uphill from the power house, whence the current is wired to Anaconda. The water power was formerly owned by the Granite-Bimetallic Mining Co. but is now the property of the Anaconda Copper Mining Co.

Silver Lake is used as a storage reservoir by the same company. The waters of Storm Lake and Twin Lakes creeks are diverted to it, and water is pumped from it to augment the flow of Warm Spring Creek when that is insufficient. Storm Lake and Hearst Lake also have been increased in capacity by damming and are used as storage reservoirs.

Limestone. — Limestone is abundant in the Philipsburg quadrangle, but it is so generally distributed over a large part of western Montana that its value in this region depends mainly on accessibility and demand. It is not exploited in this quadrangle except at the localities most accessible from Anaconda. At Browns, on the railroad up Warm Spring Creek, there is a large limestone quarry owned by the Anaconda Copper Mining Co., which employs the rock as flux in the Washoe smelter at Anaconda. Near the quarry but south of the creek is a limekiln that is supplied with rock from a small separate quarry. The rock in both quarries belongs to the Madison limestone, which is purer than that of other formations, and nearly free from magnesia.

Silica.—Quartzite of the Quadrant formation is quarried at Browns for use as a flux in the Washoe smelter.

Phosphate.—Rock phosphate, large quantities of which have been found, in late years, in Idaho, Utah, Wyoming, and Montana, is a material of great value for making fertilizer. Its presence in the Philipsburg quadrangle was not known at the time of the survey on which this folio is based, but it was found there in 1911 by J. T. Pardee, from whom the following information was obtained. The phosphate here occurs in the Quadrant formation between the two main strata of quartzite. It has been found at the same horizon in many places near the Philipsburg quadrangle and appears to be distributed coextensively with the Quadrant formation over a large part of western Montana. Careful search might reveal it in many of the Quadrant areas in the Philipsburg quadrangle, but it has been definitely recognized and studied only at Flagstaff Hill, in Philipsburg, and on Boulder Creek near Flint.

The exposures at Flagstaff Hill give a fairly good section of the phosphatic strata. The beds between the two main bodies of quartzite are described in the following table:

Section of phosphatic beds on Flagstaff Hill.

Material.	Thickness.		Percent $Ca_3(PO_4)_2$.
	Ft.	*in.*	
Brown phosphate	0	6	25.8
Brownish-yellow phosphatic shale	4	6	15.37
Black phosphate	1	4	69.80
Soft clayey phosphate	1	4	48.02
Brown to blue clayey phosphate	5	6	25.13
Brown to black phosphate	1	8	49.55
Cherty material	2	0	4.99
Dull-gray limestone	4	6	0.41

The fairly high grade of the material and its nearness to transportation make it a resource of considerable prospective importance. A special advantage of any phosphate that may be discovered in the more accessible parts of the quadrangle might consist in its nearness to the Anaconda smelter. In order to be made into fertilizer, the rock phosphate must be treated with sulphuric acid. It has been suggested that much of the sulphur dioxide which now escapes from the stack of the smelter might be thus utilized.

Building stone.—Although stone has been used to a slight extent in buildings erected in this region, the Hope mill, constructed partly of granite, is the only large structure made of that material, and building stone is not regularly quarried within the quadrangle. It is not likely that it will ever be a valuable commercial resource here, for the limestone and the granitoid rocks most nearly suitable for dressed stone are in most places too much jointed and shattered to be obtainable in blocks of proper size. The rock that seems most likely to be quarried profitably is the granite of Lost Creek, which is not much affected by joints except those near the surface, which are presumably due to weathering. It is very massive in the glaciated outcrops on Lost Creek, which are fairly accessible to lines of transportation. The cream-white tint of the rock is agreeable and rather uncommon.

The andesitic tuff on Warm Spring Creek and near Anaconda could probably be used as a building stone in structures where great crushing strength and endurance are not required, for it resembles rock that is used for building at Baker City, Oreg., and elsewhere. Its lightness and accessibility and the ease with which it could be worked would make it economical. It is broken and crumbly in surface exposures, but it might prove sufficiently firm at moderate depths below the surface.

March, 1914.

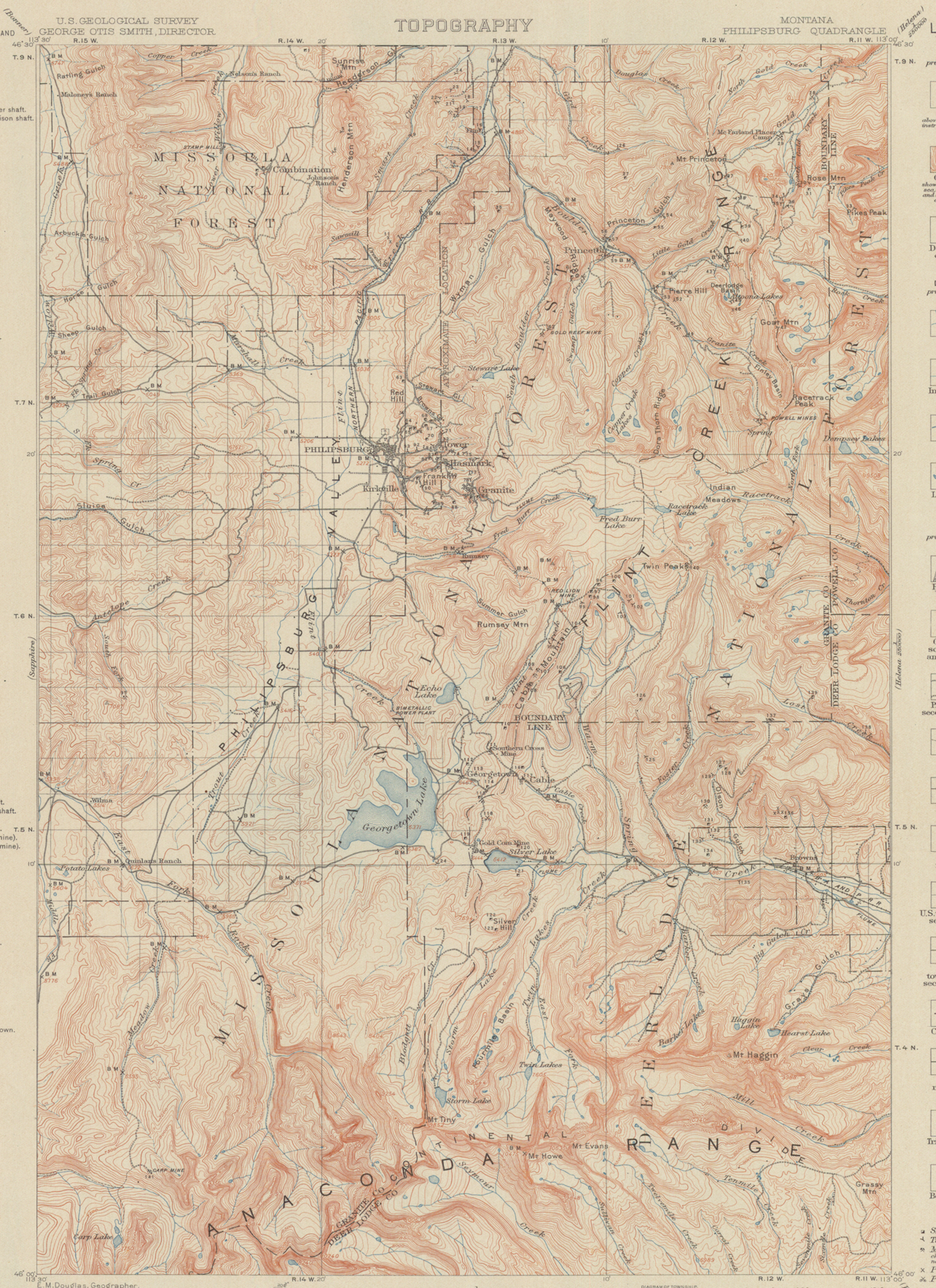
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

TOPOGRAPHY

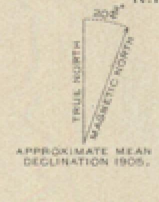
MONTANA
PHILIPSBURG QUADRANGLE

LIST OF MINES AND PROSPECTS.

1. Belleflower.
2. Russel.
3. Queen.
4. Bunker Hill.
5. Peacock.
6. Douglas.
7. Combination, Harper shaft.
8. Combination, Harrison shaft.
9. Annie.
10. Last Chance.
11. Lookout.
12. Joe Hanks.
13. Howard.
14. Heilman.
15. Twin Buttes.
16. Durand.
17. Londonderry.
18. Homer.
19. Johnson.
20. Eagle.
21. Mother Vein.
22. Last Chance.
23. Copper State.
24. Sallie Mellen.
25. North Star.
26. Barnes.
27. Delaware.
28. Tibbet placer.
29. McFarland placer.
30. John G. Carlisle.
31. Clear Grit.
32. Majestic.
33. Queen, Pikes Peak.
34. Potosi.
35. Eldorado.
36. Ophir.
37. Morning Star.
38. Clipper.
39. Tussle.
40. Bluebird.
41. Sunday.
42. Royal.
43. Bloomington.
44. Sunday Extension.
45. Albion.
46. Sixteen to One.
47. Goat Mountain.
48. Powell.
49. Rombauer.
50. Nonpareil.
51. Jefferson.
52. Brooklyn.
53. Caroline.
54. Sunset placer.
55. Mountain Lion.
56. Maywood placer.
57. Princeton.
58. Banker.
59. Travonia.
60. W. J. Bryan.
61. Gold Hill.
62. Gold Reef.
63. New Hope.
64. Shapleigh shaft.
65. Field.
66. Cuno.
67. Sweet Home.
68. Little Emma.
69. Cadgie Taylor.
70. Two Percent.
71. San Francisco.
72. Mitchell.
73. Silver Chief.
74. Hobo.
75. Puritan.
76. Three Metals.
77. Royal Metals.
78. Granite Belle.
79. Pearl.
80. Maroney.
81. Trout.
82. Cliff.
83. Blackmail.
84. Headlight.
85. Levi Burr.
86. Granite, Ruby shaft.
87. Bimetallic, Blaine shaft.
88. Elizabeth shaft.
89. West Granite shaft.
90. Silver Lode (iron mine).
91. Redemption (iron mine).
92. Mystery.
93. Basin.
94. Bimetallic tunnel.
95. Mountain Ram.
96. Modoc.
97. American Flag.
98. Hannah.
99. Red Lion.
100. Greater New York.
101. St. Thomas.
102. Nineteen Hundred.
103. Yellow Metal.
104. Montana.
105. Jubilee.
106. Robinson.
107. Flint Creek.
108. Golden Eagle.
109. Vallejo.
110. Twilight.
111. Southern Cross.
112. Montana, Georgetown.
113. Reliance.
114. Pyrenees.
115. Luxemburg.
116. Golden Gate.
117. Cable.
118. Daly placer.
119. Gold Coin.
120. Silver Reef.
121. Silver Moss.
122. Okoreaka.
123. Silver Hill.
124. War Eagle.
125. New Year.
126. Welcome.
127. Antelope.
128. Silver Chain.
129. Morgan Evans.
130. Santa Claus.
131. Black Chief.
132. Grey Rock.
133. Mayflower.
134. Cameron.
135. Jetty.
136. Blue-eyed Nellie.
137. George.
138. Silver Queen.
139. Silver King.
140. Northern Cross.
141. Carp.



E.M.Douglas, Geographer.
H.L.Baldwin, Jr. in charge of section.
Topography by J.E.Blackburn, J.Gussenhoven, L.Morrison, and J.E.Tichenor.
Triangulation by H.L.Baldwin, Jr.
Surveyed in 1905.



APPROXIMATE MEAN DECLINATION 1905.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

A later level adjustment shows the elevations on this sheet to be 4½ feet too high.

DIAGRAM OF TOWNSHIP.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of May 1908, reprinted April 1912 with corrections.

LEGEND

RELIEF
printed in brown

7155
Altitude
above mean sea level instrumentally determined

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

Depression contour

DRAINAGE
printed in blue

Streams

Intermittent streams

Flume

Lakes and ponds

CULTURE
printed in black

Roads and buildings

Church or schoolhouse and cemetery

Private and secondary roads

Trails

Railroad

Dam and reservoir

U.S. township and section lines

Located township and section corners

County line

Forest reservation line

△ Triangulation station

× B M Bench mark

▪ *Shaft*
⅄ *Tunnel*
⚒ *Mine*
character of working not distinguished
× *Prospect*
⚒ *Placer*

Mine names, represented on the map by numbers, are printed on the left margin

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

AREAL GEOLOGY

MONTANA
PHILIPSBURG QUADRANGLE

LEGEND

(continued)

IGNEOUS ROCKS

Sequence not fully known

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TERTIARY

Tva Volcanic ash *(white and buff unconsolidated silty material)*

Ta Andesitic extrusive rocks *(chiefly tuffs of coarse to medium texture; lavas near western margin of quadrangle)*

Tpg Porphyritic muscovite-biotite granite

Tpbg Porphyritic biotite granite

Tagd Acidic granodiorite *(rich in quartz; contains hornblende locally; fingers out into granodiorite porphyry)*

Tg Nonporphyritic muscovite-biotite granite

Tbg Nonporphyritic biotite granite *(contains a little muscovite: 1, plagioclase is oligoclase; 2, plagioclase is albite and fluorite is present; 3, plagioclase is abundant and chiefly andesine)*

Tgd Medium and basic granodiorite *(hornblende and biotite usually nearly equal in quantity; includes some diorite and some decomposed porphyritic dike rocks)*

Tbd Basic diorite *(dark rocks of fine to medium grain, with more or less idiomorphic hornblende)*

Tad Acidic diorite *(quartz-mica diorite, coarse grained, largely gneissoid, with allotriomorphic hornblende)*

TERTIARY ?

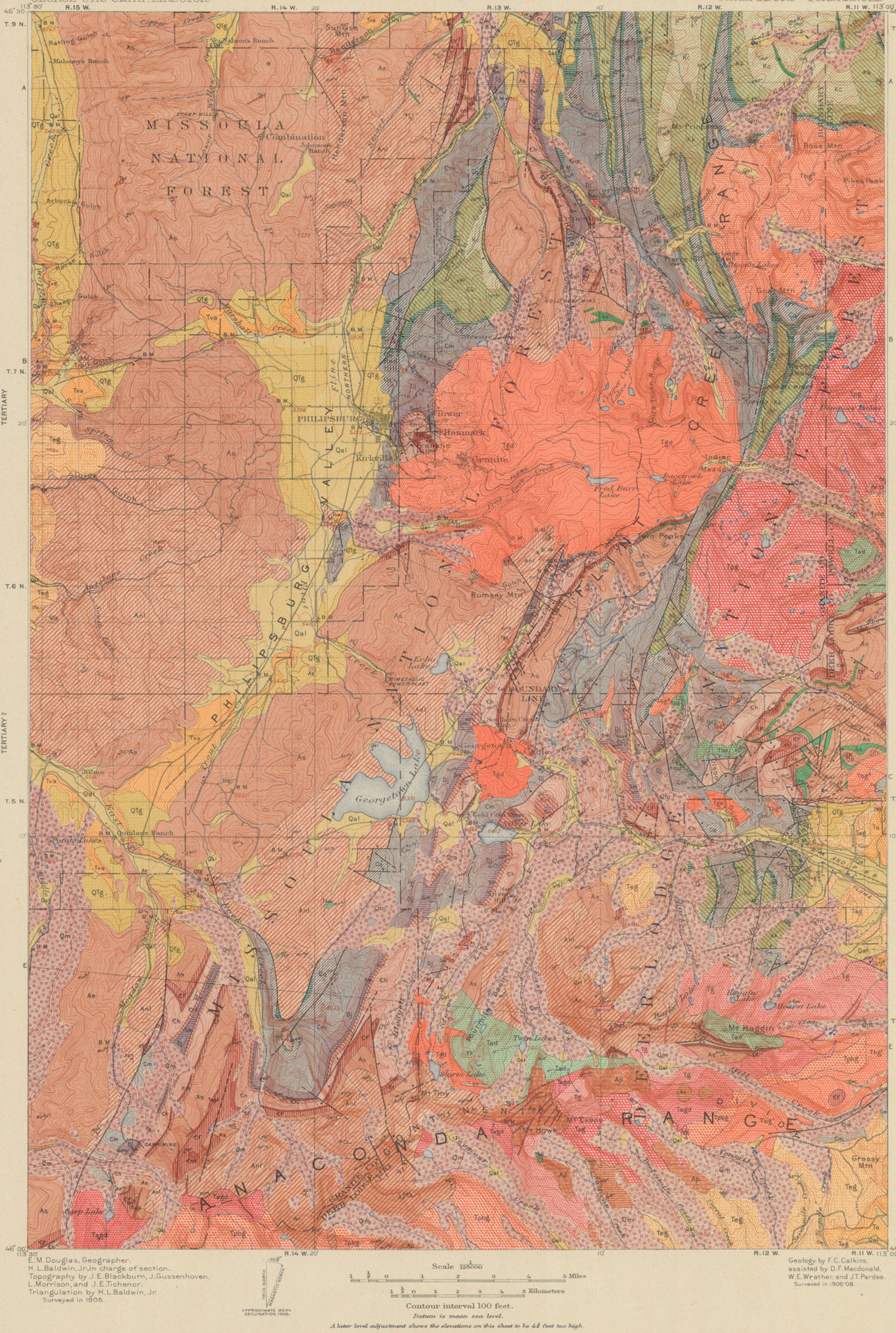
bs Basic sills *(diabase, partly altered to epidiorite, in Algonkian sediments, and other altered basic rocks in Cretaceous sediments)*

Fault

Concealed fault *(covered by surficial deposits)*

Downthrown side of drop fault
Overthrust side of thrust fault
Strike and dip of stratified rocks
Strike and overturned dip
Strike of vertical strata
Horizontal strata
Strike and dip of cleavage
Strike of vertical cleavage

Location and names of mines are shown on the topographic map



E. M. Douglas, Geographer.
H. L. Baldwin, Jr. in charge of section.
Topography by J. E. Blackburn, J. Gussenhoven, L. Morrison, and J. E. Tichenor.
Triangulation by H. L. Baldwin, Jr.
Surveyed in 1905.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

A later level adjustment shows the elevations on this sheet to be 4½ feet too high.

Edition of June 1912.

Geology by F. C. Calkins, assisted by D. F. Macdonald, W. E. Wrather, and J. T. Pardee.
Surveyed in 1906-08.

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles; metamorphism is indicated by hachures combined with the line patterns)

QUATERNARY

Recent

Qal Alluvium *(water-laid deposits on valley bottoms and low terraces)*

Pleistocene

Qm Moraines *(earlier and later moraines not distinguished)*

QUATERNARY AND TERTIARY

Pliocene and Pleistocene

QTg Later terrace gravels *(gravels capping high terraces)*

UNCONFORMITY

TERTIARY

Eocene to Miocene?

Teg Earlier gravels *(somewhat consolidated and deformed; probably of two or more epochs)*

UNCONFORMITY

CRETACEOUS

Upper Cretaceous

Kc Colorado formation *(black shale overlain by gray sandstone with subordinate shale; possibly includes Montana formation in part)*

UNCONFORMITY

Lower Cretaceous

Kk Kootenai formation *(chiefly red and green shale and sandstone; some limestone; basal conglomerate in most places)*

UNCONFORMITY ?

JURASSIC

Je Ellis formation *(chiefly buff-weathering calcareous shales and sandstones and impure limestone; conglomerate near middle)*

UNCONFORMITY

CARBONIFEROUS

Pennsylvanian

Cq Quadrant formation *(upper part mainly quartzite; lower part mainly reddish magnesian limestone and deep-red shale)*

UNCONFORMITY ?

Mississippian

Cm Madison limestone *(upper part thick-bedded, white and gray; lower part dark-gray and flaggy; chert abundant; fossils conspicuous)*

DEVONIAN

Dj Jefferson limestone *(white to black magnesian limestone with little chert; fossils usually inconspicuous)*

SILURIAN ?

Sm Maywood formation *(red, gray, and drab shales, and flaggy magnesian limestones; calcareous sandstone near base)*

UNCONFORMITY ?

CAMBRIAN

€rl Red Lion formation *(mainly limestone with closely spaced thin siliceous laminae; calcareous shale at base)*

€h Hasmark formation *(white magnesian limestone in upper part; dark calcareous shale, locally wanting, in middle; pale-gray magnesian limestone in lower part)*

€sh Silver Hill formation *(upper part calcareous shale and limestone with siliceous laminae; lower part dark-green, slightly calcareous shale)*

€f Flathead quartzite *(light-colored vitreous quartzite)*

UNCONFORMITY

ALGONKIAN

Belt series

As Spokane formation *(mud-cracked and ripple-marked sandstone and shale, prevailingly red where unmetamorphosed)*

Anl Newland formation including Greyson (?) shale *(calcareous shales and impure limestones characterized by buff tints on weathered surfaces)*

Ar Ravalli formation *(chiefly gray quartzitic sandstone with much dark shale in upper part)*

Ap Prichard formation *(schists and gneisses, prevailingly dark blue-gray, rusty on weathered surfaces, derived from clay shales)*

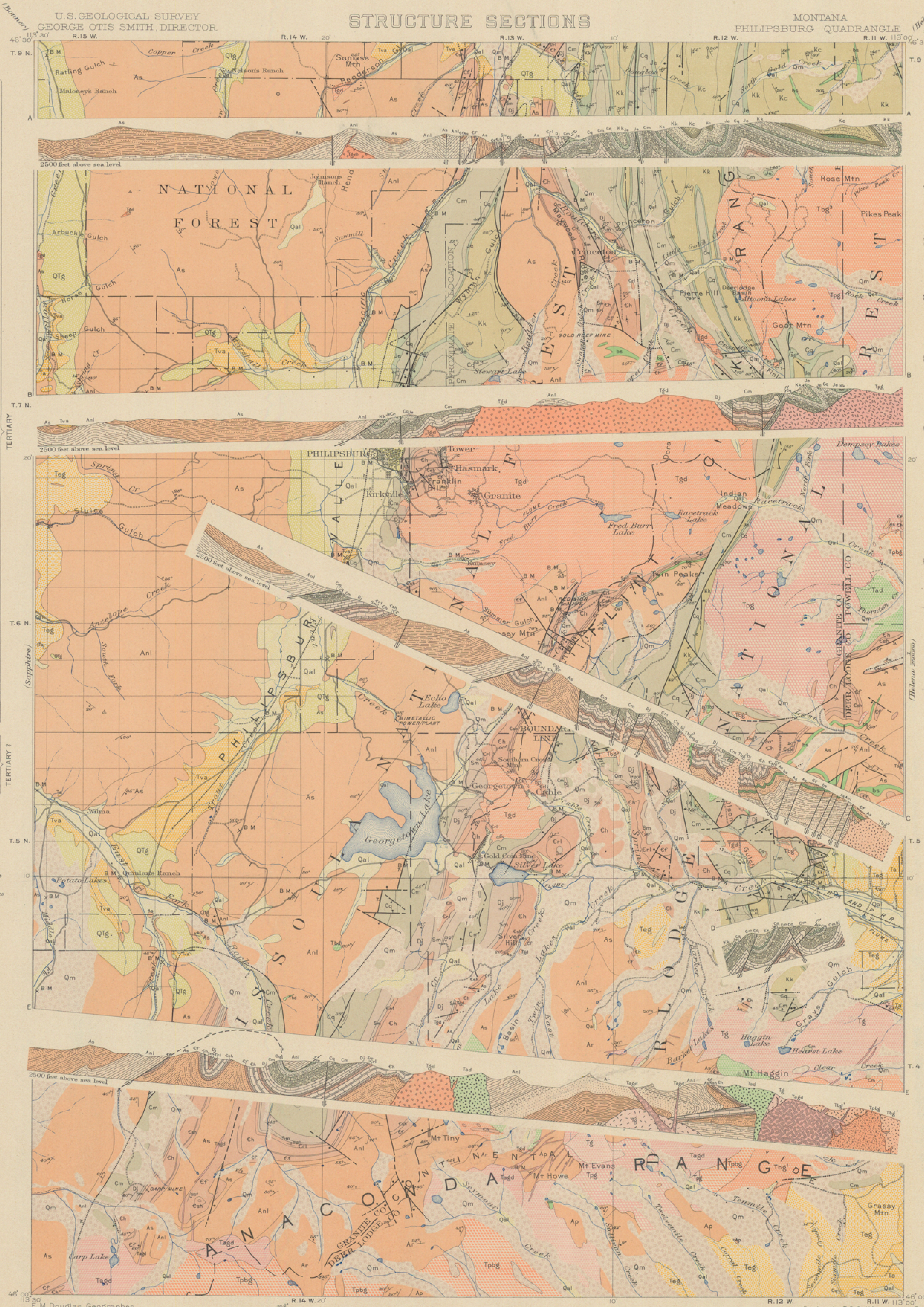
An Neihart quartzite *(pure thick-bedded light-colored quartzite)*

Legend is continued on the left margin

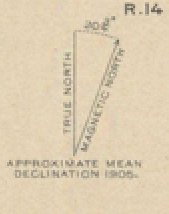
U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

MONTANA
PHILIPSBURG QUADRANGLE



E.M. Douglas, Geographer.
H.L. Baldwin, Jr., in charge of section.
Topography by J.E. Blackburn, J. Gussenhoven,
L. Morrison, and J.E. Tichenor.
Triangulation by H.L. Baldwin, Jr.
Surveyed in 1905.



Scale 1/125000

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

A later level adjustment shows the elevations on this sheet to be 4½ feet too high.

Edition of June 1912.

Geology by F.C. Calkins,
assisted by D.F. Macdonald,
W.E. Wrather, and J.T. Pardee.
Surveyed in 1906-08.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL	SECTION SYMBOL	Formation	Series	System
Qal		**Alluvium** *(water-laid deposits on valley bottoms and low terraces)*	Recent	QUATERNARY
Qm		**Moraines** *(earlier and later moraines not distinguished)*	Pleistocene	
QTg		**Later terrace gravels** *(gravels capping high terraces)*	Pliocene and Pleistocene	QUATERNARY AND TERTIARY
		UNCONFORMITY		
Teg		**Earlier gravels** *(somewhat consolidated and deformed, probably of two or more epochs)*	Eocene to Miocene ?	TERTIARY
		UNCONFORMITY		
Kc	Kc	**Colorado formation** *(black shale overlain by gray sandstone with subordinate shale; possibly includes Montana formation in part)*	Upper Cretaceous	CRETACEOUS
		UNCONFORMITY		
Kk	Kk	**Kootenai formation** *(chiefly red and green shale and sandstone; some limestone; basal conglomerate in most places)*	Lower Cretaceous	
		UNCONFORMITY ?		
Je	Je	**Ellis formation** *(chiefly buff weathering calcareous shales and sandstones and impure limestone; conglomerate near middle)*		JURASSIC
		UNCONFORMITY		
Cq	Cq	**Quadrant formation** *(upper part mainly quartzite; lower part mainly reddish magnesian limestone and deep-red shale)*	Pennsylvanian	CARBONIFEROUS
		UNCONFORMITY ?		
Cm	Cm	**Madison limestone** *(upper part thick-bedded, white and gray; lower part dark-gray and flaggy; chert abundant; fossils conspicuous)*	Mississippian	
Dj	Dj	**Jefferson limestone** *(white to black magnesian limestone with little chert; fossils usually inconspicuous)*		DEVONIAN
Sm	Sm	**Maywood formation** *(red, gray, and drab shales, and flaggy magnesian limestones; calcareous sandstone near base)*		SILURIAN ?
		UNCONFORMITY ?		
€rl	€rl	**Red Lion formation** *(mainly limestone with closely spaced thin siliceous laminae; calcareous shale at base)*		CAMBRIAN
€h	€h	**Hasmark formation** *(white magnesian limestone in upper part; dark calcareous shale, locally wanting, in middle; pale-gray magnesian limestone in lower part)*		
€sh	€sh	**Silver Hill formation** *(upper part calcareous shale and limestone with siliceous laminae; lower part dark-green, slightly calcareous shale)*		
€f	€f	**Flathead quartzite** *(light-colored vitreous quartzite)*		
		UNCONFORMITY		
As	As	**Spokane formation** *(mud-cracked and ripple-marked sandstone and shale, prevailingly red where unmetamorphosed)*	Belt series	ALGONKIAN
Anl	Anl	**Newland formation including Greyson (?) shale** *(calcareous shales and impure limestones characterized by buff tints on weathered surfaces)*		
Ar	Ar	**Ravalli formation** *(chiefly gray quartzitic sandstone with much dark shale in upper part)*		
Ap	Ap	**Prichard formation** *(schists and gneisses, prevailingly dark blue-gray, rusty on weathered surfaces, derived from clay shales)*		
An	An	**Neihart quartzite** *(pure thick-bedded light-colored quartzite)*		

Legend is continued on the left margin

LEGEND
(continued)

IGNEOUS ROCKS
Sequence not fully known

SHEET SYMBOL	SECTION SYMBOL	Rock	System
Tva	Tva	**Volcanic ash** *(white and buff unconsolidated silty material)*	TERTIARY
Ta		**Andesitic extrusive rocks** *(chiefly tuffs of coarse to medium texture; lavas near western margin of quadrangle)*	
Tpg	Tpg	**Porphyritic muscovite biotite granite**	
Tpbg	Tpbg	**Porphyritic biotite granite**	
Tagd	Tagd	**Acidic granodiorite** *(rich in quartz; contains hornblende locally; fingers out into granodiorite porphyry)*	
Tg	Tg	**Nonporphyritic muscovite-biotite granite**	
Tbg	Tbg	**Nonporphyritic biotite granite** *(contains a little muscovite; 1, plagioclase is oligoclase; 2, plagioclase is albite and fluorite present; 3, plagioclase is abundant and chiefly andesine)*	
Tgd	Tgd	**Medium and basic granodiorite** *(hornblende and biotite usually nearly equal in quantity; includes some diorite and some decomposed porphyritic dike rocks)*	
Tbd	Tbd	**Basic diorite** *(dark rocks of fine to medium grain, with more or less idiomorphic hornblende)*	
Tad	Tad	**Acidic diorite** *(quartz-mica diorite, coarse grained, largely gneissoid, with allotriomorphic hornblende)*	
bs	bs	**Basic sills** *(diabase, partly altered to epidiorite in Algonkian sediments, and other altered basic rocks in Cretaceous sediments)*	TERTIARY ?

Fault —— — —

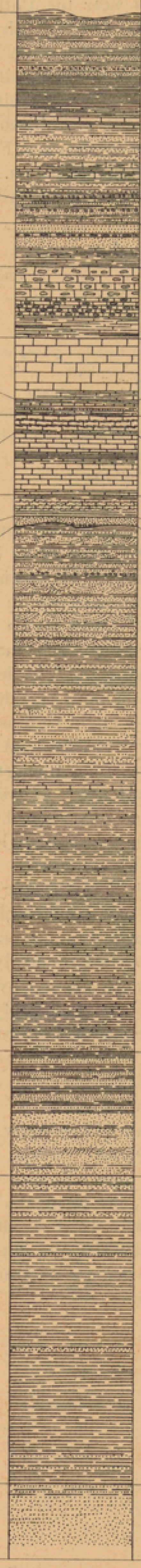
Concealed fault
(covered by surficial deposits) ………

- *Downthrown side of drop fault*
- *Overthrust side of thrust fault*
- *Strike and dip of stratified rocks*
- *Strike and overturned dip*
- *Strike of vertical strata*
- ● *Horizontal strata*
- *Strike and dip of cleavage*
- *Strike of vertical cleavage*

COLUMNAR SECTION

GENERALIZED SECTION OF SEDIMENTARY ROCKS OF THE PHILIPSBURG QUADRANGLE.

SCALE: 1 INCH = 2000 FEET.

System.	Series.	Formation.	Symbol.	Section.	Thickness in feet.	Character of Rocks.	Character of Topography.
QUATERNARY	RECENT	Alluvium.	Qal			Gravel, sand, and silt on flood plains and angular wash along bases of bedrock slopes.	Valley bottoms.
	PLEISTOCENE	Moraines.	Qm			Glacial deposits, largely of granite bowlders, representing two or more stages of glaciation.	Ridges on valley sides and hillocks and undrained hollows.
		Later terrace gravels.	QTg			Gravel, sand, and angular wash.	Broad level benches on valley sides.
TERTIARY	PLIOCENE						
	EOCENE TO MIOCENE (?)	Volcanic ash.	Tva		500	Buff to cream-colored unconsolidated ash.	Broad valleys.
		Andesitic extrusive rocks.	Ta		400-500	Pink and gray biotite-andesite flows and andesitic tuffs.	Rocky outcrops in valleys and rounded or flat-topped hills.
		Earlier gravels.	Teg		500±	Indurated gravel, well-rounded pebbles, with some volcanic ash.	Terraces and rounded hills.
		UNCONFORMITY					
CRETACEOUS	UPPER CRETACEOUS	Colorado formation. (Possibly includes part of Montana formation at top.)	Kc		1,500+	Upper part gray and olive-green sandstone, generally flaggy, locally pebbly near base, interbedded with dark blue-gray to light gray-green shales, largely sandy. Lower third black fissile shale with some sandy layers near top.	Depressions and slopes with knobs and ridges of sandstone.
		UNCONFORMITY					
	LOWER CRETACEOUS	Kootenai formation.	Kk		1,500±	Upper part calcareous shale and sandstone, dark shaly limestone, and gray fossiliferous limestone. Lower part mottled red and green shales, containing calcareous nodules, and thin-bedded sandstones, with some buff-weathering limestone interbedded near the base. Reddish to greenish quartzitic sandstone with pebbles of quartzite from the Quadrant at the base; the red shales are metamorphosed to green and chocolate-brown hornstones.	Smooth slopes as a rule, with prominent outcrops of the basal sandstone and ledges of fossiliferous limestones near the top, but where the formation is metamorphosed it forms cliffs.
		UNCONFORMITY?					
JURASSIC		Ellis formation.	Je		400-430	Chiefly dark calcareous shales, olive-green sandstones, and thin-bedded impure gray to drab limestone. Conglomerate near the middle. Weathered surfaces commonly stained yellow.	Depressions between the Quadrant formation and the basal sandstone of the Kootenai.
		UNCONFORMITY					
CARBONIFEROUS	PENNSYLVANIAN	Quadrant formation.	Cq		450-900	Upper half quartzites, generally separated into two divisions by impure cherty limestone. Lower half maroon to brick-red shales with ellipsoidal gray nodules interbedded with white, gray, and reddish magnesian limestones. Metamorphosed to greenish hornstones generally rich in diopside.	Generally forms ridges having parallel ledges of hard quartzite.
		UNCONFORMITY?					
	MISSISSIPPIAN	Madison limestone.	Cm		800-1,500	Nonmagnesian limestone, thick-bedded and mostly white in upper part, cherty and mostly dark blue-gray in middle part, and black, weathering gray and flaggy in lower part. Abundantly fossiliferous.	Largely forms rugged topography with cliffs. In part, gentle slopes.
DEVONIAN		Jefferson limestone.	Dj		1,000±	Pale-gray to dull-black, thick-bedded, somewhat magnesian limestone, locally flaggy near base. Metamorphosed to cream-white and blue-gray.	Rather steep slopes with prominent outcrops and some cliffs.
SILURIAN?		Maywood formation.	Sm		250±	Thin-bedded gray and light-green to purple or red magnesian limestones and calcareous shale, commonly stained yellow. Some calcareous sandstone near the base. Greenish hornstone where metamorphosed.	Outcrops inconspicuous.
		UNCONFORMITY?					
CAMBRIAN	MIDDLE AND UPPER	Red Lion formation.	Ꞓrl		280	Chiefly limestone with thin wavy siliceous laminæ, reddish purple, highly siliceous, and flaggy in the lower part. Black to olive-green shale, interstratified with thin-bedded magnesian limestones at base.	Prominent outcrops of siliceous banded limestone.
		Hasmark formation.	Ꞓh		1,000	Chiefly magnesian limestone, with dark shale of varying thickness near the middle. Limestone above the shale mostly cream-white, that below mostly blue-gray.	Gentle slopes with cliffy limestone outcrops.
		Silver Hill formation.	Ꞓsh		100-600	Banded green and brown calcareous shale, interbedded with gray limestone having thin wavy dark siliceous laminæ, and a little sandstone near the base.	Outcrops inconspicuous except where indurated by metamorphism.
		Flathead quartzite.	Ꞓf		0-200	Thick-bedded vitreous, white to pale-gray quartzite. Basal conglomerate in places.	Cliffs and ledges with coarse talus.
		UNCONFORMITY					
ALGONKIAN	BELT	Spokane formation.	As		9,000±	Deep-red shale and sandstone with subordinate green layers; metamorphosed equivalents green, rusty on weathered surfaces. Shale, somewhat sandy, predominates in the lower third, sandstone above. The shales are commonly ripple marked, sun-cracked, and rain pitted; the sandstones are commonly cross-bedded and contain mud fragments, and some have small well-rounded quartz pebbles.	Gently rounded hills and high knobs and ridges.
		Newland formation including Greyson (?) shale.	Anl		4,500	Chiefly light-greenish to dark bluish-gray calcareous shales and impure shaly limestones containing magnesium and iron carbonates and silica and weathering yellow to buff. A little cross-bedded calcareous quartzite occurs in thin beds. The shales in the uppermost part exhibit sun cracks. The beds are altered by contact metamorphism chiefly to hard flaggy pale-green hornstone.	Gently rounded hills, except where affected by contact metamorphism.
		Ravalli formation.	Ar		2,000	Lower part light-gray banded, thick-bedded fine-grained quartzite, somewhat sericitic; upper third light to dark gray quartzitic sandstones alternating with dark-bluish and greenish-gray shales. Contact metamorphism alters the shales to mica schist and produces knotted and gneissoid textures in the quartzites.	Rugged and steep-sided ridges with heavy talus.
		Prichard formation.	Ap		5,000±	Chiefly dark bluish-gray schists and gneisses derived from argillaceous sediments, interbedded, especially near the top and bottom, with a subordinate amount of quartzitic sandstone; deep reddish brown on weathered outcrops. Greatly altered by contact metamorphism.	Rugged mountains, some of the highest peaks in the area.
		Neihart quartzite.	An		1,000+	White to pale-gray thick-bedded medium to coarse-grained vitreous quartzite. Its purity decreases somewhat upward, and near the top thin beds of green and gray mica schist are intercalated. The quartz grains are elongated by pressure, producing a characteristic obscure lamination.	High summits with some steep cliffs.

ILLUSTRATIONS

Plate I.—ANACONDA RANGE VIEWED NORTHEASTWARD ACROSS THE UPPER VALLEY OF TENMILE CREEK.
Shows rugged topography in sheared granodiorite and the broad, flat-bottomed glaciated canyon of Tenmile Creek.

Plate II.—CONTACT OF GRANITE WITH DARK SCHIST OF PRICHARD FORMATION AT HEAD OF TENMILE CREEK.

Plate III.—DETAIL OF CONTACT OF GRANODIORITE WITH SEDIMENTARY ROCKS AT STORM LAKE.
Shows variation of the igneous rock near contacts, apophyses extending into the sedimentary beds, and process of "stoping."

Plate IV.—UNCONFORMABLE CONTACT OF CAMBRIAN WITH ALGONKIAN ROCKS ON EAST FORK OF ROCK CREEK, IN WESTERN PART OF ANACONDA RANGE.
The Spokane formation (Algonkian) dips 60° W.; the overlying Flathead quartzite (Cambrian) dips 25° W.

Plate V.—SILICEOUS LAMINATED LIMESTONE OF RED LION FORMATION WEST OF GOLD COIN.
Irregular siliceous laminæ are etched in relief by weathering.

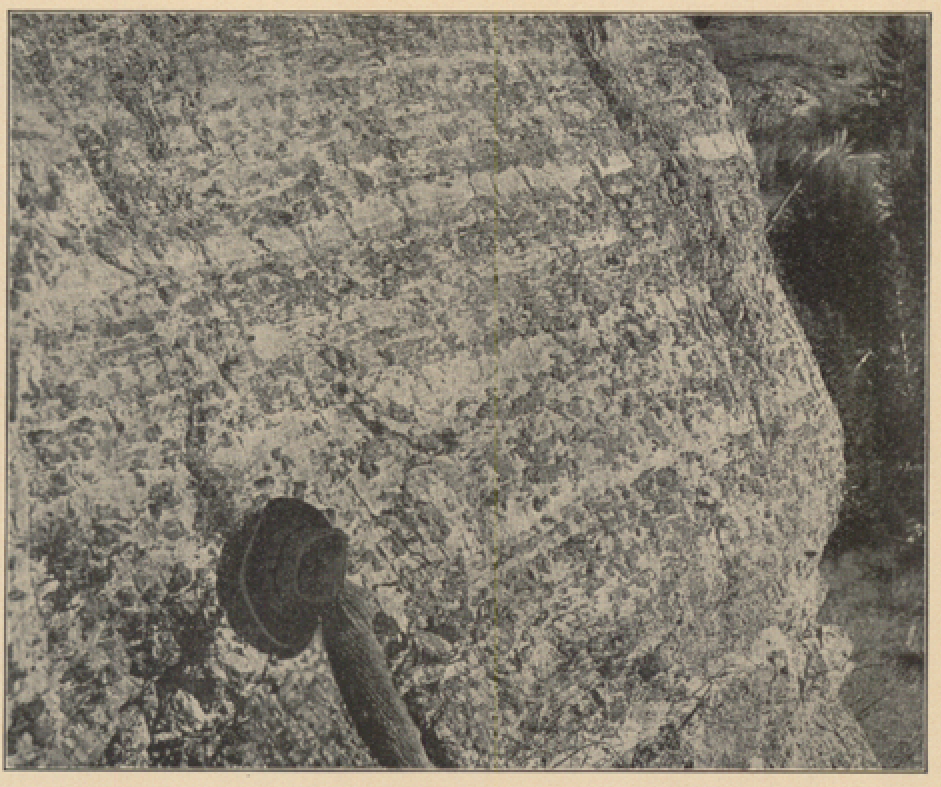


Plate VI.—CHERTY LIMESTONE OF MADISON FORMATION.
The dark cherty beds are characteristic of the middle of the formation.

Plate VII.—INDURATED GRAVELS OF EARLY TERTIARY AGE ALONG ROCK CREEK NEAR MOUTH OF SLUICE CREEK.
The gravels rest on an irregular floor of Newland formation, which slopes downward to the right in the cliff.

Plate VIII.—FOLDED AND FAULTED PALEOZOIC LIMESTONES ON FOSTER CREEK NEAR SOUTH BOUNDARY OF GRANITE COUNTY.
The closely folded limestone in the cliff is Jefferson, brought into contact with Madison limestone by a fault along the ravine at the left.

Plate IX.—MAGNESIAN LIMESTONE OF LOWER PART OF HASMARK FORMATION.
The roughness of the weathered surface is caused by projecting crystals of dolomite, which are less soluble than the calcite. The characteristic white tubular bodies are possibly fossil worm cases.

Plate X.—MAGNETITE IN LIMESTONE OF HASMARK FORMATION IN CONTACT ZONE OF CABLE STOCK.
The light-colored mineral mixed with the magnetite is iron-poor olivine, partly serpentinized.

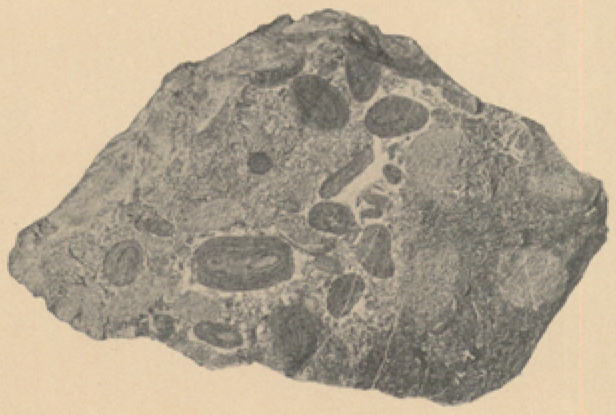


Plate XI.—FOSSILS IN LOWER DOLOMITE OF HASMARK FORMATION.
Ellipsoidal sections of bodies having concentric structure; probably calcareous algæ (Girvanella ?).

Plate XII.—MUD FLAKES IN SPOKANE SANDSTONE.
Angular and rounded fragments of dark-red argillite inclosed as pebbles in the sandstone.

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is in many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene Miocene Oligocene Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		TR	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Є	Brick-red.
	Algonkian		A	Brownish red.
	Archean		AR	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

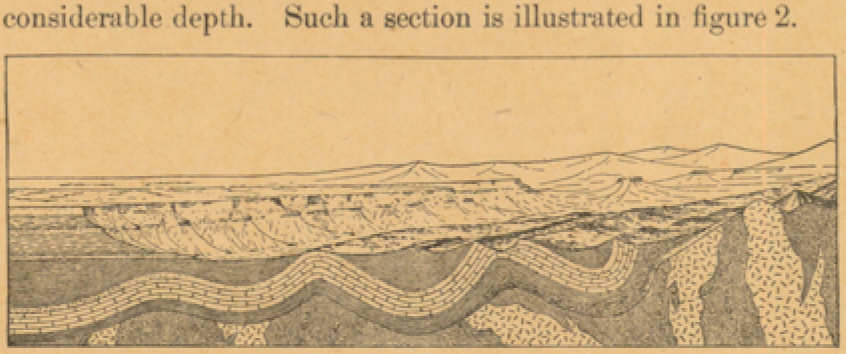


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

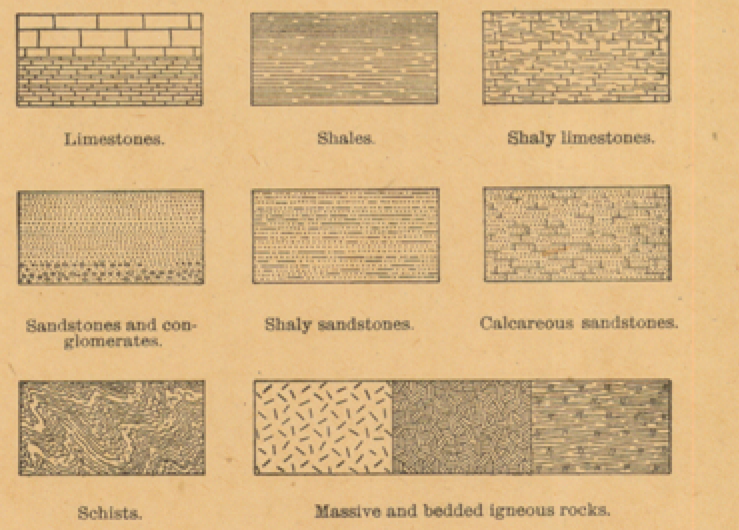


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

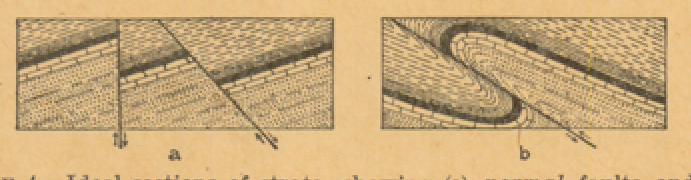


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

PUBLISHED GEOLOGIC FOLIOS

No.*	Name of folio.	State.	Price.†
			Cents.
‡1	Livingston	Montana	
‡2	Ringgold	Georgia-Tennessee	
●3	Placerville	California	
‡4	Kingston	Tennessee	
●5	Sacramento	California	
‡6	Chattanooga	Tennessee	
‡7	Pikes Peak	Colorado	
‡8	Sewanee	Tennessee	
‡9	Anthracite-Crested Butte	Colorado	
‡10	Harpers Ferry	Va.-Md.-W.Va	
●11	Jackson	California	
‡12	Estillville	Ky.-Va.-Tenn	
‡13	Fredericksburg	Virginia-Maryland	
‡14	Staunton	Virginia-West Virginia	
‡15	Lassen Peak	California	
‡16	Knoxville	Tennessee-North Carolina	
‡17	Marysville	California	
‡18	Smartsville	California	
‡19	Stevenson	Ala.-Ga.-Tenn	
20	Cleveland	Tennessee	5
‡21	Pikeville	Tennessee	
‡22	McMinnville	Tennessee	
23	Nomini	Maryland-Virginia	5
24	Three Forks	Montana	5
‡25	Loudon	Tennessee	
‡26	Pocahontas	Virginia-West Virginia	
‡27	Morristown	Tennessee	
‡28	Piedmont	West Virginia-Maryland	
‡29	Nevada City Special	California	
‡30	Yellowstone National Park	Wyoming	
‡31	Pyramid Peak	California	
‡32	Franklin	West Virginia-Virginia	
‡33	Briceville	Tennessee	
‡34	Buckhannon	West Virginia	
‡35	Gadsden	Alabama	
36	Pueblo	Colorado	5
‡37	Downieville	California	
‡38	Butte Special	Montana	
‡39	Truckee	California	
‡40	Wartburg	Tennessee	
‡41	Sonora	California	
42	Nueces	Texas	5
‡43	Bidwell Bar	California	
‡44	Tazewell	Virginia-West Virginia	
‡45	Boise	Idaho	
46	Richmond	Kentucky	5
47	London	Kentucky	5
‡48	Tenmile District Special	Colorado	
‡49	Roseburg	Oregon	
‡50	Holyoke	Massachusetts-Connecticut	
‡51	Big Trees	California	
52	Absaroka	Wyoming	5
53	Standingstone	Tennessee	5
‡54	Tacoma	Washington	
‡55	Fort Benton	Montana	
‡56	Little Belt Mountains	Montana	
‡57	Telluride	Colorado	
58	Elmoro	Colorado	5
‡59	Bristol	Virginia-Tennessee	
‡60	La Plata	Colorado	
61	Monterey	Virginia-West Virginia	5
62	Menominee Special	Michigan	5
‡63	Mother Lode District	California	
64	Uvalde	Texas	5
65	Tintic Special	Utah	5
‡66	Colfax	California	
67	Danville	Illinois-Indiana	5
68	Walsenburg	Colorado	5
69	Huntington	West Virginia-Ohio	5
‡70	Washington	D. C.-Va.-Md.	
‡71	Spanish Peaks	Colorado	
‡72	Charleston	West Virginia	
‡73	Coos Bay	Oregon	
74	Coalgate	Oklahoma (Ind. T.)	5
75	Maynardville	Tennessee	5
76	Austin	Texas	5
77	Raleigh	West Virginia	5
78	Rome	Georgia-Alabama	5
79	Atoka	Oklahoma (Ind. T.)	5
80	Norfolk	Virginia-North Carolina	5
‡81	Chicago	Illinois-Indiana	
‡82	Masontown-Uniontown	Pennsylvania	
‡83	New York City	New York-New Jersey	
84	Ditney	Indiana	5
85	Oelrichs	South Dakota-Nebraska	5
86	Ellensburg	Washington	5
87	Camp Clarke	Nebraska	5
88	Scotts Bluff	Nebraska	5
89	Port Orford	Oregon	5
90	Cranberry	North Carolina-Tennessee	5
91	Hartville	Wyoming	5
92	Gaines	Pennsylvania-New York	5
93	Elkland-Tioga	Pennsylvania	5
‡94	Brownsville-Connellsville	Pennsylvania	
95	Columbia	Tennessee	5
96	Olivet	South Dakota	5
97	Parker	South Dakota	5
98	Tishomingo	Oklahoma (Ind. T.)	5
99	Mitchell	South Dakota	5
100	Alexandria	South Dakota	5
101	San Luis	California	5
102	Indiana	Pennsylvania	5
103	Nampa	Idaho-Oregon	5
104	Silver City	Idaho	5
105	Patoka	Indiana-Illinois	5
106	Mount Stuart	Washington	5
107	Newcastle	Wyoming-South Dakota	5
108	Edgemont	South Dakota-Nebraska	5
109	Cottonwood Falls	Kansas	5
110	Latrobe	Pennsylvania	5
‡111	Globe	Arizona	
112	Bisbee (reprint)	Arizona	25
113	Huron	South Dakota	5
114	De Smet	South Dakota	5
115	Kittanning	Pennsylvania	5
116	Asheville	North Carolina-Tennessee	5
117	Casselton-Fargo	North Dakota-Minnesota	5
118	Greeneville	Tennessee-North Carolina	5
119	Fayetteville	Arkansas-Missouri	5
‡120	Silverton	Colorado	
121	Waynesburg	Pennsylvania	5
122	Tahlequah	Oklahoma (Ind. T.)	5
123	Elders Ridge	Pennsylvania	5
124	Mount Mitchell	North Carolina-Tennessee	5
‡125	Rural Valley	Pennsylvania	
126	Bradshaw Mountains	Arizona	5
‡127	Sundance	Wyoming-South Dakota	
128	Aladdin	Wyo.-S. Dak.-Mont	5
‡129	Clifton	Arizona	
‡130	Rico	Colorado	
131	Needle Mountains	Colorado	5
132	Muscogee	Oklahoma (Ind. T.)	5
133	Ebensburg	Pennsylvania	5
‡134	Beaver	Pennsylvania	
135	Nepesta	Colorado	5
136	St. Marys	Maryland-Virginia	5
137	Dover	Del.-Md.-N. J	5
‡138	Redding	California	
‡139	Snoqualmie	Washington	
140	Milwaukee Special	Wisconsin	5
‡141	Bald Mountain-Dayton	Wyoming	
‡142	Cloud Peak-Fort McKinney	Wyoming	
143	Nantahala	North Carolina-Tennessee	5
‡144	Amity	Pennsylvania	
‡145	Lancaster-Mineral Point	Wisconsin-Iowa-Illinois	
146	Rogersville	Pennsylvania	5
147	Pisgah	N. Carolina-S. Carolina	5
148	Joplin District (reprint)	Missouri-Kansas	50
149	Penobscot Bay	Maine	5
‡150	Devils Tower	Wyoming	
‡151	Roan Mountain	Tennessee-North Carolina	
152	Patuxent	Md.-D. C	5
‡153	Ouray	Colorado	
‡154	Winslow	Ark.-Okla. (Ind. T.)	
155	Ann Arbor (reprint)	Michigan	25
156	Elk Point	S. Dak.-Nebr.-Iowa	5
‡157	Passaic	New Jersey-New York	
158	Rockland	Maine	5
159	Independence	Kansas	5
160	Accident-Grantsville	Md.-Pa.-W. Va.	5
161	Franklin Furnace	New Jersey	5
‡162	Philadelphia	Pa.-N. J.-Del	
‡163	Santa Cruz	California	
‖164	Belle Fourche	South Dakota	5
‖165	Aberdeen-Redfield	South Dakota	5
‖166	El Paso	Texas	5
¶167	Trenton	New Jersey-Pennsylvania	5
‖168	Jamestown-Tower	North Dakota	5
‖169	Watkins Glen-Catatonk	New York	5
‖170	Mercersburg-Chambersburg	Pennsylvania	5
‖171	Engineer Mountain	Colorado	5
‖172	Warren	Pennsylvania-New York	5
‖173	Laramie-Sherman	Wyoming	5
‖174	Johnstown	Pennsylvania	5
‖175	Birmingham	Alabama	5
‖176	Sewickley	Pennsylvania	5
¶177	Burgettstown-Carnegie	Pennsylvania	5
‖178	Foxburg-Clarion	Pennsylvania	5
‖179	Pawpaw-Hancock	Md.-W. Va.-Pa	5
‖180	Claysville	Pennsylvania	5
‖181	Bismarck	North Dakota	5
‖182	Choptank	Maryland	5
‖183	Llano-Burnet	Texas	5
‖184	Kenova	Ky.-W. Va.-Ohio	5
§185	Murphysboro-Herrin	Illinois	25
§186	Apishapa	Colorado	5
§187	Ellijay	Ga.-N. C.-Tenn	25
§188	Tallula-Springfield	Illinois	25
189	Barnesboro-Patton	Pennsylvania	25
§190	Niagara	New York	50
§191	Raritan	New Jersey	25
192	Eastport	Maine	25
§193	San Francisco	California	75
194	Van Horn	Texas	25
195	Belleville-Breese	Illinois	25
§196	Philipsburg	Montana	25
§197	Columbus	Ohio	25
198	Castle Rock	Colorado	25

* Order by number.

† Payment must be made by money order or in cash.

‡ These folios are out of stock.

● The texts and economic-geology maps of the Placerville, Sacramento, and Jackson folios, which are out of stock, have been reprinted and published as a single folio (Folio reprint Nos. 3, 5, and 11), the price of which is $1.

‖ Octavo editions of these folios may be had at same price.

¶ Octavo editions only of these folios are in stock.

§ These folios are also published in octavo form at 50 cents each, except No. 193, which is 75 cents.

Owing to a fire in the Geological Survey building the folios in stock were slightly damaged, but those that were saved are usable and will be sold at 5 cents each. They are priced accordingly in the list above. Circulars showing the location of the area covered by any of the above folios, as well as information concerning topographic maps and other publications of the Geological Survey, may be had on application to the Director, United States Geological Survey, Washington, D. C.