DESCRIPTION OF THE LITTLE BELT MOUNTAINS QUADRANGLE.

GEOGRAPHY.

GENERAL FEATURES OF THE REGION.

Location.—The square degree forming the Little Belt Mountains quadrangle is limited by 110° and 111° of longitude and 46° and 47° of latitude. It includes 3340 square miles, situated in central Montana, and belonging mainly to Meagher and Fergus counties, with a small part of Cascade and the northern parts of Gallatin, Park, and Sweetgrass counties. The quadrangle lies north of the Yellowstone River and south of the Missouri River, and includes part of the western border of the Great Plains and of the eastern Rocky Mountain region.

Drainage.—The drainage belongs to both the Yellowstone and Missouri rivers. Only a small area of the quadrangle is included in the watershed of the former, while several large streams, whose sources are the springs and snowbanks of the mountainous part of the quadrangle, flow into the Missouri River. The rivers flow through relatively broad and long valleys, whose size and character show them to be of considerable age and to have been formed by larger streams than those now flowing in them. The smaller streams are abundant in the mountainous region, but the flowing water seldom extends beyond the mountain flanks. In summer the stream courses are generally dry where they flow through limestone areas, but carry water where they flow through shales or igneous rocks. In the sandstones and shales of the open plains the few streams are sluggish and of small size.

Climate.—There is a considerable range of climate, corresponding to the altitude. The aridity and heat of the western borders of the Great Plains prevail in the eastern part and also in the broader and lower valleys. The higher bench lands and mountain foot slopes have more moisture, while the mountains are still more copiously watered, receiving heavy snowfalls and frequent summer showers.

Vegetation.—The vegetation varies with the moisture and climate. The streams are often bordered by thickets of willow, haw, and other shrubs; more rarely with groves of cottonwood.

The bench lands are grassed, and the higher parts dotted with groves of pine and aspen. The mountain slopes are pine-clad, the forests being open, with grassy intervals, on southern slopes, but dense and thick on northern exposures. The forest growth varies somewhat with the nature of the soil and underlying rock. It consists mainly of the common lodgepole pine (*Pinus murrayana*); near the timber line there is white pine (*Pinus flexilis*), and on the wet northern slopes spruces and firs grow. The climate gives but a short growing season, and only the hardier cereals and vegetables are successfully grown. Agriculture, therefore, is not possible except in the lower valleys, and a large part of the bench land is valuable only for pasturage. Agriculture is dependent upon irrigation, for which the streams furnish an abundant and unfailing supply of water.

Culture.—The region is not thickly settled. It includes a number of important towns, but over large areas there are no settlements, and unless mining discoveries are made the mountain area will never support a large population. The largest city is White Sulphur Springs, the county seat of Meagher County; Neihart and Castle are important mining settlements, while Utica and Martinsdale are small towns supported by the sheep and cattle industries. A branch line of the Great Northern Railway runs from Great Falls to Neihart, giving an outlet to the silver mines of the Little Belt Range and the coal mines of Belt Creek. The Montana Railroad, connecting with the Northern Pacific Railway at Lombard, crosses the center of the quadrangle, affording an outlet for the silver mines of Castle Mountain and access to the region about Martinsdale. Stage lines traverse the roads through the main valleys and cross the Little Belt Range from White Sulphur Springs to Neihart.

DESCRIPTION OF THE LITTLE BELT MOUNTAINS.

The northern half of the quadrangle is a mountainous region forming part of the Little Belt Range. These mountains, from which the quadrangle takes its name, form a broad, elevated tract flanking the main Rocky Mountain region. They are sharply limited by the plains on the east, and separated from the much narrower, higher range to the west, known as the Big Belt Mountains, by the low and broad valley of Smith River.

The range extends for 60 miles in a general easterly direction from the Missouri River, narrowing eastward and ending in a point at Judith Gap, about 10 miles beyond the limits of the quadrangle. In the western part of the quadrangle the range is 32 miles wide. It is dissected by the branching head-water streams of Judith River, which have cut deeply into the heart of the range on the east, and by Belt Creek and its tributaries on the north. The main divide or crest of the range is a relatively low, broad, plateau-like summit, trending west for 20 miles and then northwest, while the highest peaks of the range lie to the east of this divide, forming detached summits. Though genetically connected with Castle Mountain, the range is separated from this neighboring mass by broad valleys and differs from it in geologic structure.

The whole range is relatively low compared with the Rocky Mountain country generally. Its highest peak reaches but 9000 feet above sea level, and its average elevation is not over 7000 feet. Yet the low relief of the adjacent plains region makes the profile an impressive one from most points of view, though from the valley of Smith River it appears low compared with the higher, more compact, and continuous crests of the Big Belt Range.

Abrupt mountain slopes characteristic of the region.

From every side the mountains are sharply delimited from the adjacent valley or plains country. They rise abruptly from gently sloping terrace levels, whose arid barrenness or open grass land is in strong contrast with the wooded mountain slopes.

These broad benches, sloping at angles of 3° to 5° away from the mountains and trenched by the gorges of the mountain creeks that cross them, are a very conspicuous feature of the district, and serve as a broad pediment upon which the mountains stand in strong relief. Along the southern flanks of the range there is a narrow foothill strip which is very prominent upon the map, where the contours suggest a decided hogback relief, though in nature the hills seem but the ends of short lateral spurs normal to the slopes.

DESCRIPTION OF CASTLE MOUNTAIN.

An isolated outlier of the Rocky Mountain front.

In the center of the quadrangle is the mountainous mass known as Castle Mountain, an isolated flat-topped elevation whose crown of ruinlike crags at once suggests its name. It is a distinct unit, a link in the chain that defines the eastern limit of the Rocky Mountains. It lies at the head of the broad valley of Smith River, closing the gap between the Big Belt and Little Belt ranges. The two forks of the Musselshell on the east and the fork of Smith River on the west inclose a diamond-shaped area, the stream valleys defining the mountain boundaries.

The highest point is 8600 feet, or 3600 feet above the adjacent valleys. There are no sharp peaks, and the scenery is not grand and impressive like that of the Crazy Mountains, though the crags and canyons are picturesque and pleasing. There is the abrupt change from mountain slope to valley level, and the contrast of forest and open plain, which accords with the boundary between soft and hard rocks, the base of the slopes being, in general, the boundary between these formations. Castle Mountain links the Little Belt Range to the Sixteenmile Hills to the southwest. These hills constitute the eastern end of the Big Belt Range, and though relatively low, they are the structural representatives of the Rocky Mountain front.

DESCRIPTION OF THE CRAZY MOUNTAINS.

The Crazy Mountains are the highest and most conspicuous mountains of the quadrangle. Surrounded on all sides by low and open bench lands, their rugged snow-capped peaks and sharp crests are visible for many miles. The mountains form a group of connected peaks and not a range. The mountain mass is from 10 to 20 miles wide and 30 long, and lies almost wholly within the limits of the quadrangle. The highest peaks reach an elevation of over 11,000 feet, or 6000 feet above the bench lands. In both elevation and ruggedness they far surpass the other mountains of the quadrangle, and indeed most mountains of the State. Yet they form an isolated mountain group that does not belong to the Rocky Mountain system, either in geographic relation and position or in geologic structure. They afford a remarkable example of a residual mountain range in flat-bedded rocks carved out simply by stream erosion.

The highest peaks in the area.

The mountains rise abruptly from broad bench lands, with rarely an outlying foothill.

DESCRIPTION OF THE ROCKS.

To clearly understand the structure and important geologic features of the quadrangle, it is necessary to recognize the various rocks which occur in it, and of which its mountains, valleys, and plains are formed. The distribution of these rocks over the surface of the region is shown by various patterns and colors upon the Historical Geology sheet. The rocks of the region are seen to be of various kinds and of diverse origin. They are grouped according to age and character into the various formations which belong to the three classes of surficial, sedimentary, and igneous rocks, whose general characteristics are noted in the Explanation given 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 ancient crystalline rocks are found only in the Little Belt Mountains. Sedimentary rocks are found in all parts of the quadrangle, but an examination of the map shows that in general the distribution of the various formations corresponds to the main geographic divisions of the quadrangle. This association of rock formations and geographic subdivisions is even more marked in the case of the igneous rocks, whose geologic occurrence as well as mineralogic and chemical natures show characters peculiar to this particular area.

ANCIENT CRYSTALLINE ROCKS.

ROCKS OF THE ARCHEAN PERIOD.

The oldest rocks.

Gneisses and schists.—The oldest rocks of the region are the gneisses and schists found in the Little Belt Range in the northwestern part of the quadrangle. They are in part at least of igneous origin, and none of them show any traces of a sedimentary origin. Being a complex of rocks whose relations and origin are uncertain, and forming a group whose characters are alike throughout and differ from those of all the other formations, they are considered to be of Archean age.

The rocks vary greatly in color, texture, hardness, and mineralogic composition. They may all be classed as gneisses and schists of various kinds. In the vicinity of Neihart the rocks show alternating folia or bands of white gneiss, dark amphibolite-gneiss, red gneiss, and rusty or gray mica-schist, together with mixtures of each of these forms. These bands are only local in occurrence, and of inconstant character, and as the different forms of gneiss and schist weather with varying degrees of resistance the outcrops are quite different in appearance. The schists, which weather readily to fine shaly débris, are in part sheared and altered quartz-porphyries. The folia are steeply inclined, and at Neihart have a southward dip, which is constant for several miles. The Archean rocks near Neihart are intruded by igneous rocks which show a gneissoid structure, but which are inclusive in and of later age than the crystalline schists. These rocks—the Neihart porphyry and Pinto diorite—are described as igneous rocks. In the second area of Archean rocks, which is drained by Sheep Creek, the rocks are mica-shists and gneisses of more uniform appearance.

SEDIMENTARY ROCKS.

All the geologic periods represented.

The bedded rocks constituting the sedimentary series cover by far the greatest part of the quadrangle. They are of many kinds, and show in their character, as well as in the fossil remains they contain, the diverse conditions prevailing at the time of their formation. In this region the rocks of each great geologic period happen to possess distinctive lithologic characters as well as peculiar fossil remains. These characters are, moreover, generally contrasted in closely adjacent formations, so that the horizons can be readily recognized in the field, and the beds of massive white limestone of the Carboniferous are easily distinguished from the Cretaceous sandstones, or from the Algonkian slates.

The series of bedded rocks appear to be conformable throughout; that is, the bedding planes seem to be parallel. That sedimentation was not uninterrupted and continuous is certain, however, from the facts described in another part of this text. The bedded rocks were originally horizontal, but are now seldom seen in that position in this region. They are bent into arches and hollows, broken by faults, injected in places with molten igneous rocks, and in some places covered by lava flows or by the fragmental products of volcanic eruptions.

The rocks vary greatly in their resistance to weathering processes. The softer rocks have been worn down and the harder beds left as ridges. Such ridges afford a means of tracing geologic structure even where the intervening rocks are concealed. In the region of the quadrangle the various formations consist largely of rocks of dissimilar lithologic character. Thus distinct tracts vary in scenery and in relief, and these differences are emphasized by those of vegetation, the latter being due to the diverse characteristics of the soil. The physical characters of the rocks have caused the areas of harder rocks to be left in especial prominence.

The distribution of the various formations composing the sedimentary series is not uniform. The older rocks occur in the mountain tracts of the Little Belt Range, in Castle Mountain, and in the low range crossed by Sixteenmile Creek in the southwest corner of the quadrangle. The younger Cretaceous rocks form the plains country and the Crazy Mountains. The formations of the sedimentary series are described in the order of their deposition, each formation having certain general characters which are common to all of its exposures, and which prevail over considerable parts of the mountain region outside the limits of the quadrangle.

ROCKS OF THE ALGONKIAN PERIOD.

BELT TERRANE.

The Belt terrane is named from its occurrence and great development in the Belt Mountains. It consists of the oldest sedimentary rocks, which upon the map have been subdivided into the Neihart quartzite and the Belt formation.*

The rocks are found in only a part of the quadrangle, and are classed as Algonkian. They lie between the Archean gneisses and the rocks containing middle Cambrian fossils.

Neihart quartzite.—In the vicinity of Neihart,

*The name Belt formation is here used as it is in earlier folios (1 and 29), as a collective designation for formations now known to be a part of the series called Belt terrane by Mr. Walcott: Proc. Geol. Soc. America, vol. 10, 1899. As the latter name is now in general use, the term Belt formation is inconsistent with it, and a new term would have been used for these beds had the maps not been already printed.

the only place where the base of the Belt terrane is seen, the lowest beds are pink and gray quartzites of very compact and dense texture, which are designated the Neihart quartzite. The rocks are very hard and form abrupt cliffs that front broad terrace levels. The Neihart quartzites are about 600 feet thick, and are the most conspicuous rocks to be seen in the canyon of Belt Creek above Neihart.

Basal quartzite.

Belt formation.—The upper member of the Belt terrane, the Belt formation, consists of thin-bedded rocks, largely shales or slates, but also containing interbedded limestone and quartzite. The thickness of the formation is variable. At Neihart it is relatively thin, aggregating but 4400 feet. At Castle Mountain, where the base is not exposed, a much greater thickness has been measured.

The bulk of the formation consists of slaty, siliceous shales, usually of a gray color. The basal quartzite passes gradually into gray shale, the rocks containing an increasingly larger amount of argillaceous matter, both as an impurity in the quartzite and as intercalated beds of shale, until the rock is all shale. A considerable thickness of shale is capped in turn by transition beds of limy shale, followed by a well-defined limestone series. This, in turn, gives place to a great thickness of lustrous sericite slates, grading into shales again, which are red at the top of the formation. All these rocks are slightly altered and of very different appearance from those in the more recent beds. These different strata have been described by Mr. C. D. Walcott as constituting eight formations. The subdivision is, however, based entirely upon lithologic grounds, though the terrane presents an ideal example of a cycle of deposition, and the subdivisions grade into one another. The formations composing the terrane have been named by Mr. Walcott as follows, the beds being given in descending order:

Altered shales, slates, and limestones.

8. Marsh Creek shale.
7. Helena limestone.
6. Empire shale.
5. Spokane shale.
4. Greyson shale.
3. Newland limestone.
2. Chamberlain shale.
1. Neihart quartzite.

The two upper formations are not found in the Little Belt Range, but occur on the flanks of the Big Belt Range in a continuation of the terrane to the west and north. Fossils found in the shales overlying the Newland limestones of the middle portion of the Belt formation represent the earliest forms of life yet known.

The Belt formation is found only in the northwestern part of the quadrangle, where it forms large areas of open valley or gently rounded slope. The slates and shales weather rapidly and large amounts are washed away by every rain. The rocks are sterile and form a poor, scanty soil that supports a sparse growth of grass, or at higher elevations a scattered growth of trees. The structure is often very well shown, however, by grass lines following the outcrops of more fertile strata.

The rocks are readily shattered and, therefore, are freely injected with sheets and dikes. They are often cut by small veins of copper ore.

ROCKS OF THE CAMBRIAN PERIOD.

The Cambrian rocks constitute readily recognizable formations in the quadrangle. They include a considerable variety of quartzites, shales, and limestones, whose characters are persistent over large areas, rendering the recognition of horizons comparatively easy. Fossils are abundant in the seven divisions into which the series has been subdivided, and they show an undoubted middle Cambrian fauna throughout. South of Neihart the rocks of this period rest in apparent conformity upon the Belt terrane; north of Neihart they lie directly upon the crystalline schists and gneisses.

Barker formation.—This formation consists of seven distinct zones. The five lowest constitute the Flathead formation of adjacent quadrangles. The two upper include the beds comprised in the Gallatin limestone. The two zones have been separated as distinct formations in other folios, as they were formerly supposed to show different faunal groupings. Owing to the small scale of the map, the various distinct units of the Cambrian are grouped together as one formation whose parts are herein distinguished as zones.

The Flathead quartzite forms the base of the Paleozoic series recognized in this region. The lowest bed, generally a quartzite or indurated sandstone, is a compact rock varying from white to yellow or red, occasionally mottled, and often grading into conglomerate at the base. It is a beach deposit, spread over the surface of a level Archean land by an advancing sea. The gently sloping plain of Belt Park is formed of the quartzite, which rests upon an older plain of crystalline schists. South of Neihart the quartzite rests upon the shales of the Belt formation. The Flathead quartzite is seen throughout the Little Belt Range and at Castle Mountain. It is a very resistant rock, and the roads over it are very rough and rocky. Scolithus borings are the only fossil evidences seen in this rock.

Conglomeratic quartzite and shale.

The Wolsey shale appears above the quartzite. It consists of micaceous shale and contains small limestone concretions near the base and interbedded calcareous shales higher up in the series. The Meagher limestone overlies the shale. It is a thin-bedded limestone, often formed mainly of flat limestone pebbles. The rocks carry fossil remains, principally trilobites and Hyolithes sheaths of middle Cambrian forms. The overlying Park shale is a very thin-bedded, soft, and crumbly rock, often containing glistening grains of mica, which is mostly greenish gray in color, but also shows various shades of red and purple. The Pilgrim limestones, which are well bedded and contain shaly layers, overlie the Park shales. They are dense, gray rocks, often spotted with green glauconite remains, and frequently carry fossils on the surface. The layers are often conglomerates formed of flat pebbles of green or buff limestones showing no definite arrangement. South of Neihart the shales and flaggy limestones constitute a series 800 feet thick.

The reddish argillaceous or arenaceous beds of the Dry Creek shale, usually about 40 feet thick, are overlain by the Yogo limestone, which constitutes the uppermost member of the Barker formation. The rocks are of gray or mottled limestone, with a few layers of interbedded shale. The fossil shells and trilobite remains are also middle Cambrian forms. These rocks resemble the limestones of Carboniferous age, but can be distinguished by their position above the green micaceous shales, and beneath the dark-colored limestones of the Monarch formation.

Mottled limestone.

ROCKS OF THE SILURIAN AND DEVONIAN PERIODS.

Monarch formation.—Above the shales and gray limestones of the Barker formation there is a series of dark-colored limestones differing greatly in appearance from the formations below and above them. The rocks are prevailingly dark colored, commonly either bluish black or chocolate brown in tint, and are mostly crystalline limestone with sugary texture on the weathered surfaces. They occur in well-defined beds 2 to 6 feet thick, which form masonry-like exposures. When struck with a hammer they give off a strong fetid odor, due to organic material. They weather with a peculiar pitted and lacelike surface. They frequently contain imperfectly preserved coral remains of light-colored material, giving the rocks a spotted appearance. The only species determined indicate Devonian age, but Silurian is supposed to be represented in the lowest beds. These rocks constitute the Jefferson limestone of adjacent quadrangles. They are a distinct stratigraphic unit, but for convenience in mapping have been united with the overlying thin-bedded and shaly limestones of the Threeforks formation, under the name of Monarch formation.

Dark, fetid limestone.

The upper member of the Monarch formation is composed of thin-bedded, shaly limestones containing much clayey matter and weathering rapidly. They are generally of a bluish-gray color when freshly exposed, but the exposures and débris are commonly of a straw yellow or rarely pink color, due to weathering. The thickness is usually 40 to 50 feet, and does not exceed 140 feet. This shale is not of economic importance, nor prominent in topography or structure.

ROCKS OF THE CARBONIFEROUS PERIOD.

Madison limestone.—This formation consists entirely of the limestone beds which constitute the great limestone series of the Rocky Mountain region of Montana. The formation is readily distinguished from that below by its lithologic characters as well as by its fossil forms.

The lower third of the formation consists of thin-bedded shaly limestones named the Paine shale, commonly of a gray color, overlain by a well-bedded, light-colored bed, the Woodhurst limestone, which forms yellow cliff exposures in some parts of the region. The beds of the Woodhurst limestone are separated by very thin argillaceous layers, and the limestones often carry much dark chert. The upper part of the Madison consists of very massive limestones showing no bedding and designated the Castle limestone. The Woodhurst limestone is well jointed and often forms masonry-like exposures of cliffs with balcony ledges and retreating benches. On weathering it breaks into small angular fragments. On the mountain flanks the streams cut narrow gorges through these uppermost limestone beds and form gates or portals that separate the mountain valleys from the open bench lands of the plains.

The great limestone series of the Rocky Mountain region.

The formation is 1000 feet thick. Fossils are abundant, especially in the lower beds; they are all Lower Carboniferous species and are of very constant character throughout the formation.

Quadrant formation.—This formation, named from its prominence in Quadrant Mountain in the Yellowstone Park, varies in character and increases in thickness from the southern exposures in the canyon of Sixteenmile Creek northward. The southern areas of this quadrangle show a series of beds 230 feet thick. The upper layers are compact, hard, pink and cream-colored quartzites, with occasional intercalated beds of limestone. The base consists of 80 feet of impure limestones with interbedded red magnesian shales that are soft and weather readily, their red muds staining the harder rocks.

Pink quartzite, limestone, and red shale.

In going northward the formation changes greatly in character and thickness. In the Little Belt Range the quartzites disappear and the most characteristic feature is the presence of a shale horizon — the Otter shale — whose vivid green color makes it conspicuous wherever exposed. At the same time the formation becomes of a variable nature. Limestones, sandstones, and shale beds appear, but are not persistent. On the Judith River the base of the formation consists of the red Kibbey sandstone, which frequently contains beds of gypsum. The thickness of the formation is nearly 1400 feet at this locality, while it is but 400 feet thick north of Castle Mountain. The limestones carry abundant fossil remains, fixing the age as Lower Carboniferous.

ROCKS OF THE JURATRIAS PERIOD.

Ellis formation.—Above the Quadrant formation there is a thickness of 90 to 200 feet of beds containing fossil-shell remains of Jurassic mollusks. The formation varies in thickness at different localities. On the flanks of Castle Mountain it consists of a bed of granular, buff-colored sandstone, weathering red, overlain by a dense, light-gray or white limestone, grading at the top into a sandstone, and capped by red shale. The thickness here is but 90 feet. The basal sandstone is often pebbly for a foot or two, and sometimes rests upon beds of pure limestones carrying Carboniferous fossils and sometimes upon barren, shaly beds. The red sandstones and marly shales which form part of this formation farther south are wanting.

ROCKS OF THE CRETACEOUS PERIOD.

The Cretaceous rocks are shown on the Historical Geology sheet to cover very nearly one-half the total area of the quadrangle. It will be noticed also that the line between them and the older formations separates the mountains from the open plains country. The Cretaceous rocks form the Crazy Mountains, but in other ranges they prevail along the mountain flanks and are the only sedimentary rocks found east of the mountain folds. This peculiarity of distribution is due chiefly to the nature of the rocks. They are all soft and easily eroded shales and clays, with slightly harder sandstones. They therefore usually form gentle slopes, in marked contrast to the bolder forms due to the more resistant rocks of older formations. It is only when hardened by igneous injections, as in the Crazy Mountains, that they have resisted erosion as well as or better than the older and massive limestones. That they formerly covered the earlier rocks and have been removed from the mountainous area is possible. This is indicated by the outliers of Cretaceous shale near White Sulphur Springs and lower Sixteenmile Creek, where the rocks form structural basins in which erosion is yet feeble.

Former extent of the Cretaceous rocks.

About the mountain flanks the older formations are upturned, so that the outcrops follow the slopes in concentric curves. Away from the mountain flanks the rocks are tilted by smaller folds, whose erosion has exposed inliers of the older formations and produced the sinuous lines of outcrop seen along the Musselshell River.

A total thickness of 17,200 feet is designated Cretaceous, but it is doubtful if the upper 11,500 of this should not be classed as of later age.

The lowest Cretaceous formation, the Cascade, is overlain by the Yellowstone. The latter embraces 4500 feet of shales and sandstones, grouped under one name for convenience, but embracing the formations well known as Dakota, Benton, Niobrara, Pierre, and Fox Hills. The formation is therefore equivalent to a group name for all Upper Cretaceous formations, the Cascade formation being distinguished by fossils of Lower Cretaceous affinities. In this region it was not found practicable, or at least the result would not warrant the expenditure of the necessary time, to divide this great series and to map the distribution of its component parts. Fossil remains are rare, and lithologic characters inconstant and difficult to use.

Above the Yellowstone formation are the coal-bearing sandstones of the Laramie, and these in turn are covered by the dark-colored grits and purple clays of the Livingston formation. In the Crazy Mountains the highest beds are sandstones and clay shales that might be separated as a distinct formation, but are here included with the Livingston.

The distinctions made are relatively simple, but quite sufficient to show the representation of the areal distribution and structural features of the coal fields of the quadrangle. The distinctions are, moreover, such as can be easily recognized in the field by the general observer as well as by the geologist, if the descriptions are carefully read.

Cascade formation.—Resting upon the Ellis formation is the series of red clays and sandstones constituting the Cascade formation. This formation, so named from its importance in Cascade County, where it furnishes half the coal production of the State, occurs in greatest development north of the Little Belt Range. It is there several hundred feet thick, but it thins rapidly southward, and has not been identified south of Cascade Mountain, where a thin seam of coal belonging to the formation has been worked.

Red clay with coal seam at the top.

In its typical form it consists of brick-red and carmine earths showing a characteristic knotty or lumpy structure, together with interbedded sandstones, generally light-gray or buff in color. The coal seam occurs at the top of the formation, the heavy beds of sandstone that lie above the coal being taken as the base of the Yellowstone formation. Fossil plant remains from the shales with the coal fix the age of the series as early Cretaceous.

Yellowstone formation.—Above the coal seam found about the eastern flank of the Little Belt Mountains, and resting upon the Ellis formation in the southwestern part of the quadrangle, is a great series of clay shales and sandstones grouped under the name of the Yellowstone formation.

Different parts of this formation exhibit diverse characters, but the gradation from one to another makes it impracticable to divide it into the distinct parts generally recognized. There is, however, an advantage in recognizing these different parts of the formation, in that one may know to what horizon the beds seen at any locality belong, even if the boundaries and precise thickness of the subdivisions can not be given.

Series of clay shales and sandstones.

The Dakota sandstone lies at the bottom of the series and is 400 to 500 feet thick. It consists of sandstones, sometimes indurated to quartzite, with intercalcated layers of reddish and blackish sandy shale. The rocks are generally open textured and absorbent, so that the sandstone outcrops are marked by pine trees. The Colorado shale, into which the Dakota sandstones grade by increase of shale and decrease of sand, consists chiefly of black or dark-colored carbonaceous or bituminous shales. The outcrops form an irregular belt following the sandstones of the Dakota zone, from which its gentle slopes and hollows readily distinguish it.

The Pierre shales are leaden gray and often sandy, and resemble the overlying Fox Hills sandstones, from which they sometimes differ little save in being softer and darker. The beds carry occasional lenticular bodies of impure limestone and sandstone and contain alkaline salts and gypsum.

The Fox Hills sandstones are quite earthy and impure in this region. The rocks are usually thin bedded, and frequently weather in long lines of slabs resembling tombstones. They are gray and not readily distinguished from the underlying shales.

The coal-bearing strata.

Laramie formation.—This formation consists of light-colored, cross-bedded, compact but not hard sandstones with interbedded clays and generally interbedded seams of coal. The upper beds are sometimes characterized by concretions resembling cannon balls. The strata are readily distinguished from the leaden-gray shales beneath and the dark-brown beds of the Livingston above. Good exposures occur in that part of the quadrangle which is included in Gallatin County; also south of Castle Mountain and along the Musselshell. South of the town of Castle the rocks are in part concealed by glacial material. Plant remains have been found in the shales overlying the coal beds, and fresh-water shells in the sandstones. The average thickness is about 1000 feet, estimating from the topmost shales of the Yellowstone to the base of the Livingston grits.

Livingston formation.—This formation consists of a great thickness of conglomerates, sandstones, and clays, with local intercalations of volcanic agglomerates and breccia near the base. The rocks rest upon the white sandstones of the Laramie coal measures, from which the lower beds of this series are readily distinguishable by their somber color. By far the larger part of the quadrangle occupied by sedimentary beds is covered by these rocks, in which are provisionally included the strata that form the Crazy Mountains, which may prove to be of later age.

Conglomerates of volcanic rocks and coarse breccias.

The lower portion of the series of beds belonging to the Livingston horizon differs materially from any formation yet described. In a thickness of 7000 feet there is a shaly upper portion resting upon grits and sandstones that become coarse conglomerates in the high hills east of the Bridger Range, and a basal portion of dark, poorly assorted grits and sandstones characteristically composed of volcanic material and containing abundant fossil leaves. An intercalation of true volcanic agglomerates occurs in this part of the series. The conglomerates of the Livingston are best exposed in the slopes of the Crazy Mountains and the hills west of them. The pebbles are well rounded and consist chiefly of a variety of volcanic rocks, but include gneissic and quartzitic pebbles, together with pebbles of Paleozoic limestone and Cretaceous rocks.

The dark-colored series of rocks composing the lower and typical Livingston beds are conformably overlain by a series designated the Fort Union beds, which are not distinguished on the map. These are composed of 4650 feet of sediments, and consist of gray clay shales with occasional lenticular concretions of impure limestone and interbedded sandstone. The sandstones are loose textured and crumbly, frequently cross bedded, and generally light colored; the grains are waterworn, and consist of quartz with some feldspar. They differ in every way from those constituting the underlying Livingston beds. The shales are generally gray, weathering into fine cubical débris, and are rarely calcareous. The limestone concretions are dense and flintlike, breaking with conchoidal fracture; they weather with a brownish surface, are sometimes netted with calcite films, and contain unios and other fresh-water fossils. Beds of impure, soft lignite sometimes occur with shales that carry fern and leaf impressions of Eocene species. The entire section is well exposed at the head of Lebo Creek.

CONTACT METAMORPHIC ROCKS.

The contact metamorphic rocks are those formed from various sedimentary or clastic rocks by alterations due to the heat and vapors of igneous intrusions.

Adinole, hornstone, and marble.—The sedimentary rocks about the granite and diorite cores are highly altered as a result of the heat and vapors of the intrusions. The shales are baked into a hard hornstonelike rock with a dense grain, which splits with a conchoidal fracture like that of jasper. There is no trace of the former fissile nature, but instead a minute jointing. The colors, too, are changed, according to the amount of metamorphism the rocks have undergone. This is illustrated in the case of the Belt shales. Nearest the intrusion the shales are white, light-purple, or green rocks; farther away they are darker, and reddish or greenish in tint. A banded appearance is all that remains to show the former bedding planes. These features are common to the altered shales of every formation, being similar in the rocks of Cretaceous and Algonkian ages. Limestones are altered to crystalline marbles. This is most marked in the vicinity of Robinson. Elsewhere the metamorphism of the limestone is less pronounced, and often is noticeable only in a change in the grain of the rock.

The width of the contact zone varies with the size of the intrusive body. At Castle Mountain it is nowhere very great, averaging about a quarter of a mile, except where intrusive sheets abound and have increased the extent of the alteration. It is in this zone of contact metamorphism that the ore deposits of the district are found, especially in the areas of altered limestone. The numerous prospect pits, with their white heaps of impure marbles, mark the contact zone on all sides. In the Crazy Mountains the contact metamorphism is more intense and the zone wider. About the Yogo Peak stock it is narrow and the phenomena are like those observed at Castle Mountain.

ROCKS OF THE NEOCENE PERIOD.

Smith River lake beds.—The beds composing this formation are irregularly bedded sands and loosely cemented conglomerates, together with beds of marl and volcanic dust. The beds were deposited in the waters of a lake that once filled the valley of Smith River, between the Little Belt and Big Belt ranges. The strata are not conformable with those of any underlying formation, but rest on the eroded surfaces of all older rocks. The finer-grained beds are composed of volcanic dust, the product of ash showers from the old Castle Mountain volcano. The conglomerates are of local occurrence, forming small lenses here and there in the sandstones.

Large vertebrate fossils.

The rocks are mostly light gray, chocolate colored, or white, and exposures are therefore conspicuous. The beds are, however, generally concealed by later alluvial gravels or soil. The beds being porous the areas covered by them are generally arid wastes on which sagebrush and a scanty growth of grass form the only vegetation. Fossil remains of large vertebrate animals occur in abundance in these beds beyond the limits of the quadrangle, the species being of middle Miocene types, but showing two distinct horizons—the "John Day" and "Deep River" formations.

SURFICIAL ROCKS.

Glacial drift.—In the quadrangle there are several areas of glacial drift which either hides the underlying rocks or constitutes the chief material seen. This drift is all of local origin and consists of the rocks brought down by local ice sheets from neighboring peaks. In most cases it consists of erratic blocks and the unassorted drift characteristic of terminal moraines, and it is not extensive enough to form conspicuous topographic features. Numerous areas of drift are not shown upon the map, for to do so would obscure the more important geology of the other formations.

Bench gravel.—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 the streams and spread over the region as their courses were shifted from time to time. The gravels consist chiefly of igneous rocks, as they are the hardest and toughest rocks of the region, but sedimentary rocks are also found.

Alluvium.—There are small areas of alluvium in the quadrangle, which are shown upon the map, where flooded streams have deposited sands and silts over the valley bottoms, and so have completely hidden the underlying rocks. The material is unconsolidated, and generally forms fertile lands suitable for agricultural purposes.

IGNEOUS ROCKS.

Igneous rocks play a most important part in the geologic structure of the district. They are of many kinds and of various ages, and are distinguished upon the map by colors and symbols. The smaller bodies, occurring as dikes and sheets, have been grouped together according to their general acidic or basic character, and no attempt has been made to designate the periods to which they belong.

The rocks fall naturally into four groups, each of which includes rocks of similar age occurring in separate localities and representing different phases of independent igneous activity. The classification by age therefore corresponds very nearly to one by localities. In each group the rocks are of closely allied varieties and show certain peculiarities in which there is a marked connection between the mineral and chemical composition and the geologic position occupied.

IGNEOUS ROCKS OF UNKNOWN AGE.

Intrusions in the Archean complex.

In the Archean complex near Neihart there are altered igneous rocks forming part of the crystalline gneisses and schists, but which have not been distinguished upon the map as igneous rocks. In the same region there are other igneous masses which are clearly intrusive in the Archean rocks. These are shown upon the map and are unquestionably the oldest unaltered igneous rocks of the quadrangle. They are thought to be older than the mountain uplift, as they show a distinct, though not very strong, schistose structure. They do not cut the younger rocks, neither do they appear as pebbles in the overlying conglomerates which form the base of the sedimentary series, for which reason their exact age is not known. From the evidence afforded by adjacent districts, it is probable that they are of Cretaceous age.

Pinto diorite.—The most noticeable rock of the Neihart mining district is the Pinto diorite, which is at once known by its peculiar spotted appearance. This spotting is due to large oval, white or pale-green masses of andesine feldspar, an inch or more across. These feldspars are closely packed together, the interspaces being filling by a dark-colored mixture of dark-green hornblende and biotite-mica with a little orthoclase and quartz. The rock is very tough and hard to break; it is massive in structure, though gneissoid or even schistose in the hornblende portions; and it forms very rough, craggy outcrops where it weathers into large angular blocks. Owing to its very angular contact with the metamorphic rocks it is difficult to define its exact boundary.

Neihart porphyry.—The rock designated by this name is a rhyolite-porphyry of a pale yellowish or earthy tint, breaking into fine angular detritus and occurring irregularly as intrusions in the schists. The rock often shows considerable shearing and cracking, due to the movements attending the uplift of the range. It is a typical rhyolite-porphyry, in which the feldspar crystals are quite prominent. It is seen on the divide above Neihart and on the slopes drained by Snow Creek and Mackey Creek.

Granite-porphyry.—This rock, which is shown upon the map by the color used for the acidic dikes, occurs as a thick dike or sheet forming a cliff along the north wall of Carpenter Creek. It is a typical granite-porphyry.

POST-CRETACEOUS IGNEOUS ROCKS OF THE LITTLE BELT MOUNTAINS.

Gradual transition between the rock types.

The igneous rocks of the Little Belt Mountains are known to be post-Cretaceous but their exact age has not been determined. They are all unaltered intrusive rocks which occur as stocks, laccolithic masses, and rather commonly as dikes and sheets. At one locality, Yogo Peak, they are quite coarse and evenly granular in texture, but elsewhere are distinguished by a very prominent porphyritic structure. As a whole they are acidic rocks very similar in appearance, though when studied under the microscope the relative amounts of plagioclase, orthoclase, and quartz show that they form a continuous series grading from syenite-porphyry, the prevailing type, to diorite-porphyry on one hand, and from granite-syenite-porphyry to granite-porphyry of the Barker type on the other hand. For convenience in mapping, and to avoid too many designations, areas of rhyolite-porphyry in the Little Belt region have been shown by the syenite color and symbol upon the map. The Yogo Peak stock is the most extensive single body in this region. At its extreme southwest end the rocks appear to fill an eruptive pipe or conduit, and there they show changes in structure and composition which are diagrammatically indicated upon the map.

Syenite and syenite-porphyry.—The eastern part of Yogo Peak is formed of syenite. This rock, whose essential minerals are orthoclase and augite, is evenly granular, of a light-gray or pinkish color, and upon weathering breaks readily into platy débris which obscures the exposures and forms the mountain slope. The Yogo Peak rock contains a small amount of oligoclase feldspar and accessory pale-green pyroxene, and a small amount of hornblende and biotite, with lesser amounts of titanite, apatite, and iron ore. It is clearly the granular equivalent of the syenite-porphyry, which is the more common rock of the district.

Syenite-porphyry (that is, a porphyritic syenite) is the most common rock of this period of eruption. It is grouped with the syenite in mapping, as it was found impossible to outline the distinction between the two rocks. The rock is evenly and finely granular, and contains many phenocrysts of white orthoclase and more rarely of plagioclase, with the same minerals recognized in the coarser-grained syenite. The rock grades into granite-syenite-porphyry and forms the laccolithic masses at the head of Tenderfoot and Tillinghast creeks, in the northwest corner of the quadrangle, as well as the Yogo Peak stock. The smaller dikes and sheets of syenitic rocks are grouped on the map with the other acidic dikes.

Monzonite.—This rock, which contains plagioclase and orthoclase feldspar in nearly equal proportions, together with augite, biotite, and iron ore, might be classed as a basic syenite. It forms the central part of the Yogo Peak mass. It is somewhat more coarsely crystallized and darker in color than the syenite, has a greenish tint, and possesses a mottled appearance due to a larger amount of the ferromagnesian minerals. The rock is very tough and breaks with an irregular platy fracture. It grades into syenite on the east side and into shonkinite on the west side of Yogo Peak.

Shonkinite.—Granular rocks consisting of augite and orthoclase feldspar with large amounts of bronze-brown biotite, together with smaller amounts of olivine, iron ore, and apatite, are designated shonkinite. The only occurrence mapped is that on the western end of Yogo Peak, where the shonkinite forms a border zone of variable width lying between the sedimentary rocks and the main body of the stock. It also occurs in the dikelike mass at the head of Lion Creek, and in dikes south of this locality. At Yogo Peak it varies greatly in granularity. The coarsest-grained parts of the mass disintegrate and crumble to sand, while the denser rock forms short and thick pillars and bowlderlike masses and crags which make the peak quite unlike any other summit of the range. The rock might be considered a syenite in which the augite exceeds the orthoclase in amount. It is the granular equivalent of minette.

Diorite-porphyry.—Diorite-porphyry occurs at Steamboat Mountain, at the head of Running Wolf Creek. The rock closely resembles syenite-porphyry and Barker porphyry in appearance, though somewhat darker in color. It shows the same phenocrysts of orthoclase and plagioclase as do those rocks, together with hornblende, biotite, and iron ore, in a granular microgranitic groundmass of plagioclase and orthoclase. The relative proportion of plagioclase feldspar shows that it must be classed as a diorite-porphyry.

Barker porphyry.—A granite-porphyry whose peculiarities of structure show it to be closely related to the preceding rocks has been designated Barker porphyry. It is a light-colored rock, usually gray or pale brown, weathering with a reddish tint. It shows large crystals (phenocrysts) of orthoclase, sometimes an inch across, with very much more abundant and much smaller irregular sections of pinkish, waxy, plagioclase feldspar, in a groundmass that is recognizable as evenly granular and is peppered with black or dark-brown biotite-mica and hornblende. The relative abundance of these dark-colored minerals varies somewhat in different localities and in different parts of the same mass. The groundmass consists of alkali feldspar and quartz. The large amount of both quartz and feldspar 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 other writers as hornblende-mica-andesite and dacite. Big Baldy Mountain consists of this rock.

Acidic dikes and sheets.—The light-colored dike and sheet rocks consist mainly of syenitic, trachytic, or rhyolitic porphyries. The first two types differ only in granularity and closely resemble the rocks already described. The rhyolite-porphyry is a dense, hard, and often flinty-looking rock, in which there are a few phenocrysts of quartz and feldspar in a felsitic base.

Basic dike and sheet rocks.—These consist, in the Little Belt Range, of dark-colored, usually dense rocks, very commonly intrusive in the soft shales of the Barker formation. The most abundant form is minette, a rock called mica-trap by many field geologists. The rock consists of orthoclase, biotite, some plagioclase, and accessory augite, apatite, and magnetite. It is usually much altered in the outcrop, forming a greenish, crumbly rock. A variety rich in nephelite occurs in dikes cutting the limestones north of Bandbox Mountain. The dikes of this locality are, however, mostly analcite-basalts, consisting of phenocrysts of olivine, mica, and occasional augites in a groundmass of pyroxene, mica, and analcite.

IGNEOUS ROCKS OF EOCENE AGE.

Eocene age of Crazy Mountain intrusion.

The igneous rocks of Eocene age are all found in or about the Crazy Mountains. They vary greatly in character and appearance, but form a group having certain characteristics of structure and chemical and mineral composition believed to be due to their having been formed from a common source of supply, but representing varied phases of the differentiation of a single magma. They are rich in alkali, soda predominating. Their Eocene age is known from the fact that they have cut sedimentary rocks containing post-Cretaceous plant remains and are overlain by Neocene lake beds and cut by eruptives of Neocene age. The rocks are all intrusive, no surface forms having been found.

Loco diorite.—This name has been given to the granular rock forming the stocks or central cores of the Crazy Mountains. The rock varies somewhat in composition, the prevailing form being a typical diorite grading into quartz-diorite and even into granitite. It varies in texture from a fine-grained to a coarse-grained rock in which the minerals are in grains large enough to be distinguished by the eye. The light-colored minerals, labradorite, orthoclase, and quartz, slightly predominate. The dark minerals are biotite, augite, apatite, and magnetite. The main or south stock consists largely of a quartz-diorite containing hornblende, biotite, augite, labradorite, orthoclase, and quartz, with accessory apatite, magnetite, olivine, and hypersthene. At the northern or Loco Mountain stock the prevailing rock is an augite-biotite-diorite with no hornblende and very little quartz. The rocks of this core present wide differences in texture and are often porphyritic, becoming diorite-porphyries in which the white feldspar phenocrysts speckle the rock. This is especially common about the borders of the main body, where offshoots and tongues intruded in the sediments consist of the same rock magma consolidated under different conditions, the coarser-grained forms being diorites or diorite-porphyries and the finer-textured rocks andesite-porphyries.

Crazy Mountain granite.—This rock is a light-colored, coarse-grained hornblende-granite. It is lighter in color and coarser in grain than the Loco diorite. It occurs intrusive in the Loco diorite of the southern of the two Crazy Mountain stocks, as a separate mass in the contact zone to the west, and as small dikes cutting the Loco diorite. It is apparently the aplite phase of the diorite.

Andesite-porphyry.—This is the common rock of the dikes and sheets of the Crazy Mountains. Only the larger bodies of this rock are represented by a distinct color upon the map, all the dikes and smaller masses being included with the acidic dike rocks in mapping. In the large masses indicated the rock has a light-gray or pinkish color and shows abundant crystals of white feldspar and small flakes of black biotite in a dense groundmass. The rocks vary greatly in texture and in appearance, according as the phenocrysts are large or small, abundant or scanty, or the groundmass is light or dark. In the dikes there is a variation from rocks containing hornblende and andesine-feldspar phenocrysts in a groundmass of plagioclase and orthoclase feldspars with quartz and accessory magnetite, to darker-colored augitic rocks consisting of augite, biotite, and labradorite-feldspar phenocrysts in a groundmass of plagioclase, biotite, and hornblende with a little quartz and orthoclase.

Trachyte-porphyry.—The rocks of the intrusive sheets of the northern part of the Crazy Mountains are in part trachytic or syenitic rock grouped under this name. In the thinner masses the rocks are porphyries; in the thickest sheets they are syenites; transitional forms also occur, the coarseness of grain being dependent upon thickness. The trachyte-porphyry is light colored, showing a pale-gray, pinkish, or brown groundmass dotted with white phenocrysts of orthoclase feldspar, and peppered with biotite scales and occasional minute crystals of hornblende. Under the microscope the groundmass shows the peculiar feathery feldspars characteristic of trachytes. The syenitic forms of the thicker sheets are finely but recognizably granular and consist of anorthoclase with much smaller amounts of hornblende and green augite, together with sphene, apatite, and magnetite as accessory minerals.

Theralite.—This extremely rare kind of rock is peculiar to the Crazy Mountains, where it is quite abundant, especially on the northern flanks. It is a dark-gray or black, basaltic-looking rock when fresh, but frequently weathers to a light-colored mass dotted with black hornblende needles. It occurs rarely in dikes, but commonly in sheets, occasionally so thick as to constitute laccoliths. It is fine grained and porphyritic in thin dikes or sheets, where the cooling was rapid, and is crystalline in texture when in thick sheets or laccoliths. Porphyritic crystals of augite in stout prisms form the most prominent phenocrysts, but large plates of brown biotite-mica are common, and clear yellow grains of titanite also occur in a dark-gray groundmass. The colorless part of the groundmass, in which the foregoing crystals lie embedded, is a granular mixture of nephelite and soda-lime feldspar, the first recognizable by its faint yellowish-gray color and greasy luster. The rock has been mapped with the basic dike rocks where it occurs in small sheets and dikes.

Dike and sheet rocks.—These rocks are shown on the map in two colors, one for an acid and the other for a basic group. There are included under these colors small dikes and sheets of the various periods of eruption, but chiefly those of the Eocene. These rocks present not only a wide variety of texture and mineral composition, due to the varying rapidity of cooling, but also a very wide range of chemical composition. The commonest rocks, and those which prevail almost exclusively in the multitude of dikes that radiate from the conical peak stock, are andesite-porphyries of various kinds. They vary from light-gray to dark, steel-gray rocks, and from those so dense that no grain or minerals can be distinguished to those in which either the light-colored feldspars or the dark minerals, or both, are so thickly crowded that there results a resemblance to granular rock.

Phonolite (tinguaite, variety sölvsbergite) is found only in the northern part of the Crazy Mountains, as dikes and intrusive sheets in sedimentary rocks. The rock is a conspicuous feature of the stream drift, especially along the Musselshell River, its bright-green color and waxy luster making it an easily recognizable form. The fresh rock is of a green or grayish-green color, of greasy or satinlike luster, and breaks with conchoidal fracture. The denser-grained varieties show no crystals, but quite often the rock is a porphyry with large tabular phenocrysts of white or pink soda-orthoclase feldspar, commonly associated with smaller feldspars of green augite, and more rarely showing white dots of sodalite and leaves of biotite. The green color of the groundmass is due to an abundance of minute needles of aegirite-augite. In the thicker sheets or laccolithic masses the rock is finely granular to the eye, generally gray in color, and, like the denser form, generally a porphyry, and therefore a nephelite-syenite-porphyry. The large feldspars are intermediate between microcline and albite, and contain inclusions of apatite, sodalite, aegirite-augite, and biotite. At a number of localities areas of pinkish rock occur with the green. It is bostonite composed of soda orthoclase.

The basic trap rocks kersantite and monchiquite occur rarely, and only as dike rocks outside of the mountain area. The former is a greenish-gray compact rock, showing no crystals, and glistening with innumerable scales of mica. Monchiquite is much more rare than the kersantite occurring at the head of Lebo Creek. The rock is dark gray, dense but vesicular, shows irregular grains of yellow olivine, more rarely small tablets of biotite-mica, and scattered white spots of decomposed analcite. In appearance it closely resembles a basalt.

Camptonite is a dark-colored, greenish-gray porphyry that occurs among the igneous sheets of the contact zone. It also occurs as a dike cutting the core of Loco Mountain. It shows crystals of white feldspar, dark augite, and hornblende in a fine-grained groundmass of plagioclase laths with hornblende and biotite, the dark-colored constituents predominating. The rock is of rather common occurrence on the borders of the northern stock.

North of Shields River Basin the dike and sheet rocks show a remarkable variation in mineral and chemical composition. Andesite-porphyry is still the most common rock, but syenite, trachyte-porphyry, and phonolite occur associated with dark trap rocks, of which theralite is the most common.

IGNEOUS ROCKS OF NEOCENE AGE.

Volcanic rocks of Castle Mountain.

The igneous rocks of this age form a group of allied rocks derived from a single volcanic center, active in Neocene time—the Castle Mountain volcano. These rocks represent the different types of crystallization and structure that a molten igneous magma may assume under the most varied conditions of cooling and pressure. They consist chiefly of members of the granitic group of rocks, of which the following forms are represented: granite, granite-porphyry, rhyolite-porphyry, rhyolite, rhyolitic obsidian, and rhyolitic tuffs and breccias. Associated with them, but in smaller amount, there is a core of the massive granular rock monzonite, together with the forms derived from it by varied conditions of cooling, and also lava flows of basalt and intrusions of other basic rocks. The rocks all belong to a single period of volcanic activity.

Castle granite.—The most important of the igneous rocks of Castle Mountain is the granite of the central core of the mountain mass. This rock occurs as a great body whose exposure, as shown on the map, is a rudely elliptical area about 8 miles long and $4\frac{1}{2}$ wide. The rock is rather loose textured and weathers readily. It forms the highest part of the mountain, where it has weathered to a broad dome, showing a smooth surface except about the borders. Here the grain of rock is denser, and it weathers into the rough craggy piles giving the mountain its name. These crags seldom rise over 50 feet above the general level. The rock shows a well-marked jointing, which varies in closeness at different places, but causes the rock to break in great blocks, or more rarely in thin, broad plates. It is a light yellowish-gray to pinkish rock composed chiefly of orthoclase and quartz together with some oligoclase, biotite, and sometimes a little hornblende. Only in the southern portion does it reach such a condition of coarse and even grain that it may be termed a true granite. Toward the north the feldspars assume a more distinct shape and along with the quartzes appear spotting a finer-grained or rather dense groundmass. It thus passes over into a true granite-porphyry, but at no place is any boundary between the two to be observed, for the transition is very gradual. Hence the area is mapped as one under the term granite, by which name it is locally known. Granite-porphyry also occurs in dikes and in many of the sheets which have been projected into the beds surrounding the central mass. Examples of these may be seen on upper Fourmile Creek. They are reddish-colored rocks and frequently carry great numbers of very large orthoclase crystals as phenocrysts.

This huge mass of granite is not believed to represent the old volcanic vent, but rather a great intrusion that broke through its cover of bedded rocks at some point, accompanied by volcanic explosions. Evidences of its intrusive nature are everywhere apparent. It cuts off the bedded rocks abruptly, the ends of the formations abutting against it. It sends out tongues, intruded between the strata, that are continuously traceable into the parent mass, and the granite core is everywhere surrounded by a ring of indurated, baked sediments, whose alteration is greatest near the granite and decreases with distance from it.

Robinson diorite.—A second and much smaller area of massive granular igneous rock is seen west of the main summit of the mountain, between Robinson and Blackhawk. It is a roughly circular mass with a projecting tongue. The rock is a diorite whose composition is nearly that of monzonite, as it is composed of orthoclase and soda-lime feldspars in nearly equal proportions, with pyroxene, black mica, and magnetite. The rock is coarsest in the central part of the mass, where it weathers readily, and becomes denser, lighter colored, and porphyritic near the borders, where it weathers into rough forms like those about the borders of the granite. It is generally altered by superficial decay to a soft, crumbly mass, but prospect pits and road cuttings expose the hard, fresh rock. Like the granite, it is cut by narrow dikes and veinlets of a white, siliceous granite (aplite).

Rhyolite-porphyry.—Sheets of porphyry intruded between the beds of sedimentary rocks are of very common occurrence about the borders of the cores of massive rocks. Between the Castle granite and Robinson diorite areas these sheets are from 1 to 5 feet thick and so numerous that only a few can be shown on the map. In many cases the rocks forming the sheets, which are from 25 to 100 feet thick, are granite-porphyries, but more often the rocks of the intruded sheets and dikes may be referred to rhyolite-porphyry rather than to granite-porphyry. The distinction lies chiefly in the facts that in the former the phenocrysts or porphyritic crystals are not so large or abundant, and the denser groundmass is more conspicuous, generally of light colors, and often contains embedded quartz grains. A great part of the talus-covered slopes of Fourmile Creek is made of this material. In the canyon walls of upper Fourmile Creek such sheets can be traced continuously into the granite, the rocks presenting all gradations of texture from a fine-grained rhyolite-porphyry (felsophyre) to a coarse-grained granite. The mountain spurs above Castle and near Blackhawk are full of intruded sheets. In the open hills below Castle, where the softer Cretaceous sandstones and shales are steeply upturned, the dense porphyry sheet rocks weather in relief as wall-like ridges.

Acidic dike and sheet rocks.—There are few dikes at Castle Mountain. Those that occur are of two kinds of rocks: the porphyries, generally light colored; and the basic dikes, the dark-colored rocks. The former are of various colors and textures, and may be designated granite-porphyry, rhyolite-porphyry, or syenite-porphyry.

Syenite-porphyry, which consists chiefly of orthoclase with some lime-soda feldspar and hornblende or biotite, occurs in dikes cutting the hill of limestone back of Blackhawk, in the combs and ridges below Castle, and in the masses intruded at Black Butte. It is a light-colored rock resembling granite-porphyry, but is lacking in quartz. The dikes and sheets of granite-porphyry and syenite-porphyry, on account of the high percentage of silica which they contain, have been grouped on the map together with those of andesite-porphyry and trachyte-porphyry as acid dikes.

Basic dike and sheet rocks.—The basic dikes are heavy trap rocks of black or dark-gray color, dense texture, and often distinguished by porphyritic crystals of mica, augite, hornblende, or olivine. They are relatively rare rocks, generally cut the other sheets or dikes as well as the bedded rocks, and commonly weather so readily that fresh material is seldom seen in natural outcrops. They are rich in iron, lime, and magnesia, low in silica, and belong to the lamprophyre group of igneous rocks. They are classed as vogesite and minette and are shown on the map simply as basic dikes. In some places they have been greatly altered by weathering, and the hydration of the iron contents has turned them to a rusty brown. It is probably owing to this fact that they have been prospected for ore veins in several localities.

Rhyolite.—The lava flows of the Castle Mountain volcano are of two kinds. The first consists of rhyolitic rocks, the second of basalts. The rhyolite flows now seen are but small remnants of extensive flows which rest on both sedimentary rocks and fragmental breccias. The rhyolite is the extrusive equivalent of the granite. It occurs in thick masses partly forming the foothills around Fourmile and Fivemile creeks. It varies from reddish, streaky, partly glassy rocks to dense varieties composed of quartz and feldspar and grading into granophyre. The latter forms are light colored. Some of these masses fill old hollows of a former surface. The mass forming a hill at the fork of Fourmile Creek is 1000 feet thick, and the rock presents a wide range in texture and appearance. South of Bonanza Creek a large flow covers the plateau, the rock being a buff-colored or orange porphyry with white phenocrysts of sanidine. The rhyolite lavas grade from rocks exactly like the intruded sheets of porphyry to forms having flowage lines, spherulites, and other characteristics of surface lavas, these variations often occurring in the same mass. The rocks are mostly reddish or gray in color, more rarely white. They are usually very dense, with conchoidal fracture, and show small crystals of glassy quartz and feldspar. They generally weather into angular fragments, which form extensive débris slopes, often concealing the outcrops. In the hilly country just above the canyon of Checkerboard Creek masses of glassy rhyolite form prominent hilltops. These rhyolite masses are remnants of lava flows of glassy pitchstone. The rock is grayish, glassy, and filled with angular fragments of a black glass which strongly resembles coal in luster. It also contains great quantities of shale fragments and other sedimentary rocks picked up in its passage. It is a fine example of a flow breccia.

Basalt.—Two lava flows of basalt are found at the northern base of Castle Mountain, covering the valley floor. The largest of these clearly has its source in an isolated conical hill known as Volcano Butte. This hill rises 500 feet above the level valley floor and is a partially eroded cone of a small volcano. It is formed of pumiceous, brecciated, basaltic material mingled with small scoria bombs alternating with denser lavas. The scoriaceous material contains numerous fragments of baked and reddened shale, and steam action has oxidized the iron-bearing minerals, giving the rock a deep-red color.

The lava flow of basalt from this small subsidiary volcano covers over 6 square miles, and is quite evidently the latest manifestation of igneous activity in the region. Its surface is a nearly level plain, through which Smith River is cutting a little narrow canyon. The rock is a very dark-gray, dense, compact basalt, in which only an occasional olivine or pyroxene crystal can be detected. Another small cone and accompanying lava flow lies 4 miles northeast of Volcano Butte.

Remnants of basaltic lava flows are found in the western part of the mountains. A small mass occurs on the summit of Smoky Mountain which rests upon the eroded edges of limestone beds belonging to the Monarch and Barker formations. A sheet of basalt resting upon Belt slates and shales also caps a summit a few miles north of White Sulphur Springs, near the road. North of Wolsey the summit of the mountain is covered by a similar sheet of lava resting upon quartzites. Another sheet is seen in the canyon of Sheep Creek, near the western edge of the quadrangle, where the basalt forms a bench, recent erosion having deepened the valley.

Rhyolite breccias and tuffs.—Fragmental volcanic rocks cover the open foothills country drained by lower Fourmile, Fivemile, and the branches of Checkerboard creeks. The breccias are usually rocks of a light-brown color, consisting of fine fragments of shale and limestone held in a cement of light-buff or brown volcanic ash. The breccias form caps or thin coverings to the slopes, and are seldom well exposed, as they are soft and weather readily. The flows of rhyolite which rest upon them at the forks of Fourmile Creek are seen to have baked and indurated them. The presence of these breccias testifies to the explosive violence with which the old volcano began its eruptions. Where denudation has almost removed this material the hilly character of the prevolcanic country is clearly shown.

Rhyolitic tuffs or ash beds resulting from ash showers of the old volcano are more or less abundant over the whole district. Upon the map they are not distinguished from the breccias. An exposure 40 feet thick occurs on the slopes west of the canyon of Checkerboard Creek. The rock is cream colored, or sometimes very pale brown, roughly bedded, and compact, but not indurated. Being soft and easily washed down, this material has been largely removed. Excellent exposures occur above the canyon of Checkerboard Creek, and in the open country east of Copperopolis the ash beds are covered by flows of basalt. Examples of these ash showers, remnants preserved in pockets, are still to be seen 20 miles to the north. On account of their soft and crumbly nature the beds have been greatly denuded, or perhaps entirely carried away, and it is often impossible to tell whether the material is where it originally fell or has been laid down in water. The lake beds around and below White Sulphur Springs consist very largely of this material, carried by rain and streams into the lake that once filled the Smith River Valley. They are of a cream or pale-buff color, crumbly, and somewhat resemble clay in character. Under the microscope they are found to consist chiefly of tiny fragments of glass.

GENERAL GEOLOGY.

DESCRIPTIVE GEOLOGY OF THE LITTLE BELT MOUNTAINS.

The Little Belt Mountains are formed of sedimentary rocks, with minor local intrusions of igneous rocks. Only the older formations of the sedimentary series are represented. These rocks are folded into a broad, flat-topped arch, whose uplift formed the range, and the erosion and dissection of this anticline has produced the individual mountain masses and intervening valleys. The broad summit of the arch is flat and the central parts of the range are plateau-like. The sides of the arch are of steeply tilted beds and form the abrupt flanks of the range, from which the softer sedimentary rocks have been eroded. These softer rocks very generally define the boundary line of the mountain region.

Little Belt Mountains an anticlinal fold.

The sedimentary rocks composing the range vary in age and in hardness. The crystalline schists composing the core of the anticline are exposed over considerable areas near Neihart. Farther south the slates of the Belt formation form the central nucleus of the range. The water parting or main divide of the range is also the crest of the anticline, from which the rocks dip away on both sides. The harder rocks form the plateau summits, terminating in abrupt cliffs where erosion has cut the deep mountain valleys. Alternating formations of hard and soft rocks form cliffs and intervening benches—a steplike arrangement of the slopes. The valleys also emphasize the difference between formations, being broad depressions surrounded by gentle slopes where cut in soft shales, and narrow canyons with abrupt cliff walls where cut in the harder limestone series. To these harder rocks the mountains owe their ruggedness. Vegetation also reflects the differences of soil, its character and density depending upon variations in soil and moisture. The limestone areas are almost universally dry, and the water courses that cross them are filled only in time of flood. Caves and abandoned stream tunnels show that these rocks are readily dissolved along joint planes, furnishing water channels. Where the limestones rest upon shales, the plane of contact or its vicinity is marked by springs, and the streams flowing through valleys cut in shales are generally constant.

Throughout the central portion of the mountains the massive beds of white Madison limestone have been largely removed by denudation. The highest plateau-tops are formed of them, but the plateaus generally are made of the resistant members of still older formations. Along the outer slopes of the range, however, these white limestones are everywhere the most prominent rocks, and the streams cut profound gorges—commonly called "gates of the mountains"—in them. They are the cliff-making rocks of the region. The dark-colored Monarch limestones cover large areas throughout the range, but are not conspicuous in topographic features. The limestones constituting the upper member of the Barker formation contain upper Cambrian fossils. These rocks are hard, and rank next to those of the Madison limestone in their importance as mountain cap rocks and cliff formers. The areas where the slates of the Belt formation are exposed are conspicuous by their relative barrenness.

The igneous rocks do not cover large areas, but are very important features of the geology of the range. The highest peaks of the mountains are formed of them, and intrusive bodies have produced a very decided local arching or doming of the limestones above or about them, these intrusions being called laccoliths. Other intrusions are irregular in form and break up through the sedimentary rocks. The most interesting occurrence of this kind is seen at Yogo Peak, which is the western end of a narrow mass of igneous rock that extends for 13 miles northeastward, and which presents a remarkable instance of a great fracture filled by a continuous body of igneous rock. This mass of igneous rock shows a gradation from very basic augitic rocks to quite acidic feldspathic types, and is an example of rock differentiation in a single mass.

The Yogo Peak stock.

Yogo Peak has a bare, crag-crowned summit that projects above the neighboring wooded slopes and plateau, and is 3000 feet above the open parks of the adjacent stream valleys. The mountain is formed of massive, coarsely granular rocks which have broken through and now form a chimney or core in the slightly tilted bedded rocks, which are much altered and metamorphosed near the contact.

Intrusive sheets of porphyry form a very prominent feature of the scenery and structure of the range south and east of Neihart. They are especially abundant interbedded with the soft micaceous shales of the Barker formation, but are also found in the shaly beds of the overlying limestone series, and sometimes in the older slates. The exposures are most prominent upon the lateral spurs of the mountains, where the cliffs and débris piles rise above the thin-wooded slopes of shale. In places where the outcrops form the cliff front of broad benches that run along the mountain sides they can be traced continuously for 8 or 10 miles. More often the exposures are isolated, but as they occur at the same horizon on neighboring ridges they are doubtless parts of one continuous sheet. Several sheets are crossed by the stage road south of Neihart, and, as shown on the map, they are common at the heads of Belt Creek and the Middle Fork of the Judith River. The rocks vary in appearance and in mineral character. As a rule they show a decidedly porphyritic texture, with white feldspar phenocrysts and dull-green or black needles. They are usually much altered, light-colored rocks. Under the microscope they are seen to vary between syenite-porphyry and trachyte-porphyry according as the sheets are thick or thin. Sometimes quartz is present as phenocrysts and the rock is a rhyolite-porphyry, but the common forms are hornblende-porphyry or mica-syenite-porphyry.

Dark-colored micaceous rocks, generally soft and decomposed, also occur as intruded sheets in shales, especially south and east of Neihart. Very often these sheets occur in the shales between the sheets of light-colored porphyry. These rocks are minettes. When fine grained they are dense, black, heavy, and look like basalt. They are composed of orthoclase and biotite. Good examples are exposed along the road at the head of Sheep Creek. The dikes of Bandbox Mountain are analcite-basalts and monchiquite.

The highest summit of the Little Belt Mountains is the round-topped mountain known as Big Baldy Peak. It is composed of an igneous mass which has broken through the crystalline schists and bedded rocks, lifting the latter about its flanks, east and north, but without producing the marked doming or arching of the beds seen in the lesser summits of the eastern part of the range. The rock breaks into plates, which cover the surface and obscure the outcrop. The eastern face of the mountain is deeply indented by an amphitheater, whose cliffs show excellent exposures of the rock, which is a variety of granite-porphyry, designated the Barker porphyry. It is light grayish in color, and thickly spotted with large and small crystals of orthoclase and smaller crystals of biotite and augite lying in a fine-grained groundmass.

Big Baldy intrusion.

The peak north of Bandbox Mountain, between Dry Wolf and Running Wolf creeks, is known as Steamboat Mountain. It is a fine example of a laccolith. The cover has been but partly stripped off and a small area of the core of syenite-porphyry exposed. Erosion has not yet cut deeply into the igneous rock, but enough to show the cover of sediments dipping away from the central core on every side. The uplift has not been uniform, for the soft shales of the older formation have slipped and yielded to the pressure, so that these older beds are seen exposed only on the south side, the more massive Carboniferous limestones abutting against the porphyry elsewhere.

DESCRIPTIVE GEOLOGY OF CASTLE MOUNTAIN.

Castle Mountain is an example of a dissected volcano. It consists of folded and eroded sedimentary rocks in which volcanic forces formed a vent from which explosive eruptions took place and lava flows poured out. Denudation of the old volcanic cone has progressed so far that the main features of its internal structure are exposed, and yet there are left remnants of the fragmental rocks and lava flows that composed the old cone of the volcano, so as to show the condition of the surface before the volcanic outbreak occurred.

A Neocene volcano.

The sedimentary rocks of Castle Mountain comprise all the formations described in this text, the greatest variety known anywhere in the Rocky Mountain region. They present the characters common to the adjacent mountain region and demand no special comment. They are folded and faulted, and the folding took place before the outbreak of the volcanic forces that formed the Castle Mountain volcano, for the folds were deeply eroded and a mountainous tract was carved out before the lava flows and fragmental rocks were laid down.

The folding took place during the general mountain folding of the Rocky Mountain region, for the Castle Mountain area forms a part of the general Belt Mountain district, and its folds are the lesser puckerings that took place in the angle or elbow between the broader uplifts of the neighboring ranges. The Castle Mountain folds are parallel elongated domes with intervening troughs. They have a southeast-northwest direction, and the structural ridges plunge beneath the valley country and die out to the southeast. The easternmost of these anticlinal ridges forms the eastern end of the mountain area, near Martinsdale. The arch widens rapidly to the northwest, and the broad, low Volcano Valley north of the mountain is eroded in the soft shales that form the core of the fold. The second great fold forms the southwestern side of the mountain. The beds forming its western flank may be seen curving about the mountain slopes, apparently upturned about the granite core. The complete fold is south of Elk Peak, where it is overturned, so that the beds all dip westward. East and north of White Sulphur Springs, where Willow Creek has cut its channel along the contact line, the northeastern side of the fold is seen to pass into an overthrust fault, bringing the softer Algonkian slates into contact with the harder Carboniferous limestones. The valley of the South Fork of Smith River is cut across another parallel fold, and a synclinal trough is seen between it and the fold to the north. In the vicinity of the ore deposits at Castle, Robinson, and Blackhawk the limestones and associated strata are seen to form parts of folds broken and dislocated by the great intrusions of massive rock. Small faults occur, as shown on the map. The softer Cretaceous rocks south of the mountain are plicated by numerous lesser foldings—the crinkles above the broader underground folds of the harder limestone series.

Folding and faulting in the Castle Mountains.

Denudation has exposed a central core of massive igneous granite, in part representing the former conduit. This is surrounded by baked and altered sedimentary rocks intruded by sheets of porphyry and in places cracked and filled with radial dikes. At a distance from the center, and forming part of the foothills, especially on the north and east, are masses of rhyolite and rhyolitic obsidian, filling the hollows of old valleys and resting unconformably upon the bedded rocks. The fragmental rocks, breccias, and tuffs occur similarly, and are in places overlain by rhyolite lava flows and cut by dikes.

DESCRIPTIVE GEOLOGY OF THE CRAZY MOUNTAINS.

The Crazy Mountain region is nearly bisected by the broad head-water valley of Shields River and the eastward-flowing American Creek. The two mountain areas thus defined differ greatly in scenery, structure, and height, though of common origin. Both groups show stratified rocks, sandstones, and clays belonging to the Livingston formation, which are intruded by dikes, sheets, and great masses of igneous rock. The molten rock that formed the dikes, together with that of the great central intrusions, gave off great amounts of heat in cooling. This heat and the vapor which it produced acted upon the sediments, baking the soft sandstones and shales into hard, resistant rocks, which slow weathering has left in relief while the neighboring parts of the quadrangle have been cut down several thousand feet.

Resistant metamorphosed strata.

Throughout the entire range the higher valleys show glacial scorings and heapings of transported bowlders and drift. The central part of the range held a number of local glaciers, which streamed down the larger valleys and overflowed the canyon walls, strewing erratics and smaller drift over large areas of bench land at the base of the mountain slopes. The glaciation was, however, entirely local in character, originating in the mountains themselves and not even forming a confluent ice cap over the group. The bench lands, great inclined planes whose average inclination is but 3° to 5°, stretch outward for many miles from the foot of the mountain slopes. They are cut across the upturned edges of the bedded rocks, and their surface is covered by waterworn gravels from the mountains. The present streams have cut gorges or valleys below the surface of the bench lands.

The southern part of the mountains, south of Shields River Valley, has a simple general structure. The mountains occupy the center of a broad and shallow basin fold lying between the mountains near Sixteenmile Creek and the Snowy Range to the south. On the bench lands and lower mountain slopes on all sides the bedded rocks dip inward, toward the peaks, and there is but little minor puckering of the beds.

The most striking feature of these southern peaks is the presence of a multitude of dikes, which form prominent walls, and may be traced for long distances. These dikes are far too numerous to be indicated on the map. An attempt has been made to show them, but each dike appearing on the map must be considered as representing a number. Most of the dikes converge toward a common center in the highest parts of the mountain.

Radial dikes.

The center of the mountains is formed of a great body of coarse-grained massive rock, whose relations to the surrounding sedimentary beds show that it was forced into and up through them. This intrusion is in the center of a broad basin of gently folded sandstones and shales extending from Shields River to the eastern limit of the quadrangle. This is the core shown on the map at the head of Sweetgrass Creek. It is of approximately oval outline, and is 4 miles broad and 6 miles across. The central core of the mountain consists of very coarse-grained rocks which disintegrate upon weathering, becoming crumbly and eroding rapidly. For this reason the main body of igneous rock has been deeply cut by the head waters of Sweetgrass Creek, and the highest peaks are formed of the denser, finer-grained rocks of the contact zone. The injection of the large mass of igneous rock forming the cores into the great thickness of nearly homogeneous rocks produced a multitude of radial fissures, which were filled with the molten magma, making the dikes whose harder rocks weather in relief. In most instances these dikes end abruptly at the base of the mountains.

Igneous core around Conical Peak.

Sheets of molten material were also forced into the bedded rocks and insinuated between the strata, usually following prominent shale beds. Such sheets are seen in the walls of the mountain amphitheaters, and are especially numerous and prominent close to the edge of the main mass. The effect of the injection of so many sheets has been to greatly thicken the walls about the intrusion, and to tilt up the higher beds, so that the original dip inward toward the center has been changed and the beds dip steeply outward and away from the main intruded mass. The steepness of dip decreases rapidly away from the edges of the intrusion, as shown in the Structure Section sheet.

Intruded sheets reversing dip.

The sheets occurring on the outer slopes of the mountains are probably in part terminations of long sheet intrusions from the central core, but in some cases at least are fed by dikes. Such rocks weather less rapidly than the little-altered sandstones and shales remote from the central core.

Where igneous sheets occur on the outer slopes of the mountains, they generally cap flat-topped hills or steplike benches. This is because the dense igneous rocks resist erosion much better than the soft sedimentary rocks. The beds in contact with such sheets usually show induration and alteration for a few feet from the line of contact.

Surrounding the central core of massive rocks there is a zone, a mile or two wide, where the sedimentary rocks have been intensely altered. The original nature of the rocks and their bedding planes can be determined only by the colors and the presence of siliceous layers, for there is a pronounced jointing which resembles bedding, and the rocks are very dense and hard. Where this action has been most intense new minerals have developed, but in most parts the shales have been altered to white, porcelain-like or green and lavender-tinted rocks, called adinole. Farther away from the borders of the core the rocks retain their original dark colors, but are hard hornstones which grade into slaty rocks that are simply indurated shales and sandstones.

The extreme induration of the sediments of the central part of the mountains makes them as resistant as the dense igneous rocks of the dikes and sheets, so that the latter do not weather in prominent relief, as they do in the mountain flanks, and though more numerous than near the margin of the core, they are less conspicuous. This complex of altered sediments and intrusions of the contact zone is the most resistant rock of the mountains, and forms the highest summits, the borders of the main body of the igneous rock being defined by a succession of sharp points constituting the highest peaks of the mountains.

Like the sheet rocks, the dikes are conspicuous features of the footslopes of the mountains, owing to their dense, resistant character. They form wall-like exposures, and often determine the existence of minor ridges and buttress spurs. Where their outcrops are examined they will be found to trend, in almost every case, directly to the center of the mountains, so that when shown on the map they are seen to radiate from the area of massive igneous rock.

The northern part of the Crazy Mountains differs in scenery, as in structure, from the rest of the group. There are no sharp alpine peaks; the summits are lower and, with the exception of Loco Mountain, generally wooded, except a narrow crest formed of the edges of steeply inclined sheets of igneous rocks. The sedimentary rocks are the same as those of the southern area, but steep dips prevail and the rocks are tilted and folded in sharp and comparatively small, long, narrow, ridge-like folds and intervening hollows and domes. The igneous rocks also exhibit a wider variation in character and mode of occurrence. At Loco Mountain there is a stock of massive, granular, igneous rock. This intrusion, though smaller than that to the south, has been the chief agent in producing the characteristic features of the group. It breaks through sediments that had already been folded or were subjected to folding stresses at the time of the intrusion. The great central body of igneous rock, the Loco Mountain stock, consists of numerous intrusions penetrating one another and extending outward as dikes and sheets into the adjacent sedimentary rocks, which are highly altered and indurated near their borders.

Loco Mountain core.

Even remote from the core, sheets are the most common form of intrusion in these northern mountains. In many instances such sheets are locally thickened, forming laccoliths several hundred feet thick. The folded sedimentary rocks are often interbedded with numerous sheets of intrusive rock, which conform to the sharp folds and even to the minor crumplings and wrinklings of the strata. As there is no crushing or evidence of movement shown by the intrusive rocks, it is obvious that their injection accompanied the foldings of the beds. The occurrence of the thickened sheets and laccoliths in the axes and flanks of the folds confirms this. Where the folds are long and narrow, the rocks form narrow ridges, whose crests are maintained by the exposed edges of the intrusive sheets. In some cases the sheets are so thick that they form one-third of the mass. At the extreme north end of the mountains a great number of such sheets, weathering as high walls with serrated outlines, resemble dikes and give the name of Comb Creek to the neighboring stream.

Injection and folding probably synchronous.

Three Peaks is an example of monoclinal structure. The beds are conformably intruded sheets, dipping eastward, forming cliffs on the west and gentle slopes on the east. They are the eastern side of a fold, and owe their prominence to a number of bent lenses or saddle-shaped sheets of igneous rock intruded at different horizons, forming parallel but echelon ridges by the erosion of the softer sediments.

A dome structure is seen northeast of the mountains on Elk Creek. At this place the harder rocks and intruded sheets forming the surrounding ridges and buttes have been eroded from the center of the dome so as to expose the soft, gray shales of the Yellowstone formation (Pierre zone).

Gordon Butte, an outlying prominence north of the mountains, deserves mention. It owes its existence to an intrusive sheet 365 feet thick, forming the summit and cliffs of the butte. A lower sheet, 150 feet thick, also occurs in the gentle, saucerlike fold of the sediments.

No surface lavas or other products of volcanic eruptions occur among the igneous rocks of this mountain group, and there is no evidence that the volcanic forces which were so potent underground, and which left such evidence of their power, ever found an outlet at the surface.

In the mountains north of Shields River dikes are far less numerous than to the south. They occur in considerable numbers about the borders of the intrusive stock, which cuts off many of them, while others extend into and cut the granular rock itself. They are not uncommon at various other localities, but do not occur in the great abundance and multitudes seen farther south. It was easier for the Loco Mountain intrusion to send out injections of the molten magma between the folded sedimentary beds than to break fissures across them. Openings were more easily formed along the bedding planes of the steeply folded rocks, especially if folding was coincident with the intrusion, as seems probable. A thickening of the walls adjacent to the main intruded mass, by the injection of sheets and an accompanying tilting of the beds, took place about this stock, but neither this feature nor the alteration of the rocks is so marked as it is in the southern peaks. The sedimentary rocks of the Crazy Mountains all belong to the Livingston formation. There are, however, two zones whose rocks present somewhat different characters and may generally be distinguished when the sediments are unaltered.

GEOLOGIC HISTORY.

Archean time.—The oldest rocks of Montana are the crystalline schists, which are referred to the Archean period. In this quadrangle they consist of typical metamorphic schists. The gneisses and more schistose rocks present no evidences of their former nature. They are associated with rocks that are clearly of igneous origin, though themselves metamorphosed and schistose. Nothing is known of the condition of this region at the time these rocks were formed.

Algonkian deposition.—At the beginning of the period of time represented by the very oldest sedimentary rocks of the quadrangle, the Neihart quartzites and Belt shales, a land area existed north of Neihart, while a sea covered the region to the west and south. In this sea the material worn from the land was deposited. The very oldest rocks are quartzites, composed of clean quartz grains with pebbles of white quartz and rarely of red or black schist, the whole being coarse material swept from the land. These quartzites are followed by a great thickness of shales with impure limestones in the middle of the series and thin-bedded sandstones at the top. These rocks, representing the silts or muds carried by the streams, were deposited in shallow waters, as is shown by ripple marks, but the gradually sinking ocean bed permitted an accumulation of many thousand feet of sediment before the region was again elevated. Near Neihart this period, the Algonkian, is represented by 4000 feet of beds, while farther south and west the thickness is much greater. During the period of time in which these sediments were being deposited the land area north of Neihart was being worn down and reduced to a nearly level plain, part of which may be seen to-day where the crystalline schists are just emerging from their cover of sediment in Belt Park.

Shallow-water conditions.

Paleozoic submergence.—The gradual depression of the region covered by the sea during the time of the deposition of the Belt formation was succeeded by a general subsidence of the district, with an extension of the sea over the land area. The sandstones and quartzites which constitute the Flathead formation were formed as the approaching shore line was gradually extended over the land. It was the beginning of a prolonged era of submergence, represented by the rocks of the Cambrian, Silurian, Devonian, and Carboniferous periods. The earliest rocks formed upon the basal sands are micaceous shales which carry limestone nodules holding fossil remains of middle Cambrian forms. These shales, with their interbedded limestones and conglomerates, the latter made up of flat limestone pebbles, represent the sediments formed at the beginning of this long period. They are succeeded by limestones, which, while they vary somewhat in composition and texture, represent a long period of relatively deeper and clearer water. The fossil remains and the occasional presence of sandy or muddy material show that the period was not one of uninterrupted and gradual subsidence beneath the ocean waters, but was marked by the alternation of shallow and deeper waters. The limestone rocks thus formed in Silurian, Devonian, and early Carboniferous time constitute the series of mountain-forming limestones of the State, the great group of resistant rocks that is so prominent a feature of its scenery and structure.

Deposition of great thickness of limestone.

Carboniferous emergence.—The long period of quiet represented by the limestones was followed by an unequal uplifting of the ocean floor, part of which, in the latter part of Eocarboniferous time, became low land areas. The southern portion of the quadrangle may have been in part a land area, but the entire region was soon occupied by a shallow arm or gulf of the sea, in which the deposits were sands, muds, and in some places the limy oozes that consolidate into limestones. These hardened sediments are distinguished from the older strata on which they rest by their brilliant colors. The shales are red near the base, a brilliant green above, and the more common purple and grays near the top. They contain many minor layers of sandstone and limestone, and locally beds of gypsum. The fossils are, however, similar to those found in the massive white limestones beneath, and show that the rocks are Lower Carboniferous. These rocks vary from 400 to 1400 feet in thickness in different parts of the quadrangle. The region was probably elevated above the sea at the close of the Quadrant stage, as is indicated by the varying horizons upon which the succeeding Ellis beds rest and the absence in this region of the formations found intervening farther south.

Juratrias movement.—Renewed submergence beneath the ocean waters in Jurassic time was followed by the deposition of lime, of which there is a beach deposit that in the same bed grades from conglomerate into sandstone and then into limestone.

Cretaceous elevation.—A decided change occurred during the Cretaceous period, when the region was elevated above the sea and held large but shallow fresh-water lakes. Red clays and sands were deposited in these, while numerous marshes existed whose accumulations of vegetable matter formed coal seams, found to-day at about the same horizon in different areas of the Cascade formation. The fossil remains comprise fern and leaf impressions and shells of fresh-water mollusks.

Large fresh-water lakes.

No break is recognizable between the beds of the Cascade and the overlying Yellowstone formation, the beds being perfectly conformable and so alike in character that they could not be separated were it not for the presence of the intervening coal seam. There is no evidence of that long interval of Eocretaceous time recorded in the deposits found elsewhere in the region. The fresh-water conditions that prevailed in the early part of the Yellowstone stage (Dakota episode) were succeeded by a gradual subsidence of the eastern part of the quadrangle beneath the sea. It is not certain that at this time the area represented by the Little Belt Range was submerged; the rocks now exposed east of them show the nearness of a shore line to the west, but the infolded beds of this age seen north of Castle

Mountain show that the mountain folding took place at a later date. Only the earlier beds of the Yellowstone formation are of fresh-water origin, the great thickness of the shales and sandstones composing the bulk of its sediments being of marine formation and characterized by varied marine fossil types. Renewed elevation of the ocean floor followed; the sands and shales of the Laramie were formed in shallow estuaries of the sea, and coal-making plants flourished in fresh-water marshes.

Post-Cretaceous uplift and mountain building.—The uplift begun in the Laramie was the beginning of great change in the history of the region. Great movements of the earth's crust resulted in folding and elevating the previously formed sediments in all but the central portion of the quadrangle — movements that were general throughout the Rocky Mountain region. Volcanic outbreaks took place upon a grand scale and continued at various intervals throughout succeeding epochs. This era of volcanic activity is, so far as known, the first in the history of this region; it was of great extent, and built up mountain masses upon the newly formed land.

The beginning of volcanic activity.

The southern half of the quadrangle was at this post-Laramie time covered by water, but it was either an estuary or a landlocked body of fresh water. It received the waters from the neighboring land with their burden of sands and gravel, which consisted largely of the detritus from the recently formed volcanic cones and lava flows. The most vigorous of the explosive eruptions from neighboring vents outside the quadrangle showered cinders and ash into its waters, and filled up its shallow reaches with breccias, and volcanic cones were built up upon its borders and extended out into the water. In this way a great thickness of bedded rocks (about 7000 feet) was built up. This consists very largely of volcanic materials mixed with more or less ordinary sand and gravel—the waste from the sedimentary rocks exposed to erosion by the mountain folding and uplift. As the eruptions ceased and the cones were worn away, less volcanic material and more waste from the sedimentary rocks were deposited on the slowly sinking sea bottom, and conglomerates found in the Crazy Mountains contain pebbles of coal, limestone, and various other rocks belonging to earlier sediments, now folded and eroded. These conglomerates are themselves proof of the vigorous erosion of an elevated region to the west, prolonged for a period sufficient to permit the removal of many thousand feet of sediments from parts of the land area. The last beds formed show very little, if any, volcanic material. These conditions continued into Eocene time and are represented by the 11,400 feet of strata designated the Livingston formation. The fresh-water origin of the formation is attested by the presence of shells of various mollusks, while the remains of land plants are numerous. At the close of the Eocene period the entire quadrangle was reduced to a gently hilly country bordered by a broad level plain.

The region reduced to a peneplain.

Neocene elevation and igneous activity.—After the deposition of the uppermost beds of the Livingston formation the entire quadrangle was elevated and drained. This change was accompanied by renewed mountain folding. The folds already formed were modified and faulted, and the newly formed sediments were crumpled into sharp and small folds. This action took place, so far as known, only in the Crazy Mountain area, where great masses of molten rock exerted a strong hydrostatic pressure upon the mountain walls, fissuring the rocks with radial cracks, filling them with the molten magma, and forming the remarkable multitude of dikes surrounding the cores. The alternation of shale and sandstone beds in the reservoir walls offered varying resistance; the weaker beds about them were invaded by sheets, the hydrostatic pressure lifting the overlying beds and producing pronounced local tilting about the borders of the cores.

This period of volcanic activity was succeeded by a period of quiet erosion. The mountain ranges and valleys of to-day were not only blocked out, but were cut by a vigorous river system into a topography far more rugged than that of to-day, the valleys being deeper and the mountains sharper. The Eocene peneplain was deeply dissected by southward-flowing and eastward-flowing rivers.

Dissection of the peneplain.

Neocene lakes and volcanic outburst.—This period of quiet was interrupted by a general uptilting that ponded the southward-flowing streams, their waters flooding the valleys and forming great lakes that filled all the larger broad valleys between the mountain ranges.

This Neocene uplift was the last great disturbance of the region. It was accompanied by a renewal of volcanic outbursts upon a grand scale and an accumulation of material which formed some of the highest and most rugged mountain ranges of the State, but in this quadrangle the volcanic forces had but one outlet, the Castle Mountain volcano. This vent, now so well dissected, went through all the phases of a typical volcano, but its products did not modify the topography of the region very greatly, save where they fell into or were washed into the waters of a lake that filled the broad valleys between the Belt ranges, its eastern end covering the area of White Sulphur Springs. The deposits of the lake consist very largely of volcanic dust.

Glacial conditions.—At a later time, when the northern part of Montana was covered by continental ice sheets, the quadrangle held many glaciers in the Crazy Mountains and Castle Mountain. These ice masses were of purely local origin and extent; they filled pre-existing valleys and gorges and carried bowlders and drift down from the highest peaks to the bench lands about the mountains. The morainal heapings are minor but striking features of the topography, and the lakelets that are a result of morainal damming or rock cutting add much to the attractiveness of the present scenery. No evidences of glaciers are found in the Little Belt Range.

MINERAL RESOURCES.

The mineral resources of the quadrangle are varied, although up to the present time the precious metals, notably silver deposits, have been the only ones developed. Copper ores occur in several localities, but, although known since the earliest settlement of the State, the deposits still await development. Iron ores occur near Woodhurst and in Lion Creek, but are too remote from railroad transportation to be mined. Coal is found in many parts of the quadrangle, yet little is known of the value and extent of the seams over large areas. Sapphire mining is one of the important mining industries, the gems being found in the original matrix. The hot mineral waters of White Sulphur Springs are a resource that has long been known. Building stones and limestones are so common as to deserve but passing mention.

COAL.

The outcrops of the coal-bearing sandstone formations are indicated upon the Economic Geology sheet by dark colors. By the use of this map and the structure sections showing the dip of the rocks, the areas in which coal seams may be found, even where they occur beneath the surface of other rocks, are readily determinable. The value of the coal and the workable character of the seams can be ascertained only by actual prospecting. In general, the coal-bearing rocks occur mainly along the mountain flanks, where they are upturned, dipping away from the ranges. The seams are rarely persistent for long distances, and a horizon barren at one locality may contain a valuable seam at another place in the vicinity. Up to the present time but little prospecting has been done in the different fields. Where natural outcrops occur they have rarely been opened sufficiently to prove either the value or the thickness of the seams. Now that railroad transportation is available there will doubtless be energetic prospecting of favorable areas.

So far as known, the only field now worked is the Sixteenmile coal field, situated west of the Crazy Mountains, at a point where the head waters of Sixteenmile Creek cut through the succession of parallel, rolling ridges that flank the mountains. These ridges are formed of the dark-colored grits and clays that overlie the Laramie coal sandstones. The beds are closely folded, and in the central part of the hills this arching brings the coal sandstones to the surface, where they are cut across by the creek and eroded back into a little basin. The coal seam is seen in natural outcrop, and has been mined in a small way at various times since 1882. It lies at the very top of the fissile, gray, sandy shales of the Laramie, and is immediately overlain by the dark tuff sandstones of the Livingston. The early openings were made on the west side of the arch, the seam dipping 45° to 60° W. Surface cuts show the continuity of the outcrop. The workings show that well under cover the seam is from 2 to 5 feet thick, with several partings. Analysis shows this coal to be of excellent quality for steam and domestic use. The deeply trenched drainage ways cut into the surrounding hills are said to expose this seam at other points nearby.

Sixteenmile coal field.

Ten miles west of the field just noted, in the hills at the head of Cottonwood Creek, the Laramie coal-measure sandstones are exposed. Here thin seams of flaky, waxy-looking coal have been reached by short prospect drifts. The largest area of Laramie coal-measure sandstones is along the Musselshell. Coal seams have been uncovered at a few places along this river, but have not been developed.

Coal seams also occur about the base of Castle Mountain. The seam found beneath the Dakota quartzite has been mined at intervals for several years near the forks of Checkerboard Creek, several hundred tons having been used at White Sulphur Springs. The coal is bituminous, of good quality, but the seam is hardly thick enough to warrant extensive workings. A seam occurs at the same horizon on Warm Spring Creek above the forks, and generally at the base of the Cretaceous rocks. It has been seen only in outcrop, but appears too thin and impure to work, and is usually inclined at high angles. A coal seam exposed on the bench land adjoining Warm Springs Creek has been opened at several places, but has so far proved too impure to encourage development.

The Laramie sandstones south of Castle offer the most promising field for exploitation, as several seams of coal of fair quality occur in the formation. The outcrops cover a considerable area, and as the rocks are folded the seams lie at different angles throughout the field. On the ridge west of Robinson Creek, southeast of Castle, a seam is exposed in this formation, but it is vertical and difficult to work, as well as impure.

At the base of the slopes of the Little Belt Mountains the southern extension of the Cascade formation has not been prospected, but may be expected to show a coal seam, though its value can be determined only by workings. This seam has been opened near Utica, north of the Judith River, but has not been worked.

PRECIOUS-METAL DEPOSITS.

The silver deposits of the quadrangle are of great value, and have already contributed largely to the mineral production of the State. The Neihart mines have been steady producers for several years past, and the Castle Mountain district was, while the mines were worked, the foremost producer of silver-lead ore in the State. The ore bodies of the quadrangle occur in two very different types of deposit; those of the Neihart district are found in well-defined veins that cut the crystalline schists, while the ores of Castle Mountain are found in the altered limestones near bodies of intrusive igneous rock. The silver-lead ores found in different parts of the Little Belt Mountains also occur in limestones, generally in the vicinity of eruptive rocks.

Ore deposits in limestone.—These ores are of relatively simple mineral composition, consisting of the unaltered sulphides, galena and pyrite, with which chalcopyrite is sometimes associated, together with the carbonates and oxides derived from the sulphide minerals by surface alteration. Gold is usually present in small amounts, and sometimes becomes important. The gangue is generally siliceous, being usually a jaspery, impure material, seldom showing crystalline quartz. The ores of Castle Mountain and of several localities in the Little Belt Mountains occur as chambers or pockets in limestone. In most instances there are no well-defined veins or fissures. The following facts have been observed with regard to their occurrence: The deposits are most frequent, largest, and most commonly rich in the neighborhood of bodies of igneous rock, especially the larger bodies, whose intrusion has been accompanied by an uplifting of the bedded rocks, with more or less fracturing and shattering. The ore deposits seldom occur at the actual contact between the igneous and sedimentary rocks, but commonly within the zone of contact action, where the bedded rocks show induration and alteration and are fissured by the intrusion. Ore deposits are seldom found in the igneous rocks themselves. They are most frequent in the purer white limestone beds and are seldom found to be of any value in the impure limestones or shales. Ores have not been found in the siliceous beds, though these beds have been explored but little. The ore deposits follow bedding planes and irregular fractures and joint planes. The ore bodies are very irregular in shape and of extremely variable size, ranging from a few hundred feet to several hundred feet across. There is no definite horizon, such as that at Leadville, Colorado. The ores are not banded, and present none of the characteristics of the filling of fissure veins, but appear to be the result of the replacement of limestone by ore. Where open cavities occur they are clearly of later formation, and the circulating waters that formed them have altered the ores. Evidences of post-mineral faulting and fissuring are rare in these deposits. Wherever limestones occur near the contact of large bodies of intrusive rock, prospecting has shown the presence of ore deposits. Such deposits have not, it is true, always proved valuable, but in the greater number of cases sufficient work has not been done to ascertain their extent or value. The lack of a well-defined vein and the uncertainty attending the development of deposits of this class have been responsible for this, while the large sums spent at Castle Mountain without return have deterred investment.

Pocket deposits of the Castle Mountain type.

Castle Mountain district.—This district was for a brief period the greatest producer of silver-lead ores in the State. In 1891 the output of the largest mine, the Cumberland, was 5,000,000 pounds of base bullion. In 1892 the mines were generally closed down, and they have produced little ore since, though the completion of a railroad in 1897 has made it possible to reopen and develop many of them.

The only valuable deposits thus far found are in the altered limestones, particularly the white Carboniferous limestones. Numerous claims located upon deposits in the altered shales, upon decayed rocks of basic dikes, upon fissures in the massive igneous rocks or on their contact planes have in each case proved disappointing. The deposits in limestone are rarely of large size. That of the Cumberland mine is a remarkable exception. In general the bodies are small and of irregular distribution. They are often called bowlders of ore by prospectors, who generally regard them as out of place, a regular vein being sought. This is a natural result of the common conception of the Cumberland ore body, which is so generally regarded as a vein.

The Cumberland mine has been the largest producer and has the largest ore body yet discovered in the district. The mine is equipped with a very complete plant, both for mining and for smelting; concentration has heretofore been unnecessary. The ore body is a remarkably regular pod-shaped mass, inclosed in the limestone and dipping at an angle of 60°. The cross section is elliptical. The upper part of the ore shoot, for about 250 feet below its outcrop, consists of "carbonate" ore. Below this there is a mixture of altered ore and galena, passing into the unaltered sulphides below. The ore body ends abruptly in depth, below the 500-foot level, the shoot leading to a mass of pyritic vein matter lying on the contact between a porphyry dike and limestone. It appears probable that the ore body is a continuation of this dike fissure. The early workings were from an inclined shaft sunk in the ore, but a perpendicular two-compartment shaft 500 feet deep was sunk later. A crosscut driven westward to the granite contact shows the intervening rock to be greatly broken and altered and cut by dikes. The actual contact is marked by a mass of pyrite that is as valueless here as it is on the surface openings.

The Cumberland mine.

The Yellowstone, the second largest mine of the district, is located on an ore body lying between highly altered limestones and a sheet of granite-porphyry.

Near Blackhawk, where there are a number of mines, the high-grade silver ores contain large amounts of manganese (pyrolusite). Similar ores are found in the Grasshopper mine, on the ridge between Fourteenmile and Willow creeks.

Neihart district.—The silver veins of the eihart district are the most important ore deposits of the quadrangle. Discovered in 1882, the veins did not become important producers until railroad communication was established, ten years later. The ores vary considerably in richness in different veins, and also in relative amounts of gold, silver, and lead. In a few instances the gold exceeds the silver in value, though generally it is much less. The ores occur in nearly parallel fissure veins traversing the crystalline schists at nearly right angles to their banding. The entire production has thus far been from less than a dozen veins, but several times that number are known and have been more or less explored. Thus far the workings all lie to the east of Belt Creek and are confined to a small area between that stream and the divide at the head of Carpenter Creek. The productive mines are near the town of Neihart.

The Neihart ores.

The mineralogic composition of the ores is simple. The usual sulphides—galena, zinc blende, and pyrite—are of common occurrence and carry varying values in silver and rarely some gold. The rich silver minerals, brittle silver and ruby silver, are common. The former, consisting of stephanite and polybasite, carry the main values of the ore. Argentite, or silver glance, also occurs. Zinc blende occurs abundantly with the galena, and, contrary to the prevailing rule in other districts, it appears here to accompany the best ore—ore that is richer than the galena alone. The ruby silver is, so far as observed, always pyrargyrite. Native silver is of common occurrence in the upper workings of the mines, resulting from the decomposition of the rich silver minerals. Pyromorphite is of rare occurrence. A "spar" consisting of carbonates of lime, magnesia, iron, and manganese is the common gangue mineral, but barite occurs in abundance; quartz and the alteration products of galena also occur. Molybdenum is present in considerable quantity in the gold ores. The amount of lead varies greatly in the different mines. Some galena is always found. The Broadwater ores now (1897) average 2 to 3 per cent lead, but formerly held 8 per cent. Surface ores—that is, oxidized alteration products of the ore minerals—are found in small amounts only. Secondary sulphide ores ("sooty sulphides") occur in some mines.

The veins at Neihart occupy well-defined fractures showing little displacement. They cut across schists, gneisses, and massive igneous rocks, and in a few cases extend upward into the overlying quartzite. Their age is probably post-Cretaceous, but is not positively determinable, as they do not cut any stratified rocks younger than the quartzite (Algonkian).

Structural relations of the Neihart veins.

The structural conditions vary, however, with the nature of the rock. In general, the veins are widest in the white gneiss or red feldspar-gneiss belts, and but little narrower in the more schistose rocks, which are mixtures of varying composition. Where the veins pass into the hornblende-gneisses they are narrow and barren. Where small masses of this rock occur in the schists the vein is sometimes deflected and passes around them, as is seen in the workings of the Florence mine. In the tough, massive Pinto diorite the veins become narrow or pinch up to mere fracture planes. In the rhyolite-porphyry the veins split up into many small branches, and the rock is shattered and checked by fine fissures. This is evidently owing to the nature of the rock, as it shatters into fine débris in ordinary weathering. In the white and pink gneisses the vein filling is from 5 to 10 feet wide; rarely it is of considerably greater width. In the Pinto diorite such veins narrow to 2½ feet, or less. Branches or offshoots of the veins occur in all the rocks, but are not very abundant. Drifting along fracture planes where there is little but rust between smooth rock walls sometimes discloses valuable ore bodies as the fracture widens out into a vein, though such work has frequently proved disappointing.

The veins have a general northeast-southwest direction and dip steeply to the west. The dip is usually 70° to 85°, but varies somewhat in each vein, both vertically and horizontally. No relation of richness to direction or dip could be determined. The veins are persistent in length and have been traced in some instances over a mile. The greatest vertical exploration of any one vein is 1000 feet. There was no change of character in this distance.

In the Galt workings the vein follows a dike of rhyolite-porphyry, which forms first one wall and then the other, as the vein crosses it. The vein walls usually show little if any alteration, but the country rock is often sheeted by fracture planes, which become increasingly far apart away from the vein. Such parallel fractures sometimes, but rarely, widen into veins.

The vein filling is largely altered, leached, and whitened gneiss, which is sheeted into thin plates. There is also very commonly a breccia of fragments of the country rock cemented by the ore minerals. Clay selvage or gouge is of common occurrence, and the softened, altered gneiss is very clayey and makes much mud in some of the workings. There is seldom a clean and continuous streak of quartz. The ores occur in the altered, silicified gneiss, and generally in well-defined ore shoots. These lenticular bodies are seldom over 2 feet wide, but extend sometimes for several hundred feet horizontally and vertically. The ore composing them is usually banded, consisting of the rich silver sulphides, with galena, zinc blende, barite, quartz, and spar, commonly arranged in well-defined parallel layers, and sometimes showing open cavities (vugs) in the center. The banding is due to a stringing out of the minerals in the ore, rather than to a definite alternation of parallel crusts arranged one upon another. More rarely the rich ore is the altered country rock netted with the silver sulphides. The zinc blende rarely exceeds 10 per cent, and then only in local ore bodies. It generally accompanies the best and richest ores, and is therefore regarded as a favorable sign in some mines.

Relation of richness of ore to wall rocks.

In all the veins there appears to be a close relation between the nature of the wall rock and the occurrence of paying bodies of ore. The veins cut the bands of schist very nearly at right angles. Paying ore bodies are commonly found in the white feldspar-gneiss and in red feldspar-gneiss, while in the intervening dark-colored schists no ore is found. In the Pinto diorite the veins are usually narrow and barren; if ore occurs it is not rich or in paying quantities. In the black hornblende-gneiss the veins are generally barren, but in the intermediate types, where the rocks are mixtures, the veins often carry ore shoots. There is also a common association of ore bodies with the presence of splits or stringers of the vein. The ore of these branch fissures is always richer than that of the main vein, and the junction of the branch is usually marked by the occurrence of larger and richer ore bodies than those in other parts of the vein. In the Galt workings a clay or "talc" gouge is always found on one wall and sometimes on both walls of the vein. When this is most abundant the ore is said to be richest. This was not confirmed, however, by personal observation.

The ore deposits found in rhyolite-porphyry have not proved permanent in depth. The surface ores are generally rich, but they consist of secondary sulphides—"sooty sulphides"—and the ores are secondary enrichments due to the alteration of primary minerals concentrated in the upper parts of the veins. Kernels and masses of the primary ore are seen as the workings are extended in depth. The playing out in depth is probably due to the shattered condition of the vein, which does not favor the concentration of the minerals in large, well-defined ore bodies.

Broadwater mine.

The Broadwater is the largest mine of the district. Originally opened and vigorously worked for a brief period in 1885, it remained idle for eight years afterward. Since 1893, when it was reopened, it has been a continuous producer, averaging, it is said, a carload of ore a day for a large part of the time, and yielding an aggregate of over 4,000,000 ounces of silver.

The vein lies high up on the mountain side east of Neihart. It has been traced on the surface for a distance of 3000 feet, and opened for a length of 2800 and a depth of 960 feet. The direction is about N. 10° E. and the dip nearly vertical, varying somewhat at different levels. The vein averages about 4 feet in width and has well-defined walls, within which the gangue consists of altered and leached gneiss which is sheeted into thin parallel layers or bands one-half to 2 inches thick with 3-inch to 8-inch streaks of ore, and more rarely thin streaks or plates parallel to the walls. Narrow open spaces (vugs) occur in the ore parallel to this banding. The ore itself also often shows a marked banding in the arrangement of the black sulphides, zinc blende and barite. The vugs seldom show good ore, but are mostly lined with worthless blende and pyrite upon quartz crystals. The ore occurs mainly in narrow lenses lying on edge, their ends overlapping. Where these are thickly clustered they constitute the ore shoots of the mine, and the values are mostly in these bodies. In one place the hanging wall is fractured, altered, and impregnated with a network of very thin films of rich silver sulphides. In only one place does the vein show a shattered condition of the rock and a vein breccia; clean, sharp fractures and sheeting generally prevail.

The other veins of the district present individual characteristics worthy of especial description, which can not be given here. The Moulton, Ingersoll, Galt, Queen, South Carolina, Florence, and Monarch veins have all been explored for considerable distances, but the observations made have been summarized in the preceding paragraphs.

In the basin of Carpenter Creek and its branches, Snow and Mackey creeks, the veins present somewhat different characters from those just mentioned. Large bodies of rhyolite-porphyry occur, and the most recent discoveries of the district, those of the rich ores of Mackey Creek, are in this rock. The workings were not sufficient to afford ground for definite conclusions as to the probable permanency of the pay ore in depth. The rich ores found near the surface are secondary sulphides, and their occurrence is the result of secondary enrichment of the veins.

Benton and Big Seven mines.

At the head of Snow Creek the veins opened by the workings of the Benton and the Big Seven mines have yielded exceptionally rich ores, with high values in gold and little lead. The workings are at a higher altitude than any of the other producing mines. The veins traverse both gneiss and Pinto diorite and present the usual contrast of values and width in the two rocks, but the most interesting feature is the upward extension of the veins of the Big Seven into the quartzite. The veins show a constant streak of quartz, spotted with rich silver sulphides, but in the Pinto diorite it is too small to pay. The quartz streak varies in position in the vein, being sometimes frozen to the hanging wall. The ores are very rich, carloads yielding $3500 being not uncommon. The richest ores assay from 250 to 800 ounces of silver, with $40 to $150 in gold. In the extension of the veins into the quartzite some remarkably high values in gold have been obtained. The workings are not sufficient to determine whether the change of rock has altered the general character of the ore; moreover, the vein contents are oxidized by surface alterations.

Yogo district.

Other mining districts.—The Yogo district is of greater geologic than economic importance. The discovery of placer gold in the gravels of Yogo Creek in 1879 brought the usual rush of miners to the locality. Extensive ditches were built, but the returns were unsatisfactory and the workings were soon abandoned. Two or three men still work the bars in the upper part of the creek for a few weeks each season. The gold is quite fine and but little waterworn. It is undoubtedly derived from the neighboring ore deposits found in the limestones north of the creek, near the syenite contact. These limestones are fissured and cut by sheets and dikes of igneous rock. A number of claims have been held for years, but only one property, the Weatherwax, has been a producer. At this mine a 5-stamp mill was erected, but the ores became too base for economical working. The Blue Dick ore body occurs in brecciated limestones at the under contact of an extrusive sheet of syenite-porphyry. The oxidized ore from this claim was treated in an arrastre, run by water power, at the now almost deserted town of Yogo. The unaltered ore consists of galena with some chalcopyrite and pyrite.

Deposits of silver ore also occur in the limestones at the head of Lion Creek.

A number of other claims have been located on ore streaks found along the contact between minette dikes (mica trap) cutting the limestones. The dike rock is generally altered and decomposed, and the clay selvage contains traces of gold. So far as present developments show, the deposits are too small and of too low grade to pay for extensive working. The development of contact minerals by the minette dikes is especially fine at this locality.

On King Creek, at the head of the Middle Fork of Judith River, ores occur in the limestones at or near the contact with intrusive sheets and masses of igneous rock. A crude arrastre was worked for a short while, treating the oxidized surface ores of the locality. The structural conditions are favorable, and the ores are said to be of high grade, but no development work has been done upon the claims. Wherever igneous intrusives break through the sedimentary rocks there are signs of mineral deposits, and in such localities there are innumerable prospects, but none of them have as yet been developed into mines.

Several ore bodies of similar character and mode of occurrence have been discovered and worked during the past decade in the head-water valleys of Dry Wolf and Running Wolf creeks.

Wolf Creek mines.

The Woodhurst-Mortson mine is, perhaps, the best known of these properties. The ore occurred in limestone at the contact with a porphyry intrusion, and was worked as long as it paid. The mine is said to have a 250-foot shaft and nearly 4000 feet of levels. In the Eureka mine, at the head of the creek, the ore bodies are in limestones broken by basaltic dikes. The developments were disappointing and the property is said to be abandoned.

A body of galena ore discovered on the limestone slopes south of the creek, and called the Yankee Girl, was parallel to the bedding planes of the rock and measured 6 feet thick, 250 feet long, and 20 feet wide. The Sir Walter Scott mine, located on the top spur of Steamboat Mountain, yielded a large amount of silver ore. The ore is of unusual character, carrying much copper, as well as lead, and the gangue contains large amounts of fluorite. The ore deposit lies near the border of a laccolith, but is on the contact of a basic dike cutting massive limestone. Numerous other workings have been made at various times on the borders of the laccoliths of syenite-porphyry and along the margin of the long intrusion extending from Yogo Peak to Woodhurst Mountain. No productive mines exist at present in this district, though several patented mines await further development.

IRON ORE.

Woodhurst iron mine.—Iron ores occur at Woodhurst Mountain in a deposit large enough to warrant extensive working. The ore occurs at the contact between the main intrusion of syenite-porphyry and the limestones. The ore body is exposed by open cuts and a shallow shaft, but only a small amount of ore has been extracted. Iron ore is also found at Lion Gulch, northeast of Yogo Peak, where it occurs as a contact deposit.

MINERAL WATER.

Sulphur springs.—The hot waters of White Sulphur Springs, from which the city is named, possess valuable therapeutic qualities, and are administered internally, besides being a valuable remedial agent in bathing. There are nine distinct springs, with an estimated flow of 13,000 gallons per hour, besides several small seepages. The temperatures range from 103° to 125° F., the water supplying the bath houses having a temperature of 123½° F. The water as it issues from the springs is clear, but has a strong odor of sulphuretted hydrogen and becomes opal blue or milky from suspended sulphur particles after standing in the bathing tank. The total amount of mineral in solution is 1.5543 parts per million, as shown in the following analysis, made in the laboratory of the Geological Survey:

Analysis of water of White Sulphur Springs, Montana.

Constituent.	Grains per liter.
Sodium carbonate	0.5571
Calcium carbonate	0.1280
Magnesium carbonate	0.0438
Sodium sulphate	0.4463
Sodium chloride	0.2460
Potassium	0.0807
Silica	0.0330
Sodium silicate	0.0194
Hydrogen sulphide	Trace.
Total	1.5543

There are no tufa deposits about the springs. The remedial qualities of these waters in the treatment of rheumatism and certain other diseases, and especially the mud baths that could be easily given here, should attract more attention than is now given to the locality.

COPPER ORES.

These ores are found at several localities in the quadrangle. They occur in well-defined fissure veins cutting the argillaceous shales and slates of the Belt formation. The veins are all narrow, show evidences of faulting, and are filled with fragments of shale cemented by quartz and calcite spotted with copper sulphides, altered to carbonates and oxides near the surface. The ores are rich, but were not sufficiently developed to afford data upon which one might form an opinion as to their size or mode of formation. The claims at Copperopolis, north of Castle Mountain, are the best known, having been discovered in 1867, when a few tons of ore were sacked and shipped. The deposits are certainly worthy of serious attention and a more careful exploration than has yet been made.

Copperopolis mines.

The prospects on Sixteenmile Creek, close to the railroad, are similar in character, but less promising as far as developed. Other prospects are found on the slopes above Spring Creek, on the south side of the Little Belt Mountains, on Richmond Creek, and near Comb Butte on lower Sheep Creek.

GEMS.

Sapphire.—The Yogo sapphire mines are the most important gem mines of Montana, if not of the entire country. The stones occur in a true dike of igneous rock cutting through nearly horizontal beds of massive white limestone. The locality is about 15 miles from Utica, in the mountain valley of the Judith River, between that stream and its northern fork, Yogo Creek. The area is a rolling bench land, in which the bare white limestone surfaces are seen, with grassy hollows intervening.

Yogo Creek has cut a canyon through the bench land, and the gem-bearing dike can be traced continuously from the canyon walls across the gently descending upland down to the alluvial bottom lands of Judith River, a distance of nearly 4 miles. The limestones are the uppermost beds of the Madison group; they form the limestone series on the top of the mountain, and are 1800 feet thick. The beds are very gently inclined to the east where cut by the dike, but elsewhere in the immediate neighborhood show small wrinklings and folding; they are the minor crumplings of the broad basin or trough inclosed on three sides by the abruptly arched beds in the neighboring summits. The red earths and sandstones that overlie the massive limestones are seen along the eastern course of the dip.

The Yogo Sapphire mines.

The dike rock is nowhere seen actually outcropping at the surface, but the course of the fissure can be traced by a grassy depression in the bare limestone surface, which is dotted with badger and gopher heapings. One of the heapings yielded several hundred carats of gems and was the direct cause of the discovery of the dike. The direction of the dike varies slightly from a straight line, but the average course is S. 56° W. magnetic. It is from 3 to 13 feet wide. A parallel dike of nearly similar rock has been found 600 feet to the north, but the rock is not gem bearing. The workings consist of open cuts and a shaft that was 50 feet deep in September, 1897. The cut shows that the dike walls are nearly vertical, and expose the rough ends of the limestone beds, which seem to be the same on both sides of the fissure.

The upper part of the dike has been decomposed by atmospheric weathering and changed for a depth of 10 to 40 feet below the surface to a yellowish-colored, soft, friable, earthy material. This contains frequent bowlders or angular fragments of limestone, evidently torn from the fissure walls, which are more or less altered but are generally hard and firm. In many places the upper part of the dike is seen to consist of a breccia composed largely of such limestone fragments held in a cement of altered dike rock. This is especially marked where the dike fissure pinches out or ends abruptly, as is seen in the limestones forming the walls of Yogo Canyon. It is evident that the dike did not reach the surface and overflow as a lava stream at the time of its formation.

The unweathered sapphire-bearing material is a dense, dark-gray rock that might be designated a mica-trap. Bowlders of it are found in the weathered matter, and it forms the solid material of the dike in the shaft at a depth of 50 feet. The rock is fissured and checked with a coarse network of calcite films, and shows a pipe or seam of blue clay running irregularly through it. The gems occur in this rock and the blue clay and in the earthy material derived from them, but are not found in the limestone fragments or in clays derived from them.

This unaltered dike rock is of undoubted igneous origin. It is of dense texture and glistens with innumerable minute specks of mica. Small tablets of brown mica are the only visible crystals, but white and pale-green inclusions are very abundant. These inclusions are angular, of various shapes, and of all sizes up to 3 inches across. They consist of white calcite, vitreous quartz, and green pyroxene, and undoubtedly represent altered fragments of the sedimentary rocks carried up in the molten mass at the time the dike was formed. Studied in thin section under the microscope, the rock is seen to consist of biotite-mica and pyroxene of diopside habit. Both minerals rarely show crystal outlines, but are mostly in irregular grains closely crowded together. No feldspar is seen. The rock is, therefore, a lamprophyre, but is unlike any rock yet named, though it closely resembles a monchiquite.

The sapphires are embedded in this trap rock and the blue clay or rusty decomposition products derived from it. The stones are mostly small transparent masses which commonly show distinct crystal forms. Their surface is always pitted or corroded, and sometimes coated with a thin blackish crust. In the unaltered rock and blue clay the crystals are unbroken, but in the weathered material the stones are often fractured, and break into fragments on washing. The common form of crystals is a thin, flat tablet with polygonal, generally six-sided, outline. The top and bottom surfaces usually show a triangle raised above the surface. Stout rhombohedral forms occur more rarely and constitute the most valuable stones. The crystals are usually small, and stones cutting over a carat in weight are not common. The largest cut stone seen weighed 3 carats. The Yogo sapphires derive their greatest value from their rich blue color. Some of the crystals show dichroism, being green by light transmitted transverse to the crystal. Stones of amethystine and red tints are rare.

Mode of occurrence of the gems.

Careful search of the washed material failed to show the presence of any mineral but pyrite and sapphire. The former occurs in irregular aggregates, rarely over an eighth of an inch across, and so far as known it is valueless. Corundum is reported to have been found in sinking the shaft to a depth of 100 feet.

The mode of occurrence and the crystalline form of the sapphires show that the gems originated in the dike while the rock was still in a molten condition. The character of the rock and the presence of abundant inclusions of altered sedimentary rocks indicate that the sapphires developed by the action of the molten magma upon fragments of clay shale torn from the fissure walls at a great depth below the present surface, and that the sapphires floated upward as the moving fluid filled the fissure.

Origin of the sapphires.

The yield of the mines has not thus far been very large, as only a small force of men has been employed. Eight men were at work in September, 1897, and 40 cubic yards of earth a day were washed. The yield is from 60 to 75 carats per cubic yard. With a single exception, all the claims belong to one company, whose output is guaranteed to be sent to London. The stones are paid for by weight. They range in value from $2 to $15 per carat, according to weight, color, and purity. The average price is $6 per carat for selected stones, $1.25 per carat for seconds, and 25 cents per carat for the "culls," which are used for watch jewels.

In 1897 the mines were worked by open cuts, from which the gem material was taken out with pick and shovel, hoisted in buckets, and carted a quarter of a mile to be washed in sluice boxes. The washing is like that of gold-bearing gravels. In the sluice boxes the soft, earthy material is loosened and the gems drop between the riffles, while the limestone fragments and kernels of unaltered trap are swept on and accumulate on the dump. Lumps of clay containing gems, especially blue clay, often escape disintegration in this treatment, but after exposure to the weather for a few months this material is rewashed and the stones are recovered. With the increase of depth the proportion of blue clay will increase, and some better mode of treatment will be demanded. The material caught in the riffles is collected each day and carefully panned by hand. The concentrates thus obtained consist of irregular grains of pyrite and the sapphire crystals, the latter being then picked out by hand. As the dike is sapphire bearing for its entire length, there is a very large amount of the soft, decomposed material available for washing.

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