DESCRIPTION OF THE FORT BENTON QUADRANGLE.

INTRODUCTION.

Position and extent of quadrangle.

General relations.—The Fort Benton quadrangle extends in longitude from 110° to 111° and in latitude from 47° to 48°. It is 69.25 miles long from north to south, 47.36 miles wide, and contains 3272.7 square miles. It includes part of Choteau, the northwest corner of Fergus, and the eastern part of Cascade counties, in central Montana. The Little Belt Mountains quadrangle adjoins it on the south, and the Great Falls quadrangle on the west. The greater part of the quadrangle is a nearly flat region which forms the western border of the Great Plains. The southwest corner is part of the Little Belt Range, one of the front ranges of the Rocky Mountains. In the center of the quadrangle an isolated group of peaks known as the Highwood Mountains rises above the general level of the plains.

Level, treeless plain.

Description of the plains.—Three-fourths of the quadrangle is an open, treeless but grass-covered tract that appears almost level, though possessing a slight general northward inclination. Between the Highwood Mountains and the Missouri River ridges and hummocks of glacial sand and gravel modify the surface. South of Arrow Creek a nearly featureless plain extends to the base of the Little Belt Range. North of the Missouri River the open plain stretches in unvaried continuity to the Canadian line. The region is devoid of marked elevations above its general surface, but is deeply etched by the streams which traverse it. All the larger streams flow in canyons, the largest being that of the Missouri River, which is 400 to 600 feet deep. As a rule, these gorges are narrow, with steep walls, and so sharply cut that the break in the plain is recognizable only within a short distance of the canyon brink.

The general aspect of the plains area would be monotonous if it were not for the neighboring mountain ranges. The scenery along the stream courses is, however, sufficiently rugged to be picturesque, and along the Missouri River it is especially so. The Great Falls of the Missouri River are a few miles west of the limit of the quadrangle. Many lateral ravines which incise the canyon walls cut the plateau into the peculiar topography so commonly called "bad lands." Pyramidal and rounded terraced buttes and ridges alternate with deep ravines, while more resistant sandstones form balcony ledges and castellated piles, with isolated pillars. No finer or more picturesque examples of erosion can be found in the State.

Geologic structure of the plains.

The geology of the plains is as simple and broad featured as the topography. The region is underlain by sandstones and clay shales, which are softer and less consolidated than the older rocks of the mountains. The beds are nearly horizontal, the dip over most of the area being but 2° to 3° N., and corresponding very nearly to the general inclination of the surface. The only pronounced flexing or faulting recognized is that seen in the walls of the Missouri River Canyon. Igneous rocks are rare, occurring only about the Highwoods and near the Big Bend of the Missouri River, where dikes of black basaltic rocks have weathered in relief above the white sandstones and gray shales. Over the greater part of the plains area the underlying rocks are concealed by a mantle of glacial débris or a thin veneer of stream drift, though the cliffs along the streams reveal the rocks.

Description of the Little Belt Mountains.—The Little Belt Range, only a small northern part of which is within the limits of the quadrangle, is a broad, relatively low range forming the eastern flank of the mountain region of Montana. It trends east and west, is V-shaped, and ends in a sharp point at Judith Gap, east of the Little Belt Mountains quadrangle. In general, it shows broad, flat summits, is deeply trenched by streams, and though picturesque it lacks the ruggedness of the main chains of the Rockies. Within the Fort Benton quadrangle the transition from open plain to mountain slope is not abrupt, as there is a zone of hilly country between.

Structure of the Little Belt Mountains.

The general structure of the Little Belt Range is that of a wide arch with flat summit and steeply inclined sides. In the center of the range the limestones and other stratified rocks are horizontal, or nearly so, while on the flanks of the mountains they are sharply inclined and dip away from the mountains to the lower plains country. The horizontal attitude is well shown in the rocks of Belt Park, whereas farther north the mountain masses near Monarch are formed of blocks of tilted limestones dipping northward. This structure is also seen in the walls of Belt Creek, which expose a complete section of the beds from the nearly level coal seams of Belt and Armington, with dip increasing southward, to the core of gneisses and schists south of Monarch.

The simple structure of the uplift is, in this area, much modified by local intrusions of igneous rock. Where these intrusions form laccoliths the stratified rocks are uplifted in local domes, like those of Tiger Butte and Barker Mountain. In this way the symmetrical distribution of the formations is disturbed. Local areas of younger formations are left as inliers in synclinal basins, as may be seen at the head of Dry Arrow Creek, while on the outer flanks of the range the laccolithic domes bring up the older rocks above the general level, as is the case at Wolf Butte. When eroded these domes show areas of the older rock as outliers surrounded by younger formations. About these domes the dips are steep and variable, but about the mountain borders, where not disturbed by igneous intrusions, as, for instance, north of Monarch, the strata dip at angles of 6° to 10° away from the axis of the range, the dip becoming gradually less toward the open plains country. Along the foothill tract from Riceville to Woodhurst this lessening dip is most apparent, since the hard strata cap hilltops whose slope often corresponds to the dip of the beds. These marginal tracts are areas of planation. Where protected by a mantle of stream drift or "wash," the surface over large areas is a very uniform inclined plain. Ravines expose bluffs in which the plain is seen to be cut across the edges of the upturned strata of sandstones and shales, or even across folds, leveled off or truncated by the ever-varying water courses. In other areas the strata have a nearly constant dip away from the mountains, their outcropping edges forming broad bands, and as the softer shales wear more rapidly than the sandstones, the surface is then an alternation of ridges and hollows, with long, gentle slopes in the direction of the dip.

Description of the Highwood Mountains.—The Highwood Mountains occupy the center of the quadrangle and form a district comprising about 300 square miles, distinct in topography and geology from the other parts of the quadrangle. They consist of a cluster of peaks standing alone and rising so abruptly from the flat plains as to present an imposing appearance, though the highest points do not exceed 7600 feet in height, or 4000 feet above the plains. The group consists of low, gently rounded northern summits, gradually rising southward to higher, sharper forms, and culminating in Arrow and Highwood peaks. Highwood Gap, a deep cut, separates the mountain group into eastern and western parts. East of the mountains two isolated buttes rise above the flat plateau level. The one nearest the mountains, called Palisade Butte, is a dark, pillared mass; the other, Square Butte, is a mesa whose white cliffs and pinnacled slopes are conspicuous features for many miles.

The Highwood Mountains present a striking example of a group of once active volcanoes which have long been extinct and exposed to the eroding agencies of denudation, so that they have been cut down, dissected, and their inner structure brought to light. The cones built up about each vent have been greatly eroded, and are no longer recognizable topographically, but the lava flows, scoria, and fragmental materials that formed these cones, though now reddened and altered, are as readily recognizable as if the eruptions had but recently ceased.

Structure of the Highwood Mountains.

As a result of dissection by long-continued erosion, the mountains now show masses of granular crystalline rock representing the cones or filling of the throat of a volcano, the dikes which radiate from these centers of activity, and the loose materials and lava flows of which the cones were built. The sedimentary strata through which the volcanoes broke up and upon which their materials accumulated are, over most of the area, nearly horizontal or inclined gently to the north. These rocks belong entirely to the Cretaceous system, and denudation has exposed them over considerable areas within the mountain tract. They are generally unaltered except at the immediate contacts with the dikes and in rings or contact zones about the cores of massive rock. In these places they show induration and baking, which about the volcanic cores at South Peak and Shonkin Creek have completely metamorphosed the sediments to dark, flinty hornstones, to pink, green, and lavender-colored adinoles resembling porcelain, or to vitreous quartzites. In these altered forms the original bedding planes are recognizable only in the horizontal color banding, as the rocks are shattered by a close system of prismatic vertical joints, which results in their breaking into dicy débris on weathering. In no case have the sediments been altered to schists. The sedimentary strata formed an eroded hilly country when the first volcanic eruptions of the district broke out, as shown at South Peak and elsewhere. That volcanic activity was intermittent and continued through a long period of time is shown by the relation of the latest breccias to the general level of the plains about the mountains, for the earlier andesitic eruptions were succeeded by a period of extensive erosion before the basaltic lavas were poured out, as is shown by the occurrence of the latter rocks filling deep ravines cut in the earlier rocks, and resting upon the core rocks of earlier dissected centers of activity.

Nothing now remains to show the original outlines of the volcanoes. It is evident that the different vents were not active at the same time, but represent a succession of volcanoes following one another, the ashes and lava flows of later vents partially covering those of earlier eruptions.

The river systems.

Drainage.—The Missouri River crosses the northern part of the plains and drains the entire quadrangle. It is throughout a flowing stream, unaffected by the aridity of this region. Belt Creek is the largest of the streams heading in the mountain tracts. In some parts of its course the stream bed for short distances is dry during the summer months, that is, it is an interrupted stream, seeping underground in places. The streams originating in the plains, as well as a majority of those draining the mountain slopes, are intermittent streams, flowing only during the rainy season or the period of melting snow. The drainage of the Highwoods is radial and consequent upon the geological structure of the mountains; that of the Little Belt Range is, in part at least, independent of geologic structure, and may be of antecedent origin. The low level of the Missouri, 600 to 800 feet below the plains, affords such a fall that the stream courses are mostly etched deeply into the plain, but in many cases the present brooks are too small to account for the size of the ravines, or coulées, as they are locally called. Many of the mountain creeks become sluggish, meandering water courses, or lose their waters entirely through seepage and evaporation in the plains country. Arrow Creek combines the several features of the different classes; in its lower course it is, in midsummer, a chain of pools of bitter alkaline water. Several lakes form conspicuous features of the region north of the Highwoods. With one or two exceptions they occupy hollows in an abandoned river course—the Shonkin Sag and its continuation. Their waters are bitter and their shores are white with alkaline salts.

Vegetation.—The plains are treeless, but generally well grassed. The borders of the streams are fringed with willows, and the larger stream bottoms are covered with groves of cottonwood (*Populus balsamifera* and *P. angustifolia*) and alder. The mountain slopes above 5000 feet are covered with forests of pine—mostly *Pinus murrayana*, the lodgepole pine.

Climate.—The region is subject to extremes of heat and cold, varying greatly, of course, with the altitude. The annual rainfall is from 13 to 20 inches, being greatest in the mountains; June and October are the rainy months. The snowfall is heavy and the mountain tracts are well watered. Agriculture is therefore confined to the foothills and stream bottoms, except where irrigation is possible.

Culture.—Fort Benton, the town from which the quadrangle is named, is the oldest settlement. It was formerly important as the head of navigation upon the Missouri River, and is now a distributing center for a large area of sparsely settled country. The Great Northern Railway (Montana Central) crosses the plains in the northwestern corner of the quadrangle, to the north of the Missouri River, and a branch line of the railroad, running from Great Falls to Neihart, is the outlet for the coal mines at Belt and Armington, and for the silver mines of the Little Belt Mountains. Stage lines to the Judith region traverse the plains, passing through a number of minor settlements. The greater part of the plains country is devoted to stock raising.

Scenery.—The great limestone cliffs and the "sluice-box" canyon of Belt Creek (between Logging Creek and Riceville), the fantastic sculpturing of Square Butte and the adjacent bad lands of Arrow Creek, and the weird monuments of erosion along the canyon of the Missouri River near Eagle Creek are the most remarkable scenic features of the region.

Literature.—Previous publications upon the geology of the region are few in number, are based upon reconnaissance trips, and treat only of particular parts of the quadrangle. The most important papers upon the Little Belt Mountains are the following: Relations of the coal of Montana to the older rocks, by W. M. Davis; with appendixes on Petrography, by W. Lindgren, and on Fossils, by R. P. Whitfield: Tenth Census, Vol. XV, pp. 696–737. Notes, by J. S. Newberry: Annals New York Acad. Sci., Vol. III, No. 8, 1884. A detailed description is given by the writer in Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, pp. 271 et seq., in which the petrography is treated by Prof. L. V. Pirsson. A brief sketch of the Highwood Mountains and their remarkable rocks is given by W. Lindgren in the report above cited, and by Weed and Pirsson in Bull. Geol. Soc. America, Vol. VI, 1895, pp. 389–422. The geology of the Belt Creek coal field is described by the writer in a paper entitled Two Montana Coal Fields, in Bull. Geol. Soc. America, Vol. III, 1892, pp. 301–330.

DESCRIPTIONS OF THE ROCKS.

Three classes of rocks.

The rocks, grouped according to age and character into various formations, belong to three classes, surficial, sedimentary, and igneous rocks, whose general distinguishing characters are noted in the "Explanation" on the cover of this folio. The oldest, whose original characters have been completely obscured by changes of structure and by recrystallization, are here set apart as ancient crystalline rocks.

The geologic map shows that the various rock formations are grouped in an arrangement corresponding to the three topographic districts of the Little Belt, Highwood, and plains areas. The older rocks are seen only in the Little Belt Mountains. The plains area is underlain only by the younger, less compact rocks, covered in part by a mantle of unconsolidated glacial drift. The Highwood Mountains consist of various rocks, of volcanic origin, peculiar to this locality. The structure also of the formation is different in each area. The Little Belt area is part of a broad mountain uplift modified by local arches due to igneous injections. The Highwoods are a group of extinct volcanoes, dissected by wind and stream, and revealing the various internal as well as the outer structures of the vents.

ANCIENT CRYSTALLINE ROCKS.

ROCKS OF THE ARCHEAN PERIOD.

Gneisses and schists.—The oldest rocks of the region are the gneisses and schists found in the mountainous tract between Belt Creek and the Dry Fork. They are unconformable with the sedi-

The oldest rocks.

mentary strata which overlie them. They vary greatly in color, texture, hardness, and composition, and are well banded, but no evidence of sedimentary origin has been observed. Being, therefore, probably igneous and the oldest rocks of the district they are classed as Archean. They underlie the surface of Belt Park, whose gentle northerly inclination corresponds to the surface of the gneisses upon which quartzite beds rest. Near Barker this old surface is steeply inclined to the northeast. The Archean is a complex of various rocks. The most abundant is a white micaceous gneiss, whose foliation planes are indistinct, and which is composed chiefly of quartz and feldspar, with micas decomposed to green chlorite and pearly sericite. Interlaminated with the gneiss there is much micaceous hornblende-schist, whose rusty weathered outcrops are very conspicuous. Stringers or dikes of white granite (aplite) usually much sheared, cut the gneiss, and veins of white or rose-colored quartz are not uncommon. Some of the rocks are undoubtedly of igneous origin, but are sheared and metamorphosed.

SEDIMENTARY ROCKS.

ROCKS OF THE CAMBRIAN PERIOD.

Basal sandstone and conglomerate.

Barker formation.—The oldest sedimentary rocks of the quadrangle form a sequence, collectively called the Barker formation, as they can not be mapped separately on the scale of these sheets. They are characterized by fossil remains of middle Cambrian age. The lowest and oldest bed is the Flathead sandstone, a coarse sandstone, which rests directly upon the gneisses and is made up of small pebbles and coarse grains of quartz and feldspar, with occasional pebbles of gneiss. This grades into indurated sandstones, which are often so finely cemented, hard, and dense as to form a true quartzite. These basal beds are overlain by the Wolsey shale, consisting of 125 feet of purple and green micaceous shales holding small limestone nodules containing fossils, succeeded by the thin-bedded Meagher limestones, 110 feet thick, overlain by several hundred feet of the Park shales and limestone conglomerates. Above this there is 140 feet of the massively bedded Pilgrim limestone, weathering as a cliff or steep slope and marking the top of what has been distinguished as the Flathead formation. Above this the brick-red shales and limestones constituting the Dry Creek shale are covered by 100 feet of the Yogo limestone, which is included in the Gallatin limestone of the Yellowstone Park region. The total thickness of the Barker formation averages 800 feet. It is well exposed near Barker and in the broad valley of Pilgrim Creek as well as in the cliffs north of it. The beds are seen at the base of the Belt Creek cliffs south of Monarch, at Keegan Butte, and at the head of Running Wolf Creek, but as the rocks are soft and the shales weather easily, the formation is not generally well exposed.

ROCKS OF THE SILURIAN AND DEVONIAN PERIODS.

Dark, fetid limestones.

Monarch formation.—The Monarch formation consists of rocks readily distinguished by their color and crystalline granular texture from the limestones above or below them. The greater part of a total thickness of 130 feet consists of the dark-colored, usually chocolate-brown or bluish-black, Jefferson limestones, which weather with a pitted surface. The rocks are finely crystalline on fresh fracture, but show saccharoidal texture on surfaces exposed to weathering agencies. The dark color is due to organic material, and the rocks give off a fetid odor when struck with a hammer. They form beds 3 to 5 feet thick, showing block joints and weathering out in layers resembling masonry. These beds often show a fine striping, due to slight variations in color. Near Barker the lower beds contain light cream-colored masses of coral in a brown matrix, the species collected being of Devonian age. The Silurian age is supposed to be represented in the rocks at the base of the formation.

The upper 30 feet of the formation consists of reddish shaly limestones carrying abundant fossil shell remains, also of Devonian species. This formation embraces both the Jefferson and Threeforks formations of the southern part of the State.

ROCKS OF THE CARBONIFEROUS PERIOD.

Thick beds of fossiliferous limestone.

Madison limestone.—The Madison limestone is the most conspicuous single group of beds in the Little Belt Mountains. It consists of a thickness of 950 to 1000 feet of limestones, which constitute mountain masses near Monarch, steep canyon walls along Belt Creek and the Dry Fork, and are striking features of the scenery wherever exposed. Seen from the plains the beds form great curved plates wrapped about the slopes of bare rock.

The formation contains a very uniform fossil fauna throughout, but may be separated into subdivisions corresponding to lithological characters. At the base the strata are thin bedded and darker in color than the upper part of the formation, owing to the presence of much argillaceous material forming the Paine shale. The outcrops are frequently stained pale orange or red by iron oxide. In the great cliffs along both Belt Creek and the Dry Fork the section shows a ribboned structure, due to differences of weathering, the harder and more massive beds of the Woodhurst limestone projecting in relief. The massive, heavy beds of the Castle limestone at the top of the formation are well exposed in the "sluice-box" canyon of Belt Creek, and generally in the "gateways" where streams leave the mountains.

Sandstones, with layers of gypsum.

Quadrant formation.—Within the limits of this quadrangle the Quadrant formation is a variable sequence of sandstones, shales, and limestones. The lowest beds are reddish and yellow clayey sandstones, often holding interbedded layers of gypsum and constituting the Kibbey sandstone. These are overlain by the Otter shales holding interbedded limestones. The shales are dark gray or purplish near the base, becoming a bright coppery-green higher in the sequence. The interbedded limestones are seldom more than a foot or two thick, are frequently oolitic, and carry fossils of lower Carboniferous types. The gypsiferous sandstones are 153 feet thick near Riceville, and the overlying Otter shales 303 feet thick, giving a total thickness of 456 feet at this locality. The best exposures noted are seen in the cliffs along Belt Creek.

ROCKS OF THE JURATRIAS PERIOD.

Limestone grading upward into conglomerate.

Ellis formation.—The Ellis formation consists of a basal limestone, usually but 10 to 25 feet thick, which grades upward into a conglomerate that passes into a well-indurated granular sandstone, the total thickness being 135 feet. The basal limestone is a very dense, compact, pinkish-gray rock carrying Jurassic fossils. No sharp line exists between the limestone and the overlying conglomerate, the rocks grading into each other. The latter contains fossil fragments and pebbles of limestone and quartzite of various sizes up to 2 inches in diameter. This rock breaks into large rectangular blocks, which cover the slopes beneath the exposures. Upward the conglomerate changes gradually into a deep-yellow sandstone, which weathers reddish and is a prominent horizon along Belt and Arrow creeks. It is overlain by a finer-grained platy sandstone of common type.

ROCKS OF THE CRETACEOUS PERIOD.

Brown laminated sandstone with coal.

Cascade formation.—The Cascade formation consists of alternating beds of sandstones and shales. The lowest bed of sandstone, 160 feet thick, is distinguished from the underlying Ellis sandstone by its dull brownish color, its weathered appearance, and its lamination. Above these sandstones is the coal seam, which in some places occurs near the top of the formation. The sandstones lying immediately beneath it are impure, micaceous, and of a lavender tint. The coal seam is from 5 to 12 feet thick, but is entirely absent in some parts of the quadrangle. A massively bedded sandstone that caps the coal seam and forms a sloping table-land over large areas, is taken as the top of the formation. The total thickness on Belt Creek is 520 feet, and at Skull Butte 225 feet.

The fossil leaves found with the coal seam are of lower Cretaceous age, and resemble those of the Kootanie formation of Canada.

Sandstone and shale with fresh-water fossils.

Dakota formation.—The Dakota formation consists of beds of sandstone alternating with red and gray shales and clays. Certain purplish sandstones are of variable composition, carrying large amounts of purplish and red shale in streaks or disseminated through the rock. Buff-colored sandstones are purer, and are often cross bedded. Some sandstones pass horizontally into clays, and these and the interbedded clays are mostly of a reddish or a lavender color, containing lumps of yellow sandy material. At a horizon 140 to 300 feet above the coal of the Cascade formation the red shales contain bowlders and lenses of limestone varying from a few inches to a foot or more in thickness. The rock is dense, blue gray in color, weathering light buff, and contains numerous fresh-water fossils. The sandstone above these fossil-bearing beds is assumed to be the uppermost bed of the formation, giving a total thickness of about 300 feet along Belt Creek.

Gray shales with ash beds and marine fossils.

Colorado formation.—The Colorado formation consists chiefly of leaden-gray shales. The base is not readily separable from the Dakota, as the sandstones of that formation become shaly toward the top and alternate in thin layers with the dark clay shales of the Colorado formation. The Colorado comprises two formations, previously distinguished as the Benton shale and the Niobrara limestone. The former is typically developed about the town from which it is named; the latter is also a shale formation in this quadrangle, but contains limestone concretions. Along the northern base of the Little Belt Range and the Belt coal field, the Benton shale consists of alternating strata of gray shale and impure shaly sandstones, a good section of which is seen in Belt Butte. At this locality and along the south base of the Highwood Mountains the formation holds a white ash bed whose rock resembles porcelain and breaks into shaly fragments. The sandstone over this ash bed contains fish-scale impressions, and 100 feet beneath it is a sandstone bed which generally holds pebbles of black chert. The Benton shale is, however, a more homogeneous series at Fort Benton, and consists of dark-gray shale with very thin beds of impure sandstone. It forms steep bluffs along the Missouri River, and the beds contain an abundance of shells, sharks' teeth, and other remains of marine life. The upper part of the formation also varies in character in different parts of the quadrangle. West and south of the Highwood Mountains it consists of dark-gray or black shales in beds 50 to 200 feet thick, alternating with yellowish, rather massively bedded sandstones. East and north of these mountains, along the Missouri River, the rocks are more uniform in composition and color, forming a homogeneous series of leaden-gray clay shales, alternating with arenaceous shales. The former contain ovoid limestone concretions, often 2 or 3 feet in length and 1 foot or 2 feet thick, in which commonly occur fossil remains that ally it with the well-defined Niobrara of other localities. These shales generally contain much gypsum in disseminated scales and crystals, and the streams draining areas where these rocks are exposed are bitter with alkaline salts.

White sandstone, making ledges and bluffs.

Eagle formation.—The Eagle formation, named from its typical exposures along the Missouri River about the mouth of Eagle Creek, consists of a sequence whose most prominent bed is sandstone. The whiteness of the formation is in marked contrast to the dark-gray shales above and below it. The formation consists at the base of thinly laminated sandstones stained light brown by lignitic material, and containing concretions and nodular masses of iron ore. These beds grade upward into a very pure white sandstone, which along the Missouri River weathers into cliffs or steep slopes, with balcony ledges and striking monumental forms capped by ironstone masses. This sandstone forms extensive bluffs 75 to 100 feet high. It is overlain by less shaly sandstones with interbedded lignite seams. The total thickness of the formation is 200 feet. Exposures also occur in the bluffs of Arrow Creek, and northeast of Square Butte, where its measured thickness is 235 feet. At these localities the beds are nearly level, or but slightly tilted, and their relation to the leaden-gray Colorado shales beneath is clearly seen, while on the Missouri River similar gray clay shales overlie the formation. At the last locality occur fossil plant remains that are similar to those found in the Belly River beds, a formation found north of the Canadian line. Fresh-water shells are found in white sandstone beds in the Highwoods which may represent the formation, but the strata are flexed and disturbed, while the species identified are forms commonly found in the Laramie. The beds on Arrow Creek and Missouri River are clearly capped by a conformable series of marine beds, 2000 feet in thickness, which are, in turn, overlain by the Laramie east of the quadrangle.

Fresh-water fossils.

Gray clay shales with interbedded sandstone.

Montana formation.—The Montana formation is composed principally of leaden-gray clay shales which are much like those of the underlying Colorado. The formation contains much sandstone interbedded with the shale in the Highwood Mountains, but along the Missouri River is a very uniform series of drab-colored clays whose fossil remains are of Montana type. The subdivisions of the Montana recognized farther east are not found here, and it is doubtful whether the top of the formation exists within the limits of the Fort Benton quadrangle.

SURFICIAL ROCKS.

ROCKS OF POST-CRETACEOUS (TERTIARY?) AGE.

Stanford conglomerate.—The Stanford conglomerate is the name applied to a conglomerate found in the very prominent hills rising above the flat prairie near that town. The rock is a conglomerate whose pebbles are like those of the neighboring stream bed, and come from volcanic intrusions of the Little Belt Range. They are not well assorted, but are finely bound in a white, light-buff, or earthy-colored cement, and resemble lake beds. The road east of Stanford crosses a flat bench covered with this conglomerate.

Bench gravels.—A part of the plains region north of the Little Belt Range is a nearly flat, featureless plain, devoid of vegetation and showing few if any exposures of rock in place. This area is covered by a mantle of local drift, sand, and gravel brought down from the Little Belt Range by streams, and spread by them over the region as their courses were shifted from time to time. The gravels consist chiefly of the harder rocks, especially the igneous rocks, as they are the most durable.

ROCKS OF THE PLEISTOCENE PERIOD.

Moraines and morainal ridges.

Glacial drift and till.—The entire northern half of the quadrangle is covered by a nearly continuous sheet of glaciated materials. Near the southern limit of the area this forms a well-defined frontal moraine, with a scattered fringe of bowlders, and high morainal ridges occur south of the Missouri near Fort Benton. The material is an unassorted mixture of sand and gravel in which bowlders of varying sizes are irregularly scattered. These bowlders consist of gneisses, quartzites, and limestones very different from any rocks found within the quadrangle in this part of Montana, but identical with Canadian rocks whose nearest outcrops are over a hundred miles distant. The finer material is largely derived from the Cretaceous formations of the plains country. In many places a true ground till is found. The bluffs along the Missouri near Fort Benton and those of the Teton and Marias rivers show a capping of fine sandy clays, without stratification, seldom containing pebbles, but of remarkably uniform character throughout. No attempt has been made to distinguish this loess-like material from the other forms of glacial drift. It varies from a few feet to a hundred feet in thickness, and probably underlies the level plains north of the Missouri River, which stretch in apparently unbroken continuity to the Canadian boundary line.

River silts.

Alluvium.—The river bottoms, more especially those of the Missouri and the Teton, are occupied by flood-plain deposits of recent alluvium composed of the fine silts, clays, and gravels transported by the streams in times of high water and deposited by them. Such areas are commonly overgrown by thickets of willow, or groves of cottonwood trees.

IGNEOUS ROCKS.

The igneous rocks of the quadrangle present considerable diversity of structure and mineral composition, corresponding to differences in their mode of occurrence and chemical composition. They are grouped into extrusive and intrusive types, the former occurring in the Highwood Mountains only. The rocks are the products of two centers of eruptive activity, the Little Belt Range and the Highwood Mountains.

Igneous rocks of the Little Belt Mountains.—The igneous rocks of the Little Belt Mountains present many transitional varieties of well-known rocks, and even in the same rock mass they show considerable variation in character. For this reason the naming of the rocks forming the intruded sheets and masses presents difficulties which are partly met by giving local designations to the principal varieties of granite-porphyry (the commonest rock), while other rocks are designated by the names of the groups to which they appear most closely related. The rocks of the various laccoliths of the range belong to one well-marked structural type, with slight variations in mineral constitution and chemical composition. The most common form is a variety of granite-porphyry to which the name Barker porphyry is given. In Steamboat Mountain the rock is a diorite-porphyry, but these rocks, while petrographically distinct, are variations of the same kind of magma, and in hand specimens are strikingly similar and clearly belong to the same type.

Igneous rocks of the Highwood Mountains.—The igneous rocks of the Highwood Mountains are of various kinds and modes of occurrence. They are found as massive granular types, filling former volcanic conduits in the shape of central stocks or cores, such as exist at Highwood, Middle, Shonkin, and East peaks, or in laccoliths, as at Square Butte and near Mallard Lake in the Shonkin Sag; as porphyritic types in the great numbers of dikes which form so striking a geologic feature of the group; as dense, fine-grained or slaggy, scoriaceous, amygdaloidal rocks composing the extruded flows of lava; and as breccias, tuffs, and ash beds, which everywhere throughout the region give abundant witness of former volcanic activity.

From a petrographical standpoint the rocks are of great interest, as they possess many unusual features, and some of them are of novel types. For purposes of classification in this folio it may be said that they are composed chiefly of pyroxene, with more or less accessory olivine and mica, together with a white feldspathic component which is generally orthoclase but is sometimes partly nephelite, sodalite, or other alkali-rich silicates of similar kind. Sometimes several of these latter minerals are present. The proportion of the white feldspathic element to that of the dark augitic one varies within wide bounds; rocks may be found which are composed entirely of the former, and there are also intermediate types, with passages into those in which augite predominates, and these transitions occur alike in the massive rocks of the cores, in the dikes, and in the effusive lavas. Hence, for purposes of brief description, and to avoid too great technicality of classification, it is most convenient to divide this group of rocks into two classes, those in which the feldspathic element predominates, which fall under the general family of the syenites, and those in which the augite rules, which when fine grained are of basaltic character. When the rocks are coarse grained and massive a further subdivision is possible, the intermediate rocks also being grouped together.

The rocks which occur as intrusive sheets and dikes are mapped as trachytic rocks, which are generally the lighter-colored forms, and as basic or basaltic rocks, which are usually much darker in color and contain much larger amounts of mica, hornblende, or augite than the acidic types.

INTRUSIVES.

Barker porphyry.—The Barker porphyry, which petrographic study shows to be a granite-porphyry, is a light-colored rock, usually gray or pale brown, often weathering reddish. It shows large crystals, sometimes an inch across, of orthoclase, with very much more abundant and much smaller rectangular sections of pinkish, waxy, plagioclase feldspar in a groundmass that is recognizable as finely granular, and is peppered with black or dark-brown micas (biotite) and hornblende. The relative abundance of each or both of these dark-colored minerals varies somewhat at different localities, and even in different parts of the same mass. The groundmass consists of alkali feldspar and quartz, and the large amount of both quartz and orthoclase shows that the rock must be classed as a granite-porphyry, despite the fact that it has a pronounced andesitic look, and has been described by others as hornblende-mica-andesite and as dacite. The laccolithic masses of Tiger Butte, Thunder Mountain, Tillinghast Mountain, Barker Mountain, and Big Baldy Mountain consist of this rock. Each mass presents slight local variations in the character of the rock, that of Tillinghast Mountain being a granite-syenite-porphyry. At the borders of these great laccolithic masses the rocks are finer grained, dense, lighter colored, lack the abundance of hornblende and mica of the normal rock, and show quartz grains. These contact forms are rhyolite-porphyries similar to those of the intrusive sheets.

Diorite-porphyry.—The laccolithic mass of Steamboat Mountain consists of a diorite-porphyry that closely resembles the Barker porphyry, but contains a greater proportion of plagioclase feldspar, so that it must be classed as a diorite-porphyry. The rock shows the same phenocrysts, orthoclase and plagioclase feldspars, hornblende, biotite, and iron ore as the Barker porphyry, in a microgranitic groundmass of plagioclase and orthoclase.

Syenite-porphyry.—The rock of Woodhurst Mountain is classed as syenite-porphyry, as it is the end of the Yogo stock. The rock is in appearance essentially similar to the Barker porphyry, but microscopically it contains so little quartz that it is no longer a granite-porphyry. The intruded sheets of Clendennin Mountain near the Barker mines, though mapped under this name, are more properly designated as rhyolite-porphyry.

Wolf porphyry.—This rock is the very typical granite-porphyry which forms the intrusive mass of Wolf Butte and the peak south of it, as well as the mass of Mixes Baldy east of Barker. It is easily distinguishable from the Barker variety by the large, glassy quartz crystals which lie thickly scattered through it. Near the borders of the intrusions the rock is finer grained and dense, and is then a rhyolite-porphyry (quartz-porphyry). The porphyry of Wolf Butte has a white to pinkish color when perfectly fresh and unaltered, but is usually greenish or rust stained in the exposed material. The rock shows large phenocrysts of orthoclase and quartz lying embedded in a groundmass of dense felsitic character. The glassy feldspars often weather out in perfect crystal forms, sometimes 2 inches long; the glassy, smoky-gray quartzes are smaller, seldom over one-fourth of an inch across, are fractured, and break into fragments on weathering. This rock itself is generally much crackled, and breaks into small, irregular lumps on weathering.

Syenite.—This rock forms the stock or core cutting through the sedimentary rocks east of Barker. It is a hard and compact, moderately coarse-grained granite-like rock, consisting of a mixture of pinkish soda-orthoclase feldspar and hornblende, in which occasional large imperfect crystals of orthoclase sometimes give the rock a porphyritic appearance.

Highwood syenite.—The light-colored coarsely granular feldspathic rocks of Highwood Peak and the neighboring laccoliths are grouped under this name. The southern portion of Highwood Peak is composed of a very typical syenite. The outcrops and massive exposures of this rock are divided by joint planes into large blocks and plates. It has a white color, which varies into pale red, brown, or gray tones. It is composed almost entirely of alkali feldspars which have tabular forms and are in places arranged so as to show a fluidal structure, giving the rock a trachytic appearance on a coarse scale. Besides the feldspars, the rock contains a few little prisms of pyroxene and a small quantity of interstitial quartz.

The inner and upper portion of Square Butte is composed of a white rock which is a sodalite-syenite. The mass as a whole has a remarkable platy structure, due to contraction on cooling, and is divided into huge slabs. The rock is very light in color, appearing almost white at a short distance. It is moderately coarse grained and composed mainly of alkali feldspars, with more or less sodalite of a pale-pink color, through which are freely scattered small, slender, glittering black prisms of a peculiar hornblende.

The light-colored platy mass composing the summit of Palisade Butte is a rock of a somewhat similar character.

Monzonite.—This rock, which might be called basic syenite, is intermediate in composition between syenite and diorite. It is a fairly coarse-grained, evenly granular rock, consisting of nearly equal parts of orthoclase and plagioclase feldspar, together with smaller amounts of augite and mica. The northern half of Highwood Peak, the great core between it and South Peak, and the massive outcrops along the intervening ridges are referable to this family of rocks. They are dark gray in color, rather coarse grained, and in appearance recall many gabbros and diorites. They are rather basic rocks for monzonites, containing a large amount of augite, with variable amounts of olivine, hornblende, and mica. The white constituent is chiefly alkali feldspar, but the rocks contain also more or less nephelite and sodalite. Treated with hydrochloric acid, the rocks gelatinize readily and abundantly, and they also give good reactions for chlorine, showing that there is considerable sodalite present.

The great exposures of massive granular rock forming the cores near East Peak and at the head of Davis Creek, are of a similar character, but are believed to contain leucite as an important ingredient among the white components.

Shonkinite.—This name has been given to a rock of the syenite family which is very rich in augite and contains accessory olivine and black mica. The chief white compound is orthoclase, and there are varying amounts of nephelite and sodalite, though the latter minerals are sometimes absent. The rock is granular, and varies in the coarseness of its grain in different localities. The dark outer zone of "hoodoos" around the lower base of Square Butte is composed of a typical form of this rock. It forms also the lower portion or columns of Palisade Butte, and the laccolith in the Shonkin Sag, near Mallard Lake. Closely related types of it form the massive rock composing the intruded stocks or cores at the head of Shonkin Creek. The most southern and largest of these, the Shonkin Creek core, is at times very coarsely granular and resembles many very coarse-grained gabbros. These rocks are of very dark tones, owing to the abundance of the augite.

Missourite.—This unique rock, discovered and named from its occurrence in the Highwood Mountains, has been included with shonkinite in mapping. It is coarsely granular, dark gray in color, and resembles gabbro in appearance. It contains no feldspar, but consists of augite, olivine, and leucite, with lesser amounts of biotite, magnetite, and analcite.

Trachytic dikes and sheets.—In the Little Belt Range the dike rocks are mostly rhyolite-porphyries of various types. The most common type seen in the vicinity of Barker is a purplish or chocolate-colored rock resembling the Barker porphyry. The rocks are dotted with very small white feldspar phenocrysts and slender prisms of green hornblende and brown biotite in a dense groundmass of quartz and orthoclase. They are commonly altered, and are then dull and lusterless. The intrusive sheets east of Spring Coulée are quartz-diorite-porphyries.

In the Highwood Mountains the trachytic rocks compose a considerable proportion of the dikes found in and around the central masses of the granular stocks. They are light-colored rocks, of light-brown, gray, or green color, in places spotted with porphyritic crystals of hornblende, mica, or pyroxene, and generally with alkali feldspar. In the latter case the feldspars are sometimes present as small white dots, at other times as rather large, flat tables. The groundmass of these rocks consists mainly of alkali feldspar, with variable quantities of nephelite and microlites of augite and mica, the amount of nephelite sometimes present making phonolites of the rocks.

Basaltic dikes and sheets.—The dark-colored rocks occurring as intrusive sheets and dikes are grouped together under this title, and are shown upon the map by one color. In the Little Belt Mountains three varieties of rocks are included under this heading, viz: minette, vogesite, and kersantite, but in some instances the rocks are so decomposed that their original character can not be determined.

Minette is found only in intruded sheets and in dikes, but occurs rather commonly over the whole area. When very fine grained it is dark gray to black and has a basaltic appearance. It is composed chiefly of orthoclase and black mica, and when the grain is moderately coarse the abundance of the mica is at once seen and is its most striking characteristic. It weathers into a dark-green friable rock, which is likely to be foliated from the parallel arrangement of the mica plates. It occurs especially in the form of sheets intruded into the thin-bedded horizons of the Cambrian and the Carboniferous.

Vogesite occurs intruded in the Cambrian shales 8 miles below Barker, along the banks of Dry Fork of Belt Creek. It is a tough rock of grayish-green color, weathering to a soft crumbly form. It is fine grained and holocrystalline in structure, composed of an interlaced mixture of hornblende and orthoclase feldspar, and shows no phenocrysts.

Kersantite forms a dike cutting the syenite stock east of Barker. It is a dense and dark, almost black, rock resembling basalt, and showing large quartz grains and scattered feldspar and biotite phenocrysts in a groundmass composed of plagioclase feldspar.

Basalts.—These are the fine-grained porphyritic or effusive equivalents of the monzonite and shonkinite types of coarse-grained rocks. The basalts constitute by far the greater number of the dikes and the intruded sheets. When found in these occurrences they may be roughly divided into three classes, according to the appearance of the hand specimen. In the first group the rocks are black, dense, heavy, and of basaltic appearance. They are thickly spotted with well-formed crystals of basaltic augite, which attain a length of several millimeters, and they commonly contain smaller crystals of yellow olivine. The dense groundmass is made up of minute augites, olivine, a little mica, and a variable white feldspathic component, largely orthoclase. These rocks pass into types which are thickly spotted with small, round, white masses consisting, at times, as has been shown by analysis, of analcite.

The basalts of the second type do not carry large augites and olivines, but in their place are large crystals of black mica, at times a centimeter in diameter. Much mica occurs in the groundmass along with the small augites and variable white components, highly alkaline, of which orthoclase is the most important. These rocks thus constitute transition forms between the first type described and a minette. In only a few localities have they been found absolutely fresh and unaltered; they are generally deeply affected by weathering, and appear as soft, dark-green, crumbly masses, to which the altered micas lend a scaly appearance.

The third class is composed of those types which are not so strongly basaltic in character. In this group the white components are more abundant, and the rocks are more thickly spotted with the rounded analcite grains, are grayer in color, and are less evidently porphyritic. They are analcite-basalts, constituting in fact transition forms from the heavy black basalts in the lighter more acid porphyries and phonolites. They make up a considerable proportion of the dikes.

EXTRUSIVES.

Andesite breccia and tuffs.—The older light-colored extrusive rocks are essentially similar to the acidic dike rocks. They are perhaps better designated trachyte-andesite breccias. They are essentially feldspathic rocks which contain hornblende and biotite. They occur as fine-grained tuffs, as conglomerates, and as true breccias, are generally hard and well cemented and more or less altered, so that the decomposed iron-bearing minerals stain the rocks a red or brown color.

Basaltic breccia, flows, and scoria.—The bulk of the Highwood Mountains consists of dark basaltic rocks which are extrusive in character and represent the lava flows or ejected fragmentary material from volcanoes. These rocks present varying colors and textures, but all are varieties of analcite-basalt similar to those of the dikes. The commonest types are gray rocks thickly spotted with minute analcite grains. The massive form is found in the flows which alternate with the basic tuffs and breccias on the ridges around Lava and Arrow peaks. These basalts are abundant on the higher ridges, in the form of cellular, scoriaceous, slaggy rocks composing the masses of basic flows and breccias. They are generally reddened and altered by the action of water, which has oxidized the iron-bearing minerals, the augites and olivine, besides filling them with amygdules and masses of zeolites, of which latter natrolite is the most common.

Nearly all of these basalts have suffered so much in the hydration and alteration of the white feldspathic component that it is often impossible to define its exact original nature. It may be safely said, however, that in all cases they are probably high alkali basalts, and that common basalt with soda-lime feldspar as the chief component of the base is either very rare or wholly absent in the district.

RELATIONS OF ROCK MASSES.

THE ARCHEAN NUCLEUS.

The Archean nucleus of the region is exposed only in the southwest part of the quadrangle, where it has been disclosed by the degradation of the Little Belt uplift. It forms the floor on which the stratified rocks were laid down. This nucleal mass is often the resistant base for numerous igneous masses intruded between it and the sedimentary rocks.

The Archean rocks all show pronounced banding and schistosity. The folia lie at steep angles, and their dip and direction vary in different parts of the region, though similar for several miles along Belt Creek. The bands are not persistent, and bear no constant relation to the overlying rocks.

Schistosity and banding.

STRUCTURAL RELATIONS OF STRATA.

Contacts between successive formations.—The sedimentary rocks form an apparently continuous and conformable sequence from Cambrian to Cretaceous beds. No well-marked unconformity other than that between the Archean and Barker formations has been recognized in the region, though it is known that there are several gaps in the geologic succession. About the flanks of the Little Belt Range and the isolated domes near by, the Paleozoic limestones and associated strata dip more steeply than the younger beds, but, as is indicated in the Structure Section sheet, the border of the range is marked by a rather gentle fold.

Unconformities.

Low dips under the plains.—The beds which underlie the plains dip northeast at an angle of about 3°. This inclination is disturbed by slight warping in different parts of the quadrangle, as, for example, by a low dome in the coal field at Belt, and in several relatively small areas where the beds are disturbed by igneous intrusions. About half of the surface of the plains tract is concealed by drift, so that local flexures may exist to which no clue is afforded by existing exposures.

Dome of the Little Belt Mountains.—The Little Belt Range is a broad dome-shaped uplift, the beds on whose summit are flat or but gently inclined, while those on the flanks of the range are steeply inclined. This dip, which is away from the range, decreases as the distance from the mountains increases, until it coincides with that of the plains area. The small part of the range included within the quadrangle forms part of the northern side of the dome, but the simple fold is obscured by several local domes along the side of the arch and immediately outside of it. These local domes are so large and abundant as to form the most prominent structural feature of the mountains, as they modify the general arch and produce several troughs, in which areas of the younger rocks are surrounded by older ones, as a result of the general degradation of the region. No folds belonging to the general uplift were seen. Minor puckerings and faultings—too small to show on the scale of the map—are common accessories of such domes and intervening areas. The mountain north of Barker, which projects northward beyond the general border of the range, is another such uplift, and its fold merges with the folds near it.

Little Belt anticline.

Quaquaversal domes.—Skull Butte and the Woodhurst and Kibbey domes are symmetrical uplifts, with the beds flat on the summit and dipping away from the center, at angles of 18° to 20°, one very side. No igneous rocks are exposed, but the arching is probably due to concealed central cores of igneous material. Structural domes due to laccolithic intrusions also occur in the eastern end of the Highwood Mountains, Square and Palisade buttes being surrounded by tilted beds of sandstone dipping away, at 20° to 30°, from the buttes. The deep-cut lateral ravines about these elevations show that tilting occurs only about the borders of a mass of igneous rock, the beds resuming their normal nearly horizontal position a few hundred yards from the igneous rock. Two other domes are cut across by the old river course known as the Shonkin Sag. The beds underlying the intrusive mass are seen to be horizontal, while the beds at the sides are sharply flexed and arch over the igneous rock in a low dome which has been partly removed by erosion. Such arches in horizontal strata are regular, and do not show the faulting and asymmetry of the domes in the flexed beds of the Little Belt region.

Domes probably laccolithic in origin.

Asymmetric domes.—The large intrusive masses which constitute the principal mountain peaks of the Little Belt area are not symmetrical, but show a break or faulting in some part of the arch. This faulting is always upon the side of the dome nearest the plains, thus having a constant relation to the range uplift. The result of this asymmetry is that the older rocks, usually those of the Barker formation, are raised to the same elevation as the Madison limestones on the northern or northeastern side. Thunder Mountain and Barker Mountain both show this structure, as may be seen on the areal and Structure Section maps.

Synclinal basin.—Where two domes occur close together the space between forms a trough or basin, a good example being the area drained by the head waters of Arrow Creek, in the Little Belt Range, where the clays and soft shales of the Quadrant formation are seen.

Landslides: blocks of strata.—Along the Missouri River there are areas a quarter of a mile or less in extent which show beds tilted at angles at variance with those of the surrounding strata. These are blocks detached from place and thrown down by landslides—large masses of strata loosened by the saturation of the underlying soft clay shales so that their weight causes them to slide.

STRUCTURAL RELATIONS OF THE IGNEOUS ROCKS.

Igneous rocks play a most important part in the geologic structure of the mountainous portions of the quadrangle. They occur in various forms of intrusive masses, breaking up through the sedimentary rocks as stocks and dikes, or pushing apart the strata to make room for themselves as intruded sheets or laccoliths. The Highwoods are, as already stated, largely made up of effusive rocks and ejectments of volcanic eruptions.

Stocks.—The intrusive body of syenite in and about which the ore deposits of Barker occur is probably to be classed as a stock, as it breaks abruptly up through the other rocks. It is a mile or more across, of oval outline, and is composed entirely of granular rock. The rock forming Woodhurst Mountain is the extreme northeast end of another stock which at this place has tilted the surrounding strata so that the structure is partly laccolithic in character.

Volcanic cores.—In the Highwood Mountains several centers of eruptive activity are recognized by the cores of massive rock formed of the molten magma that congealed in the throats of the volcanoes when they became extinct. These masses have been exposed by erosion at Highwood, South, East, Shonkin, and Arrow peaks. At South Peak the fragmental rocks of which the former cone was built are entirely removed, and the root of the old volcano is seen as a core of massive rock intruded in sedimentary beds. The aureole of metamorphosed rocks is not more than a few hundred feet wide, and the alteration diminishes rapidly away from the borders of the massive rock. The border of the core is further marked by a great number of dikes, which generally radiate at right angles to the border, and in most cases do not penetrate the massive core rock.

Old volcanic vents.

Highwood Peak, the loftiest summit of the mountains, is formed of a mass of breccias, with a central core of two kinds of massive rock, both of coarse grain but very unlike in appearance. At East Peak the coarse-grained rock is seen intrusive in the basaltic breccias, the younger fragmental rocks.

At the Shonkin Creek core, and those masses near by, the granular rocks vary greatly in appearance, in coarseness of grain, and in form of weathering. They are all dark-colored basic rocks, coarsely granular to the eye. The Shonkin Volcano, though the youngest vent, is well dissected by the deep ravines that score this part of the mountains. The throat of the volcano is filled with a tumultuous mass of blocks cemented by a finer-grained rock which is itself cut by dikes. The vent is at the south end of a large body of massive rock, about the borders of which the baked sedimentaries show fine examples of contact metamorphism of clay shales and sandstones, and the igneous mass has also baked and altered the older acidic (andesitic) breccias and later basaltic breccias that form the old cone.

Radiating dikes.—Throughout the Highwood Mountains there are seemingly innumerable dikes. Those shown upon the map have been actually located in the field, though in the area north of the Shonkin Creek core they are too numerous to be indicated upon the map, and each one shown really represents a number. Over seventy dikes were counted in a distance of a half mile along the ridge between Shonkin and Alder creeks. In the breccia areas these dikes are not recognizable from a distance, as they are like the breccia in color and do not weather very differently from that rock. In the light-colored and soft sedimentary rocks, however, the soft mica-basalt weathers rapidly, and dikes of it can be traced by lines of green vegetation growing on them. The hard basaltic dikes, on the contrary, resist weathering better than the stratified rocks and stand out as broken-down walls. The dikes, when mapped, are seen to have a system, and not to be a haphazarded network of injections. In almost every instance compass readings show them to radiate from one of the various volcanic rocks. The dikes about the Shonkin vent are especially numerous and notable, being traceable for many miles across the open foot slopes north of the mountains. At the contact these dikes have, as a rule, narrow bands, a few inches wide, of altered sedimentary rock.

Relation of dikes to stocks.

Intrusive sheets.—In the Little Belt Mountains the sedimentary strata about the larger igneous masses are intruded by sheets of igneous rocks. They occur in various formations, but are especially abundant in the shaly strata of the Barker formation. These sheets have been intruded along the partings between the sedimentary strata, and conform to them in dip. They are of various thicknesses, from 1 to 60 or more feet, and are often many miles in extent. A fine example is seen along the banks of Dry Fork of Belt Creek above Barker, where a sheet of chocolate-colored porphyry forms a persistent cliff. In one place this sheet divides into three parts, separated by shale bands. In the Highwood Mountains intrusive sheets are sometimes found where dikes have spread out horizontally along shale beds. Intrusive sheets are abundant at Square Butte and at Palisade Butte, where they underlie the great mass of igneous rock forming those hills.

Laccoliths.—A laccolith is a body of igneous rock which has intruded itself between sedimentary strata, making room by lifting the overlying beds. The laccolith differs from an intrusive sheet by the thickening of the mass into a lenticular body, over which the strata arch. A perfectly symmetrical dome-shaped body is the ideal form. The examples in the Little Belt Range are not perfectly regular, but have broken up into higher beds at some part of the margin. Subsequent erosion has removed the domes over many of these laccoliths and cut deeply into the igneous masses beneath, forming mountains, the height of which depends upon the amount of the original uplift and the degree of denudation. Laccoliths in various stages of denudation are seen in the quadrangle. The Little Belt Mountain laccoliths occur partly denuded of the sedimentary cover, and also in domes where the overarching strata have not been removed or igneous rock exposed, though the structure leaves no doubt as to its presence.

The laccoliths of the Little Belt Range are all in a plicated region. The uplift and folding of this tract to form the range favored the intrusion of such igneous masses in the spring of the arches and the saddles. Lateral pressure acting upon the massive beds of limestone overcame the weight of the strata to a great extent, and the Cambrian shales offered an easy plane of parting. These conditions favored the injection of intrusive igneous sheets, both in these shales and at higher horizons where the beds if not actually split apart by lateral pressure were certainly under stress and yielded readily to the hydrostatic pressure of the lava. As these folds preceded the intrusions, a symmetrical laccolith is unusual, since the fold would occasion a line of weakness which would develop into a fault on one side of the laccolith. This is the prevailing type in the Little Belt Range, the fault being on the northern monoclinal fold of the range. It is well illustrated at Tiger Butte, at Barker Mountain, and at Steamboat Mountain. The Mixes Baldy and Wolf Butte masses are not typical laccoliths, as fracturing is there the prevailing feature of the contact. At Thunder Mountain the heaving force of the intrusion was so great that only the rocks immediately adjacent to the contact are uptilted. Barker Mountain is an example of an intrusion from which the cover has been partly removed, and the smooth, rounded southerly slope of the mountain is the surface of the laccolith, as yet but little scored by streams. The mountain northeast of it is still covered by stratified rocks, horizontal on the summit and dipping steeply away on its slopes, but a branch of Otter Creek has cut deeply into the heart of the mountain on the west and exposed the igneous core. Steamboat Mountain, south of Big Park, Dry Wolf Creek, is another example of a laccolith just revealed by the erosion of its cover. The great dome-shaped hill near Kibbey is believed to represent a laccolith from whose summit the softer shales and sandstones have been stripped and the massive Madison limestones cut through by Little Otter Creek, but the igneous core is probably still far below. A similar dome is cut through by Dry Wolf Creek. A smaller dome, forming the prominent rounded hill rising above the open plains near Stanford, called Skull Butte, is not yet stripped of its higher, softer beds.

Conditions favorable to the formation of laccoliths.

In the eastern part of the Highwood area, the earliest volcanic disturbance resulted in the formation of laccoliths in the stratified rocks. These were greatly denuded before the earliest breccias of the region were laid down, and hence may be regarded as the oldest of the igneous rocks of these mountains. The Shonkin Sag is cut across two of these laccoliths, excellent sections of which are exposed in the cliff walls of the sag. Square Butte is a large laccolith now entirely stripped of its sedimentary cover. The flat summit and upper slopes of the butte are formed of sodalite-syenite, a very hard and resistant rock. The lower slopes and base are of a very dark and crumbly shonkinite, which disintegrates readily and erodes into fantastic pinnacles, towers, and grotesque forms, often called "hoodoos." The borders of Square Butte present some very peculiar and picturesque examples of erosion. Palisade Butte is a dark, pillared mass, whose slender columns rise abruptly above the grassy prairie. It is believed to be the core of an eroded laccolith whose outer portions have all been removed. The pillars, like those seen in the section of the Shonkin Sag laccolith, are normal to the cooling surface, and rest upon horizontal beds of sandstone and shale. The rocks of this butte are also of the two types, syenite and shonkinite, already noted. Intrusive sheets are common accompaniments of these bodies.

Highwood Mountain laccoliths.

The product of the earlier eruptions was a light-colored andesitic tuff and breccia. This filled the pre-existing valleys, greatly modifying the surface, but was itself deeply eroded before the basaltic materials thrown out by later eruptions covered it. The earlier breccias show rude bedding and assortment, while the later ones are mostly chaotic and odorless accumulations of scoriaceous breccia with occasional lava flows. About the borders of the mountain area the breccias show a rude arrangement. The nature of these rocks show that the eruptions were violently explosive.

Fragmental igneous rocks.

Association of the igneous rocks.—In the Highwood laccoliths and at Highwood Peak masses of Highwood syenite and basic rocks occur together. At the latter locality the two forms are quartz-syenite and monzonite. At Square Butte it is sodalite-syenite and shonkinite. The relations of these dissimilar rocks is beautifully illustrated in the Shonkin Sag laccolith. The walls of the Shonkin Sag show sections cut through two of these lenticular intrusions, disclosing the abrupt folding of the beds about them, and exposing the sheets—which run out from the main intrusion and whose outcropping edges are traceable for many miles—intruded between the beds of sandstone and shale. The top of the northern laccolith has been partly bared by erosion, presenting a broad, gently rounded surface which is deeply cut at one or two places by stream gorges, showing the internal features of the mass. The section thus presented shows that the liquid rock cooled rapidly about the borders of the main body and in the intrusive sheets, consolidating as analcite-basalt. In the center, however, where cooling took place more slowly, the magma differentiated into two very unlike portions, and consolidated in two very dissimilar, coarsely granular rocks. The central core is composed of a syenite consisting chiefly of light-colored minerals, mainly feldspar. This is surrounded by a darker rock composed of the darker and heavier iron-bearing minerals, augite, mica, and olivine, with a small amount of feldspar and its allied minerals. This differentiation is more strikingly illustrated in the large flat-topped mountain mass named Square Butte, which forms the extreme eastern member of the Highwood group.

Differentiation of the cooling magma.

RELATIONS OF POST-CRETACEOUS BEDS TO TOPOGRAPHY.

The post-Cretaceous beds rest upon the eroded surfaces of the older rocks. The Stanford formation, of which only isolated fragments now remain, caps hills and interstream terraces which owe their prominence to the protection afforded by the Stanford rocks during the degradation of the region. The bench gravels form a usually thin veneer over the terraces of local streams, and also fill minor depressions in the plain. The level character of the area covered by the gravels is, however, the result of a planing down of the region by streams.

The glacial gravels, tills, and silts lie upon a surface as uneven as that of the unglaciated plains area seen at the present day. They fill pre-existing hollows and stream beds, and the resulting surface is a rolling plain. The southern part of the glacial drift area shows well-marked terminal moraines or ridges, and the extreme limit is generally marked by an abandoned river channel (the Shonkin Sag) whose course is transverse to the present drainage. The morainal heaping along its northern border is, however, not continuous enough to deflect the present drainage. North of the Missouri River the present topography is wholly glacial in character and the drainage is dependant upon it. A narrow ridge, in places but a few yards wide, deflects the Teton River, so that instead of entering the Missouri River near Fort Benton it empties into the Marias River near the mouth of that stream. The alluvial deposits fill the present stream hollows, and therefore rest upon the eroded surface of all earlier rocks.

The leveling effect of the glacial deposits.

HISTORICAL GEOLOGY.

The quadrangle presents a wide diversity of rock types, whose lithologic characters, structure, and chemical composition indicate a varying manner of formation. The fossils found in the sedimentary beds show that although the stratified rocks are seemingly conformable and the result of continuous deposition, yet such is really not the case, and that the area was from earliest geologic times subject to oscillations of level, by which it was alternately submerged beneath the ancient seas or elevated above them, until the final continental elevation drained the entire region of the Great Plains. Since that time unceasing erosion has removed many thousand feet of the softer, newer beds, remnants of which are seen in the Highwood Mountains where the sediments have been preserved beneath a covering of lavas, or baked by them into hard, resistant forms. Their presence shows the extent of the long-continued period of erosion.

PRE-CAMBRIAN LAND.

The oldest rocks found in the quadrangle—the Archean gneisses and schists—are thought to represent here, as elsewhere, the earliest-formed rocks of the earth's crust. In the limited tract exposed in this quadrangle they consist largely of sheared and altered rocks, whose igneous origin is often still apparent.

Algonkian submergence.—The Little Belt tract was a land area during that early period of geologic time known as the Algonkian. In this region the Archean rocks were worn down to a nearly level plain, and formed a lowland during the gradual subsidence of the region to the south, over which a thickness of many thousand feet of shallow-water beds were deposited. This was followed by an uplift that raised the entire Belt Mountain area above the sea, as is shown by an absence of rocks of lower Cambrian age, and also by an unconformity of the succeeding formation upon the previously deposited strata. The Algonkian rocks are not found exposed in the limits of this quadrangle, though they constitute the nucleal core of the Little Belt Range and cover large areas in the adjacent quadrangle to the south.

Absence of Algonkian sediments.

PALEOZOIC SUBMERGENCE.

Middle Cambrian transgression—A gradual depression of the region, with a widespread transgression of the sea and the formation of a beach deposit of conglomerates and sandstone, marked the beginning of middle Cambrian time. The subsidence was gradual, for the basal sandstones are widespread, and the succeeding deposits, of shallow-water origin—shales, limestone-conglomerates, and limestones, with rarer beds of quartzose sandstone—show widely varying conditions. These rocks, resting directly upon the old continental land surface, were formed from detrital materials derived from the disintegration of the schists and gneisses under atmospheric agencies. These earlier sediments consist of quartz grains and pebbles, with fragments of the underlying rocks. Over this basal bed comes somewhat finer and lighter material, largely mica and clay, derived also from the basal crystalline rocks. Upon these shales the calcareous sediments were deposited, at first associated with quartz sand and mica, but carrying less and less foreign matter, until the beds consist of nearly pure limestone carrying marine fossils of middle Cambrian types.

Evidence of shallow water.

Marine occupation from Cambrian to Carboniferous.—From these early-formed beds of limestone to the top of the Madison formation, the great limestone body of the Little Belt Range, the beds consist almost entirely of calcareous deposits which vary considerably in purity, some carrying more or less clayey material, others containing much quartz sand; still others hold magnesia, thus becoming dolomites. Differences in color, mode of bedding and fissility or massiveness, render it possible to separate this great body of limestones into several series.

Predominance of calcareous deposits.

The limestones, which are supposed to represent the Silurian and Devonian periods, are grouped with the thin-bedded fossil limestones carrying fossil shells of Devonian species, under the name of the Monarch formation. The beds are, so far as observed, conformable, and give no indication of the great stratigraphic and paleontologic break which exists in the Silurian of the eastern United States.

In this quadrangle the succeeding limestone series is characterized throughout by an assemblage of fossil remains of marine forms of lower Carboniferous types. A local unconformity has been observed between the Madison limestone and the underlying Monarch limestone, but none has been found at the top between them and the very different series of beds composing the Quadrant formation. This latter formation shows a very decided change of conditions of deposition, indicating a rising of the region, with shore and estuarine deposits which preceded the emergence of this tract above the sea. The change from pure limestone to red sandstones with gypsum beds and limy shales is abrupt, but the Quadrant contains also several beds of very pure limestone. The shaly beds and the limestones both contain fossils of species identical with those of the Madison formation, but smaller and of impoverished aspect. The beds are fossiliferous to within a few inches of the top, and though there is a marked change in the character of the forms of life there is little change in the character of the beds between this and that of the overlying Ellis formation, whose fossils are of Jurassic age.

JURATRIAS PERIOD.

Hiatus of Neo-Carboniferous and Triassic epochs.—There is no representation of the upper Carboniferous (or Coal Measures) epoch, nor of the succeeding Triassic epoch, and it is inferred that the region was a land area during that time, as, indeed, is indicated by the facts observed in neighboring parts of the State.

Jurassic aspects.—The Ellis beds show an emerging land, the impure limestones carrying more and more siliceous sand; the last-formed beds consist of a mass of comminuted wave-worn shells and sand grains held in calcareous cement.

CRETACEOUS PERIOD.

Early Cretaceous lowlands.—At this epoch the region emerged from the sea, forming a tract of low-lying land with shallow lakes or estuaries and swampy areas in which a luxuriant vegetation of ferns and rushes furnished the material for the beds of coal now so extensively mined.

Coal marshes.—The beds which contain the coal constitute the Cascade formation and are supposed to be the equivalent of the Kootanie beds of Canada, for they are similar in stratigraphic position and the plant remains found with the coal show a similar flora. The beds of volcanic ash and tuff found interbedded with the Canadian strata, and seen also in the Cascade beds of the quadrangle south of this, have not been observed here.

Alternation of fresh and marine waters.—There is no evidence showing the condition of the region during the long period intervening between the Cascade and Dakota epochs. After the formation of the coal seams the basins were covered by a varying thickness of sand which now forms the heavy bed of sand rock everywhere seen above the coal. This was succeeded by the deposition of alternating beds of shale and reddish or lilac-colored sandstone. The shales hold limestone nodules and lenses that contain fresh-water fossils at a horizon 140 to 190 feet above the coal. The fossils found do not fix the age of the beds, being plain, unornamented shells whose characters remain persistent through several geologic periods, but they establish the nonmarine origin of the rocks, in distinction to the truly marine origin of the succeeding epoch.

Fresh-water deposits.

From the Little Belt Range northward, the strata of the Colorado formation show a change in character that increases with the distance from the shore line. The fossils are well preserved and common, especially the pearly rod-like baculites, sharks' teeth, and numerous shell remains. The white tuff bed found in this formation shows that volcanic activity prevailed in some neighboring region, but the material is fine and might have been transported many miles by the wind before falling into the sea. At the close of the Colorado epoch the land again rose above the sea, for the white sandstones of the Eagle formation are of fresh-water origin. The source of the pure white sand is unknown. This formation corresponds in lithologic character and in stratigraphic position to the Belly River series of Canada, and the few fossil remains, plants, and fresh-water shells support this correlation.

Marine conditions.

The rocks of the Montana epoch show a submergence of the northeastern corner of the quadrangle beneath marine waters; the sea was not deep, for the deposits consist of clays and sands. The observed facts do not prove the submergence of the entire quadrangle, and the evidence of neighboring regions indicates that the borders only of the Little Belt area were covered.

Late Cretaceous mountain growth.—The uplift of the Little Belt Range above the sea appears to have taken place during late Cretaceous time, but the mountain-folding and blocking out of the range probably took place after the close of the Laramie, or later than the deposition of any of the sediments found in the quadrangle.

IGNEOUS INTRUSION AND VOLCANIC ACTIVITY.

The mountain-folding was accompanied or followed by the intrusion of great masses of igneous rock into the flexed strata. The hot liquid rock magma was forced between the limestones, invading most readily along stratification planes or in beds of soft shale, forming sheets, or bulging up the overlying beds into great arches or domes, and sending out minor sheets between beds ruptured by the forces. In many instances these intrusions form these lenticular masses of igneous rock called laccoliths, which in the Little Belt Mountains rest upon an inclined floor, and in this case are seldom absolutely symmetrical, but generally rupture the strata upon one side and break up to higher horizons. In other cases the force of the intrusion was too great or was exerted too suddenly to permit the overlying rocks to bend, and a plug-like mass similar to that of Thunder Mountain was driven up through the sedimentary rocks. These intrusions, so far as can be determined, did not reach the surface, but cooled as great masses beneath the cover of sediments.

Igneous intrusion associated with the folding.

During this or some later period not definitely determinable, the Highwood Mountains area became the center of volcanic activity. The laccoliths of Square Butte, Palisade Butte, and the Shonkin Sag were formed, and somewhat later active volcanic action began. Cones of fragmental rocks ejected from the vents were built, lavas were poured out, and the region was cracked and fissured, the cavities being filled with molten rock. That this continued for a considerable period is certain, for the earlier vents now seen at Middle and Highwood peaks were denuded and stripped of their fragmental volcanic rocks before the more recent basaltic lavas seen to-day were accumulated.

POST-CRETACEOUS EROSION AND DEPOSITION.

Since this later volcanic period denudation has obliterated the contours of the most recent of these volcanic cones, has stripped the laccoliths whose cores now form Palisade and Square buttes, and has worn away the country to its present level.

Glaciation.—During the Glacial epoch the northern part of the quadrangle was invaded by a tongue of the great Canadian ice sheet, the Laurentide Glacier, but it did not reach the flanks of the Highwoods. The ice leveled off the sharper eminences and filled the hollows with local and far-transported débris. The glacial deposits include a covering of till and loess, as well as the usual morainal heapings. Since the melting of the ice, stream action has cut the canyons which score the plains, has modeled the peaks, uncovered many of the laccoliths of the Little Belts, and carved the "hoodoo" parks about Square Butte and the labyrinth of the Arrow bad lands.

Extent of the ice sheet.

A remarkable feature of the plains area is the Shonkin Sag. This is a continuous depression that is clearly an old river channel, with wide valley floor and steep walls and precipitous cliffs, whose tortuous course can be traced from Highwood Creek to Arrow Creek. Shonkin Creek follows it for a few miles, then continues directly northward. Four large lakes mark its course. Flat Creek, a small stream that drains two of the lakes in the sag, meanders sluggishly through its broad floor, but leaves it in the gap north of Square Butte, the sag continuing eastward to Arrow Creek. From this point the Arrow Creek Valley is coincident with the sag for some 15 or 20 miles. The glacial drift is heaped up in morainal ridges along the northern border of the sag, which, with its relations to the present topography, shows that the sag must have been formed by a stream flowing eastward about the borders of the great ice field which extended southward to this place from Canada, bringing up gneiss and limestone drift from the Laurentian Hills.

Shonkin Sag.

ECONOMIC GEOLOGY.

The mineral resources of the quadrangle are varied, including deposits of the precious metals, coal, gypsum, limestone for flux and quicklime, iron ore, building and ornamental stone, brick clay, and fire clay. The silver ores of the Little Belt Mountains and the coal of the Belt Creek field are by far the most important. Each of the minerals mentioned occurs in deposits having a definite association with certain geologic formations or structure, and their occurrence is therefore indicated in a general way upon the geological map showing the distribution of the rock formations, called the Historical Geology sheet. As, however, the entire area of such formations is not always mineral bearing, the areas indicated by dark colors are probably underlain by workable deposits of coal or gypsum, and the areas where ore deposits occur or where the conditions are especially favorable for their occurrence, are indicated upon a special map called the Economic Geology sheet. On this sheet all the mines actually worked and many of the prospects are indicated by appropriate symbols. The areas of limestone, building stone, and clay suitable for economic use have not been emphasized, but are noted in the text.

Mineral resources.

Gold.—Gold and silver are found only in that part of the quadrangle belonging to the Little Belt Range. Gold has been found in limited quantity in small areas of placer gravels of existing stream beds, and at a number of localities in quartz veins, but of these none have as yet been developed into mines. Quartz veins carrying a few dollars of gold to the ton are found throughout the Archean area, on Belt Creek, on Hoover Creek, and on the branch of Dry Fork of Belt Creek which heads north of Big Baldy Mountain. The Belt Creek locality yielded a small amount of rich quartz, and was actively exploited for the few weeks following its discovery, but no paying mines were found.

No developed gold mines.

Gold also occurs in small amounts in some of the silver ores, especially in those found in the prospects of Pilgrim Creek, but in the silver-lead ores, which form the bulk of the mineral product of the region, it is commonly present in minute amounts, if at all. Assays of the iron ores of Thunder Mountain are said to show $1.00 to $2.00 in gold to the ton.

Silver.—The Little Belt region was for many years an important silver producer. In that part of it included within the quadrangle the metal occurs mainly in silver-lead ores. Promising prospects showing good ore were found at a number of localities, principally about the margins of the eruptive masses of porphyry. For this reason, and because the zone of altered rocks about such masses offers the most promising structural and mineralogical conditions for ore deposition, these contact areas have been emphasized by a distinctive color upon the Economic Geology sheet. This mode of occurrence has been generally recognized by prospectors, for these areas are often dotted with shallow prospect pits, but considerable tracts still remain untouched, and those already visited by prospectors have not been either carefully or thoroughly searched. In most cases the ores occur at or near the contact of the limestone with eruptive porphyry. In some cases a distinct fissure or vein is recognizable. More often the ore occurs in bunches in the limestone. In this latter case much time and energy have been fruitlessly expended hunting for a well-defined vein. Such pockets or bowlders of ore are commonly connected by stringers, often mere rust-stained fractures of the rock, but these deposits have often yielded large returns in other parts of the State.

Barker mining district.

The Barker district has thus far been the only one that has produced any considerable amount of ore. Discovered soon after the first settlements of the State were established, in 1879–1880, it became the site of a promising mining boom, and the town of Barker, which on most maps is given its former post-office name of Clendennin, was established. A number of claims yielded large amounts of ore, and a smelter was erected to treat the product of the mines. Since the completion of the railroad to Great Falls, in 1891, the ores have been shipped to that city or beyond for treatment.

The exhaustion of the rich ore bodies first discovered ended the boom. Since that time the district has had several partial revivals of activity, only to lapse into all but total abandonment. The different mines have from time to time been leased and worked for short periods, more ore bodies discovered, extracted, and the leases relinquished. The history of the camp has therefore been a disappointing one, despite the fact that the conditions for successful mining appear, even to-day, to be favorable. This is probably largely due to the generally small size of the ore bodies, and to the fact that they occur in a number of small mines, and not in great ones like those of the noted mines of the State.

The ores are of simple mineralogic character, consisting of galena together with pyrite, zinc blende, and sometimes a little copper pyrite. Calcite and quartz form the gangue veinstone.

Mode of occurrence of the ore.

The ore deposits all occur at or near the contact with the eruptive rocks, with which they are undoubtedly genetically connected. There is some difference in the manner of occurrence, however, and the ore bodies thus far found on contacts between porphyry and limestone having been the largest have, of course, been most remunerative. The Silver Bell, on the northern bank of Galena Creek, opposite the town, and the Carter, Paragon, May, and Edna group on the Kibbey divide, are examples of this class.

Silver Bell mine.

The Silver Bell mine yielded between 120,000 and 150,000 tons of argentiferous galena in 1890. The ore occurs at the contact between the limy shale of the Barker formation and an intrusive sheet of porphyry, the plane of contact dipping about 50° N., into the mountain. The galena gave out in depth and was replaced by pyrite, and the mine was consequently abandoned. As no search was made for other ore bodies along the lateral extension of the contact, the property can not be said to be valueless, and efforts were made in 1898 to lease the mine and look for further bodies of ore.

Carter mine.

The Carter mine showed a somewhat similar structure. The ore was found at the contact of limestone and porphyry in a pipe or chimney-shaped body, which is said to have shown 10 feet of galena for a depth of 120 feet. For 100 feet below this the ore body widened to 30 feet, but held only 5 to 6 ounces of silver, with much iron pyrite and a little copper pyrite. The ore sheet became poorer at 220 feet below the surface, the galena occurring only in kidneys.

Barker mine.

The Barker and the Wright and Edwards mines are situated on veins in the mass of granular syenite which has broken up through the other rocks in the upper valley of Galena Creek. The ore is an argentiferous galena that occurs in bunches in fissure veins which cut the syenite itself, or which follow contact planes between it and intrusive dikes or sheets of porphyry. The Barker mine was one of the first discovered in the district, and it is said to have yielded considerable ore in 1890–91, but remained unworked for several succeeding years. It is developed by a vertical two-compartment shaft, with crosscut levels to the veins, and also a long drift level. The ore contains much calc-spar, and the syenite is shattered and reticulated with pyrite films. The dump shows crumbly porphyry and hard, dense syenite, but the relations of the two rocks are not known, as the workings were inaccessible.

Wright and Edwards mine.

The Wright and Edwards property includes three parallel adjoining claims north of the Barker mine. Though closed down for many years, the mine has recently (1898) been reopened under a lease to the company operating the Great Falls silver smelter. The tunnel shows that syenite is here cut by a dike of vogesite-porphyry about 20 feet wide, which forms the west wall of the lode. The crosscut tunnel, driven through syenite to the lode, shows eight well-marked parallel fracture planes seaming the country rock in a northeast-southwest direction, each one marked by a bleaching and whitening of the rock for a few inches on each side of the fracture. The mine was a steady producer of silver-lead ore in the summer of 1898.

Not far from the Barker mine, and situated in the porphyry near its east contact with the mass of Wolf porphyry forming Mixes Baldy, are the two mines known as the Liberty and Queen Esther properties, which were worked in 1897, shipping several carloads of silver-lead ore, but have since been idle. The veins trend N. 80° to 85° E., and dip 50° to 55° S.

The Liberty shows a vein 3 to 4 feet wide, of banded quartz and galena. An inclined shaft 190 feet deep and two surface tunnels show an ore shoot 130 feet across on the upper tunnel, and one not yet cut across when seen but over 90 feet wide on the tunnel 110 feet below. The mine yielded ore for two years, but is now idle.

The Queen Esther shows a vein carrying from a half inch to 6 inches of galena, the shoot pitching into the mountain. The vein is in part on the contact of a granite-porphyry dike which forms the east wall in the lower tunnel. In 1897 the mine was developed by two tunnels of 75 and 95 feet respectively. Only four carloads of ore are said to have been shipped up to 1898. In 1898 it was under lease, and enough ore was taken out in driving tunnels to pay expenses, though the main ore shoot was not then reached.

The Moulton, Tiger, and T. W. mines are situated on the slopes south of the little branch of Galena Creek heading north of Mixes Baldy. The mines have been worked at intervals since the early history of the district by various leasers. The first two mines are said to be on the same vein, and to carry similar ore. The ore is a silver-bearing galena and occurs in bunches, most of them but 5 to 6 feet across and a few yards deep. Both mines are equipped with steam hoists. The latter was in 1898 leased by the United States Smelting and Refining Company, for the purpose of supplying lead ore for the Great Falls smelter, and further development work has given satisfactory results.

Other mines—the St. Louis, Sunlight, Defiance, Ontario, Pride of the West, Black Hawk, and Alice No. 2—have yielded small amounts of ore, but are not sufficiently developed (1897) to prove their value.

Occurrence of the iron ore.

Iron.—On the north side of Thunder Mountain, at an altitude of 6000 feet, the contact between the porphyry and the sedimentary rocks is marked by lenses of iron ore. The sedimentary rocks are locally baked and metamorphosed by the igneous rock, and the soft micaceous shales are changed to hard, flinty, brittle hornstone. The iron ore is in part a replacement of these rocks and occurs between them and the porphyry. The ore occurs in lenses varying in thickness from a few feet to 20 feet, but their lateral and vertical extent have not been determined. Analyses made for the owners show: Fe_2O, 76.90; FeO, 0.07; MnO, 0.03; SiO_2, 8.80; Al_2O_3, 0.74; S, 0.03; H_2O, 13.36. Total, 99.93.

The ore is seen in an open cut and is said to assay from $1.50 to $3.00 in gold. The analysis shows it to be an impure limonite mixed with a little quartz. The Edna, Tornado, and Hurricane claims are located upon these deposits.

Gypsum.—The red sandstones and shales which constitute the lower beds of the Quadrant formation generally contain some gypsum, but these deposits are of workable extent, so far as has been observed, at only two localities—near Riceville and at Kibbey. The beds consist of white or grayish, nearly pure gypsum, easily quarried and separated from the red sandstones. The beds vary in thickness from a few inches to several feet, and are of local extent, though often traceable for several hundred feet. As shown in a section given in the Columnar Section sheet, the strata near Riceville hold four beds of gypsum, aggregating 12 feet, besides numerous thinner intercalated lenses. Gypsum also occurs in the clay shales of the Colorado formation, in thin seams and isolated crystals, but is not workable.

Limestone.—Limestone of various kinds occurs in the Madison formation. The thinly bedded rocks about midway in the series have been quarried for making quicklime, and at Logging Creek Station, on the railroad line, the thin-bedded strata near the base of the formation are quarried for flux. The rock is broken to a uniform-sized product in a rock crusher, driven by water power, and automatically loaded into ore cars for shipment to the Great Falls smelter. Analysis shows it to be a very satisfactory rock for mixing with the siliceous silver ores treated there.

The limestone nodules occurring in the clay beds above the Belt coal seam have been locally used for making quicklime.

Clays suitable for fire brick and refractory materials are found in connection with the coal seam, but have not as yet been utilized.

Sandstone for building purposes.

Building stone.—The stones suitable for structural uses are all sandstones of the Cascade and Dakota formations. Sandstones occur in many other formations, but lack the essential requirement of ease of quarrying and dressing combined with durability. The first requisite for successful quarrying is a matter of local exposure. The rock must not be covered by a heavy capping or its extraction is costly. It must break readily into large, square blocks, and yield easily to the stone mason's dressing pick. These conditions, together with a moderate degree of strength, durability, and variety of pleasing tints of color, are found in the sandstone beds which occur in the Cascade formation. The beds vary in thickness from 1 to 6 feet, rarely exceeding the latter figure. This formation has not been emphasized because it is only in the vicinity of Belt and Armington that the material will have any immediate value.

The limestones of the quadrangle have thus far not been used for building purposes. They are undoubtedly suited to such uses, although they are less easily dressed than the sandstones.

Granite, gneiss, and igneous rocks for ornamental work might be utilized, as they occur in great variety and are capable of taking a high polish. The syenite of Square Butte furnishes a splendid material of any desired size, but is at present very inaccessible.

Clays suitable for brick making occur abundantly in the alluvial areas along the streams of the plains region, and less abundantly in the mountain district.

Artesian water.—The sandstones which underlie the broad expanse of arid prairie land that constitutes so large a portion of the quadrangle are probably porous enough to hold water and to furnish an artesian flow if wells were sunk to the water horizon. As there are many square miles over which even grazing is impossible, for lack of water, the practical importance of this is worth testing.

Coal.—The coal lands of the quadrangle are shown on the Economic Geology sheet by a dark shade of green. The area so colored is not coincident with that of the Cascade formation, to which the coal seams belong, for the seam occurs at the top of that formation, and the greater part of the area where these beds are exposed is not underlain by coal. For this reason the outcrop of the seam has been taken as one boundary of the area emphasized, and, as the beds dip beneath the flat bench lands, a strip of country which the seam is known to underlie, or probably does underlie, is shown by color. The northern boundary of the coal land area is also very largely conjectural. Where the limits of the seam are known from exposures, workings, or borings, this boundary conforms to it. Elsewhere it is based upon field observations, the known peculiarities of the seam, and structural considerations. By the aid of this map and the dip of the coal measures, as shown on the Structure Section sheet, the areas where coal seams may be found and the probable depth of the coal beneath the surface are readily determinable. The coal seam is not everywhere workable along its outcrop, and it has been considered best not to attempt to define the commercial extent of the fields. The commercial value of the seam, its thickness, quality, etc., can be determined only by actual exploitation and by sampling the coal as obtained under cover, that is, where it has not been altered as it is at the surface outcrop. But one coal bed is known, and though not always workable it can be followed from Sage Creek, on the eastern limit of the quadrangle, westward over the foot slopes and bench lands north of the Little Belt Range to Belt Creek. Throughout this distance the seam preserves its general characters and the coal is of the same nature, but the seam as exposed in outcrop varies greatly in thickness and purity, and is not everywhere workable.

Position of the coal bed.

The coal occurs at the top of the series of sandstone beds and shales constituting the Cascade formation, and the seam is generally capped by a bed of massive sand rock, 20 to 50 feet thick, which forms outcropping ledges upon stream bluffs and the summits of gently inclined benches. Though but one coal horizon has been recognized, the bed is, so far as known, always a compound one, consisting of two layers separated by 1½ to 5 feet of shale or sand rock. Very rarely this intervening parting thickens to 10 or 15 feet. Both seams vary greatly, from place to place, in thickness, in purity, and in the number of partings, but the upper seam, so far as known, is always noncoking, bituminous coal, while the lower seam is a coking and blacksmith coal. Both coals are jointed and blocky, but show a decided lamination, and carry iron pyrite in scattered nodules an inch or two in diameter. The upper seam shows a compact, dull coal, streaked with irregular laminæ of bright, shiny coal, burns with a steady, long-continued heat, and is generally characterized by a red ash, rather large in amount. The lower seam shows a much larger proportion of bright, shining jet-black coal, which burns with a longer flame, sinters or cokes upon heating, generally makes a good coke, and burns to a white ash.

The coal lies in rather shallow basins, on the borders of which it is impure and contains many partings. The limits of these basins can be determined only by actual exploitation, and have been ascertained only in the Belt Creek field.

There are five localities in the quadrangle where the seam has been opened and coal extracted, but the mines of Belt Creek field are the only important ones, and are to-day the largest single producers in the State, having yielded a gross output of 719,600 tons in 1896, and 800,000 tons in 1897. The attitude of the seam varies somewhat at different localities. At Belt and vicinity it is nearly flat, dipping at low angles into the mesas, while at Skull Butte it dips at an angle of 15°.

Belt Creek coal field.

The Belt Creek field embraces the coal lands on both sides of Belt Creek, extending from the mouth of Cora Creek northward to the confluence of Little Belt Creek, a distance of 7 miles, along which the seam is exposed in the canyon walls on both sides of the Belt Creek Valley. The coal lands belong to a number of owners, and are worked at nearly a dozen different openings, but by far the largest production is from the mines of the Anaconda Mining Company, at Belt.

The coal of the field was first mined in 1877, when a few tons were shipped to Fort Benton. Since that time a few hundred tons a year have been mined. The product was 1200 tons in 1885, 600 tons in 1886, and 2000 tons from the various mines in 1888, but the opening of the mines at Sand Coulée, with railroad transportation, closed the market temporarily to the Belt Creek mines.

In the autumn of 1895, Mr. P. J. Shields leased a large tract on the west side of the creek. Convinced that the lower part of the seam, consisting of coking coal, would increase in thickness westward, he drove a drift entry and proved the correctness of his surmise. The property was acquired by the Anaconda Mining Company in 1894, and exhaustive tests having proved that the coal, though high in ash, could be washed and coked, an extensive washing plant and one hundred coke ovens were erected, and development of the property upon a large scale was begun. Since that time the mine has been the largest single producer of coal in the State. The product in 1896 was 731,125 tons, of which 517,860 tons were shipped to Anaconda, and 63,660 to Butte. The Lewis and the Millard mines shipped 1140 tons the same year. The total product of the Belt Creek mines was 779,050 tons (of 2000 lbs.) in 1897.

Structure of the coal field.

The geological structure is very simple. The coal measure series dips gently downstream, or northward, conforming to the general structure, in which the formation dips at a low angle away from the Little Belt Mountains. Between Armington and Belt the beds show a very gentle warping, however, rising in a low, flat, anticlinal dome, which has been cut across by the valley. The workings east of Belt Creek show that the seam has a gentle easterly inclination toward the Highwood Mountains. West of the valley the dip is about 1 foot in 70 to the west. North of Belt the gentle northward dip is resumed, and the coal horizon passes out of sight near the mouth of Little Belt Creek. The coal seam thins out or becomes impure south of Armington and a mile north of Belt. The bed is not workable beyond these points, though the coal horizon can be followed several miles south of Armington, being traceable by the sand-rock cap.

The largest mines lie west of the creek and belong to the Anaconda Mining Company. The mine openings show that the seam presents the nearly constant division into upper and lower benches, separated by 2 to 3 feet of dense, hard, argillaceous sand rock (or argillite?).

Variations in the seam.

Detailed sections of the seam show considerable variation throughout different parts of the mines, but establish the nearly constant presence and character of the partings, though they vary somewhat in thickness, as does the coal also. The floor is not constant, showing very gentle undulations, but it nowhere rolls up to the roof and cuts off the coal. Only the lower bench of coking coal is generally mined, the 2-foot to 3-foot parting separating the seam being used as a roof. For 700 feet from the face of the bluff the entry driven through the level showed a bony, impure fuel, but beyond this the lower part of the seam showed 5 to 5½ feet of coking coal, having a persistent 4-inch to 10-inch parting about one-third of the distance from the floor. The roof (which is really the midseam parting) occasionally rolls, and for a few yards pinches up or even cuts off the coal. Sometimes the roof sends an offshoot into the coal forming a 4-inch to 12-inch parting.

The coal as mined runs about 20 to 30 per cent slack. The run of the mine averages 30 per cent of ash by analysis, but this is reduced to 7 per cent in the slack, by washing before it is coked.

East of Belt Creek coal is found in the open upland country lying north of the Little Belt Range. Openings from which coal has been mined were found at the forks of Otter Creek, Frost Creek, Skull Butte, and Sage Creek. The Otter Creek seam is about 4 feet thick, but so far as exposed is too impure for shipment. The Frost Creek openings show the usual separation of the bed into two seams, with 5 feet of shale between. Only the lower seam has been opened, showing 2½ feet of good fuel in a total thickness of 3½ to 4 feet. The beds dip 5° N., and are capped by a heavy bed of sand rock whose upper surface forms the bench land.

At Skull Butte the coal seam is warped about the flanks of this dome-shaped hill and nearly encircles it. It has been prospected at several places, and is mined at the point where Skull Creek cuts through the coal measures. Both the upper and lower seams have been worked, the lower one showing the section illustrated on the Columnar Section sheet. The coal at this mine is flaky, and shows the effects of the uplift of the hill, the dip of the seam being 15° N.

The Sage Creek mines are situated on Spring Coulée, a fork of Sage Creek. The bed dips 5° N., and is covered by the heavy sandstone bed which forms the surface of the surrounding bench land. The seam shows the two benches found elsewhere, but the lower one alone is forked; it shows 4½ feet of clean coal, dull with bright streakings, carrying occasional balls of pyrite. A section of the bench worked is shown in the Columnar Section sheet.

Near Woodhurst, on Running Wolf Creek, the seam shows 16 inches of coal.

The analyses below represent samples taken by the writer, not to show the average composition of the coal or the run of the mine, but to ascertain the variation in composition in different parts of the same seam at the same locality, and the variation at different localities. The analyses will be found, however, to give a very close approximation to the general composition of the coals from which the samples were taken.

Lignite.—Lignite beds are found at the head of Shonkin Creek in the Highwood Mountains, as outcrops in the walls of the Shonkin Sag, and are seen in the bluffs of the Missouri River near Eagle Creek. These lignites are inferior to coal in heating power, but being found in a treeless region they may prove valuable for local use as household fuel.

WALTER HARVEY WEED,

Geologist.

December, 1899.

Analyses of coal from Belt Creek field, Sage Creek, and Skull Butte.

Locality.	Moisture.	Volatile combustible matter.	Fixed carbon.	Ash.	Color of ash.	Coke.	Remarks.
South tunnel, Armington's mine, west side of creek, Armington.	1.08	26.03	48.13	24.76	White	Poor......	....
Millard, top coal, Belt, east side of creek.	1.95	30.61	61.61	5.83	....do........	Worthless.	Blocky, streaked coal.
Millard, middle bench	1.73	19.49	46.80	31.91	Gray	....do.....	A dull coal.
Millard, lower bench...............	2.05	41.48	51.67	4.80	White	Good	Blacksmith coal.
Watson mine, east side of creek....	2.80	37.48	53.13	6 59	....do........	Poor......	....
Sage Creek	4.54	33.06	55.91	6.49	Gray	None	Corwin and McGregor mine.
Skull Creek mine..................	3.42	39.06	47.06	10.	White	Poor......	L. H. Hamilton, owner.
Selected sample Anaconda mine, Belt	3.08	41.01	52.31	3.63	....do........	Good	....