DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER 78

GEOLOGY AND ORE DEPOSITS

OF THE

PHILIPSBURG QUADRANGLE MONTANA

BY

WILLIAM HARVEY EMMONS

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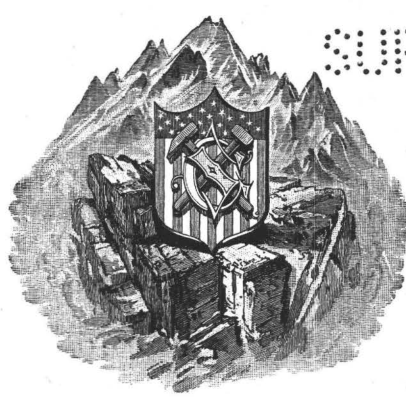

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By William Harvey Emmons and Frank Cathcart Calkins.

CHAPTER I.

INTRODUCTION.

GEOGRAPHY.

POSITION, AREA, AND OROGRAPHIC RELATIONS.

The Philipsburg quadrangle is bounded by parallels 46° and 46° 30′ and meridians 113° and 113° 30′. Its length from north to south is 34.5 miles, its average width east and west

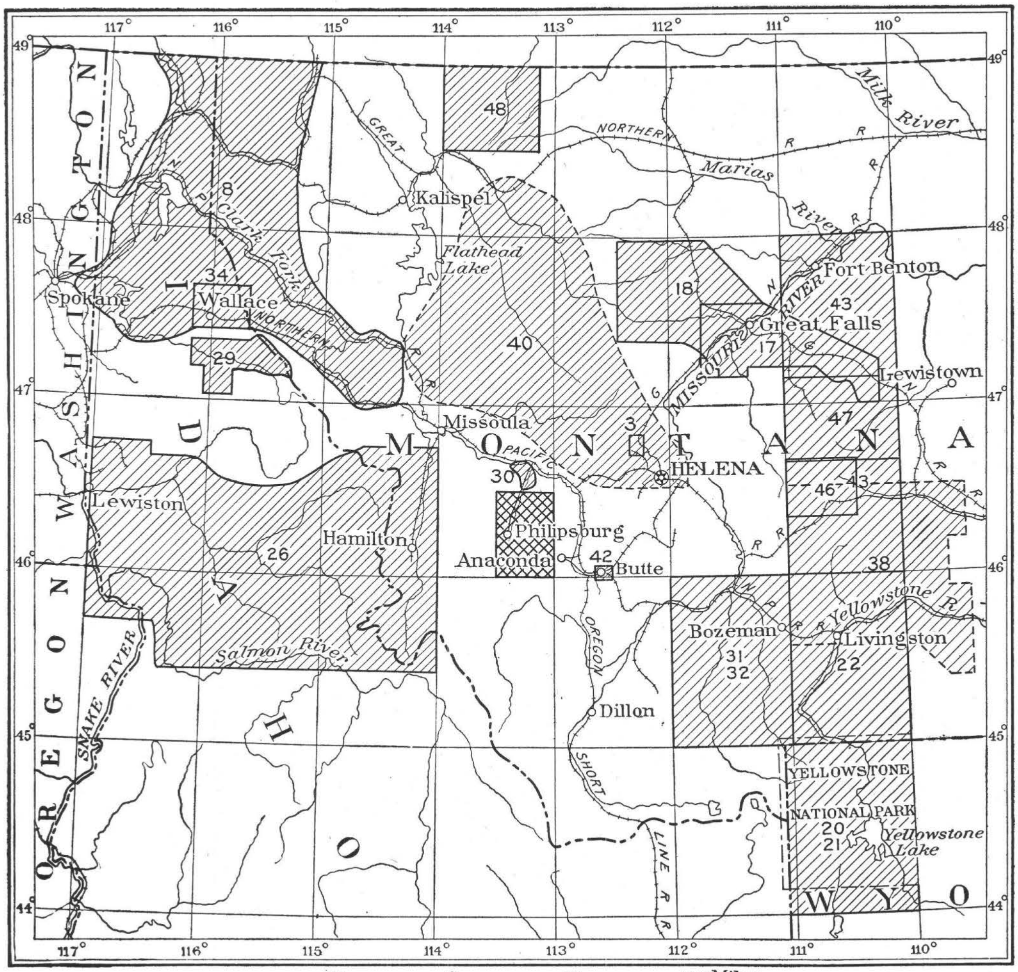


Figure 1.—Index map showing location of the Philipsburg quadrangle and of the principal areas in the same region previously studied. Numbers refer to titles in the bibliography (pp. 24–26).

23.8 miles, and its area 827.42 square miles. As shown on the index map (fig. 1), it is not far from the western border of Montana and nearly midway between the northern and southern boundaries of the State. The nearest large town is Anaconda, the site of the great smelter of the Amalgamated Copper Co., which is on Warm Spring Creek, a mile or two beyond the eastern boundary of the quadrangle.

Philipsburg lies about midway between the eastern and western limits of the Rocky Mountain system, if the term be used in the broad sense prevailing in the United States. In the general latitude of Montana the system as defined by American usage is bounded on the west by the Columbia River basalt plain and on the east by the Great Plains. The western limit is fairly definite, but on the east there is no very definite line between the plains and mountains; the mountains are fairly continuous west and north of the Philipsburg quadrangle, but to the east and southeast mountains alternate with broad stretches of semiarid lowland. The quadrangle therefore overlaps the line between two physiographic provinces, one characterized by isolated mountain groups, of which the Flint Creek Range is the most westerly, and the other by more continuous elevations, of which the Sapphire Mountains are an example.

TOPOGRAPHY.

RELIEF.

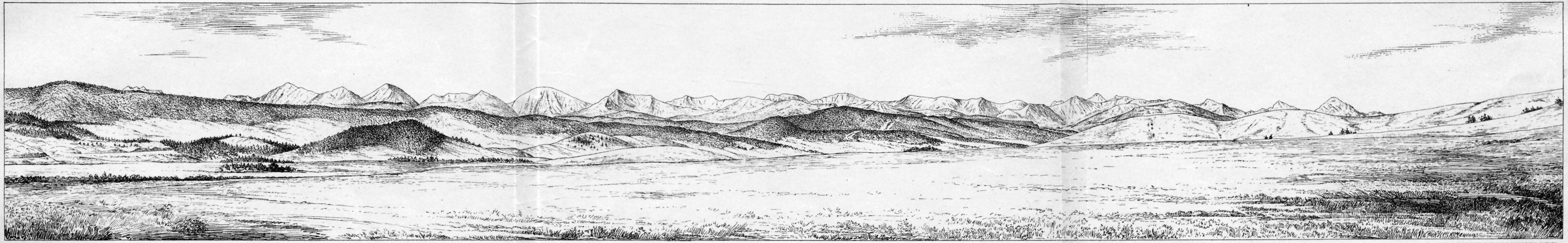
The Philipsburg quadrangle is an area of strong relief, ranging in elevation from about 4,500 to about 10,500 feet. It comprises a number of large topographic features which must frequently be mentioned in the discussion of the geology, and as unfortunately many of these are without names that are in general use appropriate names have here been provided.

The position of these features may most conveniently be indicated by stating their relation to the valley on whose eastern border the town of Philipsburg lies. This valley, which trends north-south near Philipsburg and northeast-southwest in the southern part of the quadrangle, is overlooked on both sides by rather gentle slopes. Its average width is between 2 and 3 miles, and its length, from the East Fork of Rock Creek to the entrance of the gorge through which it drains, about 16 miles. Although it is sometimes called the upper Flint Creek valley, the name is inappropriate because the valley is occupied only in part by Flint Creek, and for about half its length by Trout Creek. The name Philipsburg Valley is therefore proposed to designate the well-defined depression here described without including any other portions of the drainage basin of Flint Creek.

From the northern end of the valley, at a point about 3½ miles north of Philipsburg, Flint Creek flows in a relatively narrow, steep-walled canyon almost to the northern boundary of the quadrangle, near which it enters a second basin-like depression even broader than that in which Philipsburg is situated. The southern limit of the valley in the ordinary geographical sense must be considered as formed by the escarpment which leads abruptly down to the East Fork of Rock Creek, but in a physiographic sense the valley is really continued by the broad terrace southwest of that stream.

Philipsburg Valley and Flint Creek canyon together constitute a natural boundary between large mountain groups, and the quadrangle is partly traversed by a similar boundary of equal importance. This is the depression occupied by Georgetown and Silver lakes and by a part of Warm Spring Creek, which opens into Clark Fork valley (Deer Lodge Valley) at Anaconda. Its total length is more than 20 miles. East of the western extremity of the basin of Georgetown Lake it is a well-defined valley, considerably broader than those that open into it. Its extension west of Georgetown basin may be considered as formed by the uppermost part of the drainage basin of Trout Creek. A convenient name for this depression is Silver Lake Valley.

Within the quadrangle lie parts of three mountain masses, to which the new names Anaconda Range, Flint Creek Range, and Sapphire Mountains are given. Their boundaries lie for the most part without the quadrangle, and some portions of them have never been visited by the authors of this report. For this reason the following definitions may later require revision, but it seems better to risk some errors of this kind than to postpone the assignment of names that are so obviously needed.



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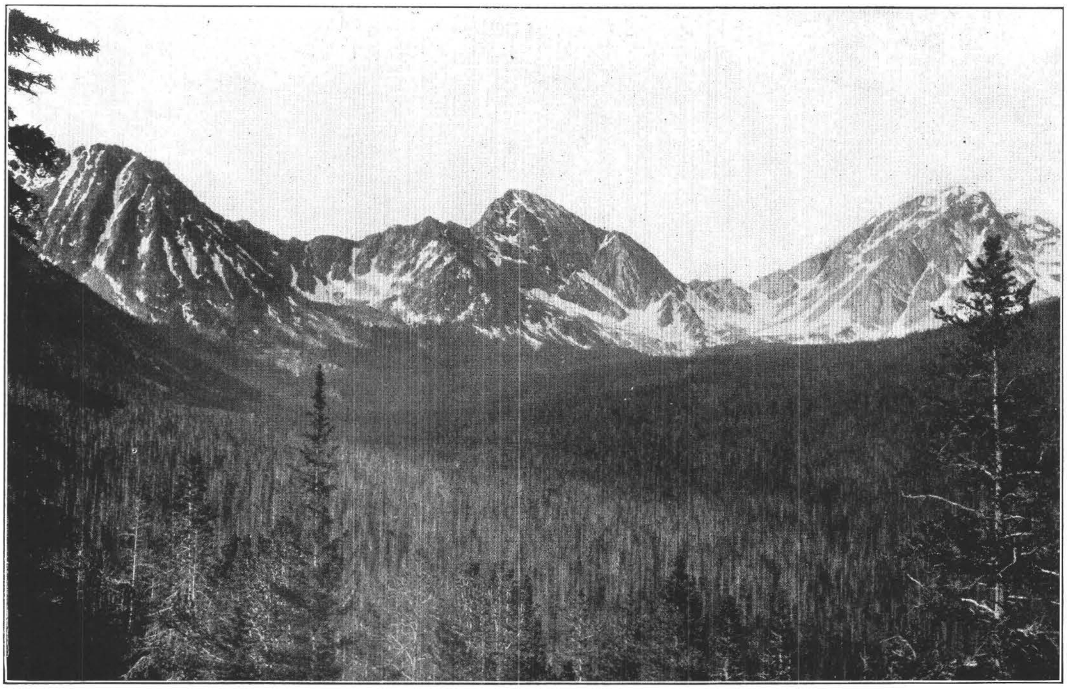
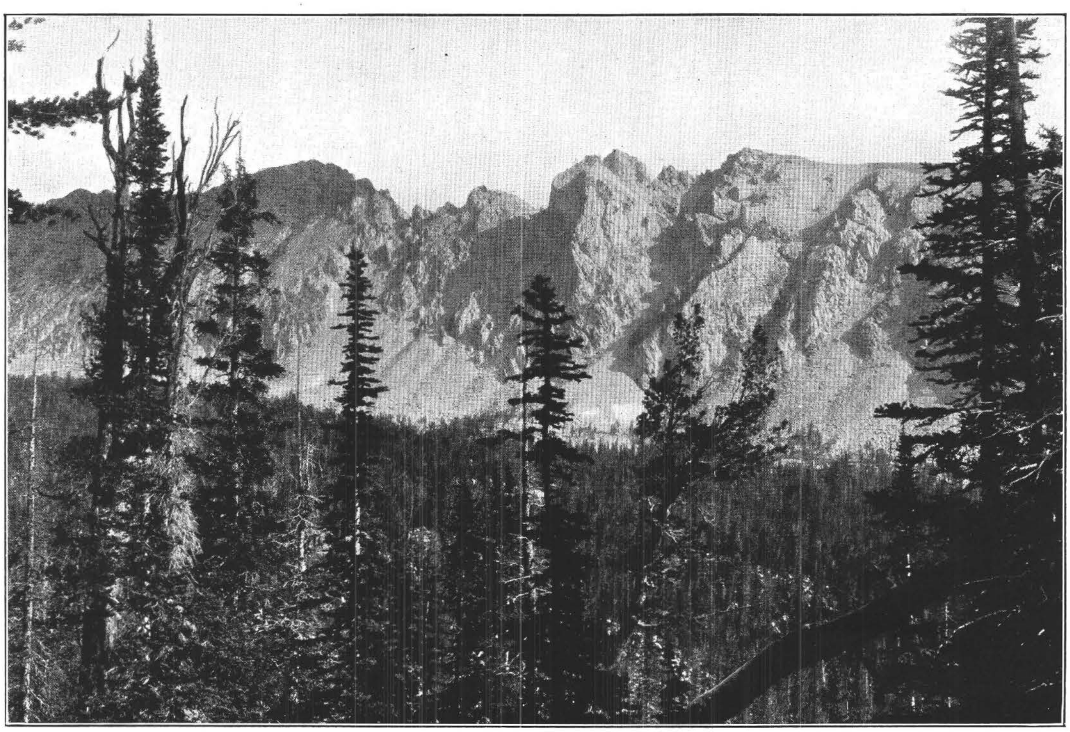
ANACONDA RANGE, MONTANA



A. EXTREME WESTERN PART OF ANACONDA RANGE.

Shows glacial cirques opening into broad glaciated valley and bold sculpture in metamorphosed calcareous rocks of Newland formation forming Mount Warren (at the right). Looking south.



B. UPPER VALLEY OF TENMILE CREEK.

Shows characteristic weathering of sheared granodiorite (in center), dark tone of Prichard rocks (on crest at left), and junction of remarkably broad, flat bottom with precipitous wall of glaciated valley. Looking northeast.

The Flint Creek Range, which occupies the northeastern part of the quadrangle, is named after the stream that drains its greater part. Its limits are sharply defined. It is bounded on the west by Philipsburg Valley and the canyon and valley occupied by Flint Creek north of that depression, on the south by Silver Lake Valley, and on the north and east by Clark Fork valley.[1] That part of Clark Fork valley which has been known as Deer Lodge Valley is one of the largest and most typical of the intermontane valleys of Montana.

The Anaconda Range, named for the town which lies at its eastern base, is formed by the Continental Divide and the slopes descending from it toward the north and south. Its eastern end is at Deer Lodge Pass, and from that point it extends westward and southwestward to a point a short distance west of Mount Warren. The northern base of the range coincides with Silver Lake Valley along the entire length of that depression. The Anaconda Range is in general higher than the Sapphire Mountains, to be defined presently, which adjoin it on the west, and the boundary between these two orographic units is of the same character, though not so distinct, as that between the rugged and lofty Bitterroot Range and the lower plateau-like Clearwater Range, these terms being used in the sense given by Lindgren.[2] The southern base of the range adjoins the broad hollow locally known as the Big Hole, which is drained by the Wisdom or Bighole River.

The Sapphire Mountains, which form an extensive and sparsely settled tract of rough and forested territory, are named from a small mining camp where sapphires are washed from placer deposits, probably the most important settlement within their limits. Their southern boundary is rather indefinite. The mountains abut against the western limit of the Anaconda Range and narrow gradually. Their western and northern limits, which are well defined, are formed, respectively, by the valleys of Bitterroot River and Clark Fork (Hellgate River). On the east the most logical boundary seems to be that formed by Philipsburg Valley and the canyon and lower valley of Flint Creek. Rock Creek flows in a somewhat diagonal course through the entire length of the group and may be regarded as cutting it into two major subdivisions, but inasmuch as most of its valley is a narrow and steep-walled canyon its importance as a boundary is hardly equal to that of the broader depressions already mentioned as delimiting the principal mountain masses.

Each of the three ranges defined in the preceding paragraphs has a distinct topographic character. The Sapphire Mountains, viewed broadly, have the aspect of a somewhat maturely dissected plateau, as is typically shown in the hills southwest of Philipsburg. The portion seen by the writers of this report includes no prominent summits, and few points in the range rise higher than 8,500 feet. The Anaconda Range, or at least that part of it extending from Mount Haggin at the east to Mount Warren (about 3 miles southwest of Carp Lake and a little outside the quadrangle) at the west, has a ruggedness and diversity of relief in marked contrast to the relatively monotonous expanse of the Sapphire Mountains. Its lofty serrate crest closes the vista southward from Philipsburg (Pl. III), and from most commanding points within the quadrangle it presents a strikingly rugged sky line. It has the picturesque scenery of a strongly glaciated range; the streams that drain it rise in broad amphitheaters that have steep, rocky walls and flat bottoms, in which lakes and meadows alternate with stretches of open park-like wood (Pl. IV, *A*). The range includes many peaks that are over 10,000 feet high, the most lofty being Mount Evans (10,630 feet) and the next Mount Haggin. The Flint Creek Range is intermediate in character and elevation between the Sapphire Mountains and the Anaconda Range. Many of its peaks and ridge tops lie near a gently warped surface that stands between 8,000 and 9,000 feet in height, but it has no definite crest, and from no point does it present a deeply indented sky line. The most rugged portion of the range lies northeast of the trench occupied by Boulder and Racetrack creeks, and its highest summit, Mount Powell, 10,145 feet high, is a little east of the quadrangle boundary. It resembles the Anaconda Range in that its

[1] The United States Geographic Board has recommended the extension of the term Clark Fork of the Columbia to the streams long known to the inhabitants of the region as Missoula River, Hellgate River, Deer Lodge River, and Silver Bow Creek.

[2] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904.

higher peaks are flanked by ice-carved amphitheaters, but these are of less ample dimensions than those in the loftier range to the south.

DRAINAGE.

The Continental Divide, following the crest of the Anaconda Range, crosses the Philipsburg quadrangle near its southern margin. A small area in the southeastern part of the quadrangle ultimately drains into the Atlantic Ocean, for the waters that run from the southern slope of the Anaconda Range reach Bighole River, which is tributary to the Jefferson Fork of the Missouri. Most of the quadrangle is in the drainage basin of the Clark Fork of Columbia River.

The greater part of the quadrangle is abundantly watered by streams, although in the hilly tract north and west of Philipsburg Valley only the two Willow creeks and Smart Creek maintain perennially a considerable flow. Most of the lakes of the quadrangle are the small tarns that generally abound in mountain regions where intense alpine glaciation has occurred, and lie in the high amphitheaters. Three larger bodies of water, Georgetown Lake, Silver Lake, and Echo Lake, all near the center of the quadrangle, owe their origin primarily to the damming of old valleys by deposits laid down by the larger glaciers. Silver Lake has been deepened by constructing an artificial dam along its western shore.

Not many years ago the floor of the basin where Georgetown Lake now lies was a marsh through which Flint Creek slowly meandered until it plunged at the north into a rocky gorge, whose fall in about 1½ miles is nearly 700 feet. The exceptional opportunity for power development here offered seems first to have been recognized by the late Mr. Paul Fusz. He and his associates in the exploitation of the Granite-Bimetallic mines constructed at the head of the gorge a small dam behind which a lake, now about 6 square miles in area, gradually formed. From this reservoir the water is conducted by a flume to a power plant at the lower end of the gorge, from which the energy developed by its fall is transmitted in the form of electricity to Anaconda.

The lake should be called artificial only with a qualification, for those who made it did nothing more than to repair an ancient natural reservoir, in whose walls the overflowing water had made a breach through which at last almost all of it escaped. The dam which first ponded the water in this hollow and caused it to rise so high that it overflowed the lowest point in its rim was of ice flowing from the summit of the Anaconda Range, but after the ice retreated the moraines left by it probably formed the dam of a shallower lake that existed for a considerable period before it was drained by the deepening of the outlet.

Among the other water resources of the quadrangle are a few exceptionally large limestone springs. The greatest of these issued from a point near the eastern edge of Georgetown Flat, but is now covered by the lake. Another spring of great volume rises at the margin of the basin, about 1½ miles west of Silver Lake, where the country rock is limestone. It is at the mouth of a small gulch whose catchment is only a small fraction of the copious and perennial flow from the spring. A probable source for this flow is strongly suggested by the fact that Blodgett Creek, except in times of freshet, entirely sinks about 2 miles due south of the spring. The north-south line connecting these two points is parallel to the prevailing strike of the country rock, and it is a reasonable supposition that the sink and the spring are connected by a subterranean channel dissolved out along the bedding of the limestones. Two other large springs issue from limestones in the basin of Meadow Creek. The water of all these springs is cold, which proves that it is not derived from a very deep source.

CLIMATE.

The temperature of this region is generally low and is marked by wide seasonal and daily variations. In winter the mercury frequently falls as low as 30° below zero. In summer many of the days are fairly hot, but owing to the dryness and lightness of the mountain air the temperature is always relatively low in the shade and drops very suddenly at nightfall. The precipitation is not abundant, and the greater part falls as snow during the winter. The distinction between the wet and the dry season, however, is not so marked here as it is in regions farther west, and occasional showers may be expected in the summer. Near mid-September or a little earlier a brief period of stormy weather usually brings the first snow, some part of which remains on the higher mountains, but these "equinoctial storms" are generally succeeded by several weeks of fair weather, and October is usually the pleasantest month of the year. Toward the close of October occasional snowstorms may descend even to the valleys, and in November the country may be mantled in snow. In the winter there are usually some heavy snows, which partly melt in the warm chinook winds that occasionally blow from the west. The inhabitants generally believe that for many years the winters have been growing milder and the summers less dry.[1]

VEGETATION.

The lower slopes and broad valleys are without trees or are but sparsely wooded, and the same is true of the mountain slopes above the 9,000-foot contour. (See Pl. IV.) Between these treeless zones there is a fairly continuous cover of rather open forest, in which the principal species is the lodgepole pine but which comprises various kinds of fir, spruce, and tamarack. The open spaces below the timber are thickly carpeted with grass which provides good pasturage for domestic animals, and on the gentler slopes above the timber there is good grazing for the few remaining bands of mountain goats.

INDUSTRIES, SETTLEMENTS, AND ROUTES OF TRAVEL.

The wealth of the Philipsburg district lies chiefly in its deposits of silver and gold ore, and mining is by far its most important industry. Agriculture is the only industry that is independent of mining, to which the lumbering and wood-cutting done is essentially tributary.

The agricultural activity consists mainly in the raising of live stock. Small herds of horses and cattle are grazed on the hills and considerable hay is grown in the valleys. Until recently no grain but rye was grown, but during the last few years it has been found possible to raise hardy varieties of oats and wheat. The climate is too cold for fruit growing, but a small farm on Boulder Creek produces the hardier vegetables with good success.

Except for the valley lands and sparsely timbered hills southwest, west, and north of Philipsburg, most of the quadrangle is included in the Hellgate National Forest. The timber and grazing resources are therefore, in a measure, protected by the Forest Service from loss by fire or wasteful exploitation. Most of the timber cut is bought from the Government. Some is used for domestic purposes, but the greater part is used for mine timbers and fuel by the mines.

Philipsburg, whose site was determined by its convenience as a receiving and distributing point for the mines of the Flint Creek district, is the most important town of the quadrangle, and is accredited by the census of 1910 with a population of 1,109. It is pleasantly situated and well laid out, and has several churches, a substantial public-school building, waterworks, an electric-light plant, telephone exchanges, and other urban conveniences. As it is the terminus of the railway and a convenient trading place for most of the farming population, Philipsburg has suffered much less from the decline of mining activity than Granite, Princeton, Rumsey, Georgetown, and Combination, which were dependent for their existence on the prosperity of certain mines and are now almost deserted.

Nearly all the commerce of the district passes through either Philipsburg or Anaconda, The area drained by Flint Creek and its tributaries south of Stone, as well as a considerable but sparsely settled tract to the west, is tributary to Philipsburg; the inhabitants of Cable and of the area south and east of it, however, trade chiefly in Anaconda. The only post offices in the quadrangle are Philipsburg, Flint, Princeton, and Cable.

Philipsburg is connected with the transcontinental route of the Northern Pacific Railway by a spur 26 miles long, which joins the main line at Drummond. Anaconda lies only a short distance from the Northern Pacific Railway and is connected with Butte by the Butte, Ana-

[1] Pardee, J. T., oral communication.

conda & Pacific Railway. The extension of this line, which enters the quadrangle from the southeast, is used mainly for hauling limestone from the quarry at its terminus. This road has recently been extended to the mines near Georgetown.

The quadrangle is well provided with wagon roads. Most of those shown on the map as of the first class are of easy grade, but not all of them are well surfaced. Secondary roads and a number of trails render most portions of the quadrangle fairly accessible, considering its strong relief.

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Little has been published dealing particularly with the geology and ore deposits of the Philipsburg district beyond some brief geologic notes in papers devoted mainly to mining and a few cursory references contained in articles devoted chiefly to neighboring regions. The more important publications relating to other portions of western Montana whose geology is similar in some respects to that of the Philipsburg quadrangle are cited below. The mining industry of this once richly productive district has received more attention than the geology and forms the subject of several valuable papers.

[The areas considered in the principal papers listed are shown on the map (fig. 1, p. 19) by shading, the numbers there given corresponding to certain of the numbers prefixed below.]

1. Akers, W. A.; see Goodale and Akers.

2. Bancroft, H. H., History of Montana. 1890.
Gives perhaps the best account of the early history of Montana from 1728 to 1889. The discovery of gold, the first attempts to work the quartz mines, the routes of transportation, the building of railroads, the political and judicial organization of the State, and the development of its stock-raising and mining industries are treated in a comprehensive manner.

3. Barrell, Joseph, Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907.
Discusses briefly the relations of Butte, Elkhorn, Unionville, Granite, and other mining camps of Montana to the Boulder batholith and outlying areas of related igneous rocks.

4. Bohm, W. D., The Cable Mountain gold mining district of Montana: Min. Mag., May, 1906, p. 373.
Describes the Cable and Southern Cross mines and other mines near Cable Mountain, and gives considerable information relating to the early history of the camp.

5. Brinsmade, R. B., A wet silver mill: Mines and Minerals, vol. 26, June, 1906, p. 492.
Gives an excellent description of the mill of the Combination Mining & Milling Co. and the methods of treatment there, with brief notes on the geology and ore deposits.

6. Brown, R. G., The Georgetown mining district, Mont.: Eng. and Min. Jour., vol. 58, 1894, p. 345.
Gives notes on the geology of Warm Spring Valley between Anaconda and Georgetown and describes briefly the Pyrenees vein and neighboring deposits.

7. Calkins, F. C.; see Ransome and Calkins.

8. Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: Bull. U. S. Geol. Survey No. 384, 1909.
Describes briefly the geology of the region west, north, and east of the Cœur d'Alene district. The sedimentaries are chiefly of the Algonkian Belt series, but comprise some of Paleozoic and possibly some of Archean age.

9. Douglass, Earl, Fossil Mammalia of the White River beds of Montana: Trans. Am. Philos. Soc., n. s., vol. 20, 1902, p. 237.
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11. ——— A geological reconnaissance in North Dakota, Montana, and Idaho, with notes on the Mesozoic and Cenozoic geology: Annals Carnegie Mus., vol. 5, 1908–9, pp. 211–288.
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12. Eaton, A. K., Notes on Montana: Mineral resources of the States and Territories west of the Rocky Mountains, 1869, p. 146.
Notes on the Atlantic Cable mine and the Hope mill.

13. Emmons, W. H., The Granite-Bimetallic and Cable mines, Philipsburg quadrangle, Mont.: Bull. U. S. Geol. Survey No. 315, 1907, pp. 31–56.

14. ENGINEERING AND MINING JOURNAL, vol. 44, 1887, p. 430. The Granite Mountain Mining Co.
An abstract of the annual report of this mining company for the year ending July 31, 1887. Gives many interesting data regarding the discovery, development, and production of this mine, with a composite map of the mine levels and a section along the vein. A table shows the details of milling costs.

15. ——— vol. 48, 1889, p. 450. The Granite Mountain Mining Co.
An abstract of a report of the president of the company to the stockholders for the fiscal year ending July 31, 1889. Gives a detailed account of the operations of the company for the fiscal year with a composite level map and a longitudinal section of the mine.

16. EXECUTIVE DOCUMENTS, House of Representatives, Second Session of Forty-first Congress, 1870, Condition of mining industry, 1870, p. 265.
A résumé of the development of placer and quartz mines and of the mills operating in Deer Lodge County, Mont.

17. FISHER, C. A., Geology of the Great Falls coal field, Mont.: Bull. U. S. Geol. Survey No. 356, 1909.
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33. PIRSSON, L. V.; see Weed and Pirsson.

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Gives petrographic descriptions and chemical analyses of intrusive rocks which somewhat resemble those of the Philipsburg batholith.

45. ——— See also Iddings and Weed.

46. WEED, W. H., AND PIRSSON, L. V., Geology of the Castle Mountain mining district, Mont.: Bull. U. S. Geol. Survey No. 139, 1896.

Describes the Algonkian, Paleozoic, Mesozoic, and Tertiary sedimentary and igneous rocks.

47. ——— Geology of the Little Belt Mountains, Mont.: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 271–461.

Describes a section of pre-Cambrian and Paleozoic sediments somewhat similar to that of the Philipsburg district.

48. WILLIS, BAILEY, Stratigraphy and structure, Lewis and Livingston ranges: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305–352.

Gives a detailed account of the character and thickness of several pre-Cambrian formations as developed near the northern boundary of Montana. Describes the great overthrust at the east base of the Rockies in this region.

49. WINCHELL, A. N., Metal production of Montana for 1905: Mineral Resources U. S. for 1905, U. S. Geol. Survey, p. 242.

Detailed notes on the condition of mines in the Philipsburg quadrangle.

BASIS OF THE PRESENT REPORT.

FIELD WORK.

The contour map which has served as a base for the plotting of the geology was made in 1905. The triangulation was done by H. L. Baldwin, jr., who also was in charge of and participated in the topographic mapping, which, however, was done chiefly by J. E. Blackburn, with the assistance of J. Gussenhoven, L. Morrison, and J. E. Tichenor.

The field study of the general geology was done in 1906, 1907, and 1908 under the direction of F. C. Calkins, to whom, during the first two field seasons and the intervening period, D. F. MacDonald rendered invaluable assistance. In both these seasons Mr. MacDonald began the field work and collected in large part the materials for the chapters on general geology. During the field season of 1907 W. E. Wrather rendered efficient aid.

The ore deposits were investigated by W. H. Emmons, this investigation occupying the time from the end of July, 1906, to the middle of January, 1907, and the month of September, 1907.

In 1908 J. T. Pardee assisted for about two weeks in the areal mapping. His contribution, however, has been far more considerable than this statement implies. The report has greatly profited by many observations made by him as an amateur student of the geology of the region. His observations relate chiefly to the Tertiary and Quaternary deposits and physiographic features, although he made, in 1892, a topographic and geologic map (not published) of the area about Philipsburg. Aid in the correlation of the Cretaceous and Tertiary formations was also derived from the results of work done by him in 1910 in land classification.

AUTHORSHIP.

Both authors have contributed in about equal measure to the introduction. Chapters II to IX, which deal principally with the geology, were written by Mr. Calkins. Chapter X, on the mineralogy of the district, was written jointly, the notes on the valuable minerals being wholly by Mr. Emmons, and those on the nonvaluable minerals chiefly by Mr. Calkins, although those relating to occurrences connected with ore deposits are by Mr. Emmons. The remaining chapters, which deal with ore deposits and mining development, and in which are given descriptions of the mines, are by Mr. Emmons.

ACKNOWLEDGMENTS.

During the progress of the field work both authors have become indebted to many persons for courtesies which have facilitated their task. It would be impossible to mention here by name all those who have deserved gratitude by thus indirectly aiding in the preparation of this report, but especial indebtedness should be acknowledged to Mr. Paul A. Fusz, Mr. C. D. McClure, Mr. J. R. Lucas, and their associates in the management of the Granite-Bimetallic mine; to the Messrs. Bacorn, Mr. Henry Morse, and Mr. C. J. Adami, of the Cable; and to Mr. Lucian Eaves, of the Southern Cross. The courtesy of the officers of all the mines has made the field work more agreeable, and the maps and records, in most cases carefully kept, have made it more effective than it would otherwise have been.

In the office the authors have had the advantages of consultation with those whose duty it was to supervise their work, and of the interchange of ideas with colleagues on subjects of common interest. Especial acknowledgment is due to the helpful suggestions and valuable criticisms of S. F. Emmons and Waldemar Lindgren. In the correlation of the sedimentary formations Charles D. Walcott, Secretary of the Smithsonian Institution, and Messrs. Stanton, Girty, Kindle, and Ulrich, paleontologists of the Survey, have rendered indispensable aid. Thanks are due to W. F. Hillebrand and George Steiger for five careful and detailed analyses of rocks, to W. T. Schaller for several partial analyses, and to Messrs. Hillebrand and Schaller for a number of mineral determinations.

CHAPTER II.

PRELIMINARY SKETCH OF THE GEOLOGY.

GEOLOGIC RELATIONS OF THE QUADRANGLE TO NEIGHBORING REGIONS.

The Philipsburg quadrangle lies on a frontier with respect not only to its topographic but to its geologic relations, for the physiographic differences of the mountains on the north and west from those on the southeast depend in large measure upon differences in geologic structure. The relatively continuous mountains on the north and west are carved from thick and comparatively homogeneous accumulations of Algonkian sediments and large masses of intrusive rock. The isolated groups on the south and east are geologically far more complex, but are similar in the broader features of stratigraphy. Typically they have cores of Archean foliates, Algonkian or Paleozoic sediments or intrusive rocks, and marginal slopes of younger sedimentary or volcanic rocks. The Philipsburg quadrangle is the most western district to display with approximate completeness the remarkably comprehensive stratigraphic sequence typical of west-central Montana.

The most obvious reason for the difference in the geology of the two provinces overlapped by the Philipsburg quadrangle is that the deformation of one has differed in character from the deformation of the other. In the region of isolated ranges the average depth and height of synclines has been greater than in the region to the west and north; in other words, what might be called the "structural relief," which would be expressed by structure contours, is greater in the one region than in the other.

Another reason for the differences in the areal geology of the two regions is that the algebraic sum of depression and elevation is greater in the territory occupied mainly by Algonkian rocks than in that occupied largely by post-Algonkian rocks. The most effective single cause of this greater relief is probably a dislocation that is among the most important known on this continent—the Lewis overthrust, first recognized and named by Willis.[1] Near the international boundary the east base of the main Rocky Mountains is sharply defined by the Lewis overthrust, which has brought Algonkian rocks upon those of Cretaceous age. No attempt has yet been made to follow this fault continuously southward to its disappearance. The fragmentary evidence at hand, however, indicates that its southerly continuation is to be found in a fault or fault-zone that extends from the center of the north boundary to the southwest corner of the Philipsburg quadrangle, and passes just west of the town of Philipsburg. West of this fault, in the Philipsburg quadrangle, the pre-Tertiary sedimentary rocks are all Algonkian; east of it they range from early Algonkian to late Cretaceous. If the course of the Lewis overthrust is as here supposed, it must be at least roughly true that the Lewis thrust delimits the two great geologic and physiographic provinces of western Montana.

Deformation, then, accounts for much of the difference between the two provinces. To suppose, however, that it accounts for all the difference is to suppose that both provinces were covered with a similar series of post-Algonkian sedimentary rocks, and that this series was removed almost completely from the region that was on the whole more elevated, but much less completely removed from the region that was on the whole less elevated. This hypothesis is open to several objections.

In the first place, it implies an enormous amount of Tertiary and post-Tertiary erosion. Undoubtedly many thousands of feet of rock ranging from Algonkian to Tertiary have been removed from certain uplifted areas in western Montana; probably 20,000 feet have been removed from parts of the Anaconda Range. Nevertheless, it is obvious that in a given time erosion

[1] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305–352.

could remove a far thicker layer from the steep slopes of a small isolated uplift or the margin of a large one than from an uplift as vast as the area now occupied almost continuously by the Algonkian rocks.

The presumption thus raised against the hypothesis is confirmed by certain observed facts. First, the radical difference between the pre-Tertiary stratigraphy of the eastern Rockies and that of the Blue Mountains in Oregon and the northern part of the Cascade Range in Washington indicates the existence of a barrier between the two regions during a great part of geologic time. Second, as observed by Willis,[1] the Carboniferous, near the international boundary, broadly overlaps the pre-Cambrian.

It is probable, therefore, that in Paleozoic and Mesozoic time the Philipsburg district was not so definitely on a geologic frontier as the present areal geology of western Montana might suggest. It was probably at times in the marginal part of areas of Paleozoic and later deposition, but its sedimentary rocks of these series are not marked, in general, by shore features, and show great similarity to their equivalents in west-central Montana as described in previously published reports. The geology of the Philipsburg quadrangle, now to be briefly outlined, is therefore typical in large measure of much of western Montana. Those phases of the geology of western Montana which are recorded obscurely or not at all in the area dealt with in this report will be but lightly touched in this outline.

OUTLINE OF THE GEOLOGY.

PRE-CAMBRIAN RECORD.

The most ancient rocks of Montana—the Archean gneisses and schists—are not exposed in the Philipsburg quadrangle. The oldest rocks of this area are of Algonkian age and belong to the Belt series, known from observations elsewhere to be separated by a profound unconformity from the Archean, from which it differs in being free from conspicuous alteration, except where it is locally affected by contact metamorphism.

This remarkable series, estimated by Walcott to have a maximum thickness of 37,000 feet,[2] consists for the most part of sandy shales; these grade, however, on the one hand into quartzites, and on the other into shaly, siliceous, and ferruginous limestones. There is a noteworthy scarcity of pure limestones on the one hand and of conglomerates on the other. The series is divisible on lithologic grounds into several thick formations, which are fairly distinct from one another on the whole, but have gradational limits. The succession shows that conditions of accumulation were fairly constant for long periods, but that at times they changed more or less rapidly. The older formations are such as might have been deposited in waters of slight or moderate depth, but some of the later ones are abundantly marked by such features as ripple marks and sun cracks, which show them to have been frequently exposed to the air. Barrell[3] concludes that these sun-cracked formations were probably accumulated on broad river flood plains where subsidence must have kept nearly even with sedimentation, while the others were deposited in sea water which was usually shallow. The present areal distribution of the Belt series, if it represents approximately the area of deposition, indicates that this was a geosyncline or trough, somewhat elongated in a north-south direction, with its axis near longitude 114° W. Its limits are not very definitely known, for it is not easy to tell whether the absence of the series in particular areas is due to its not having been deposited or to its removal after deposition. Proximity to contemporaneous land masses on either side is indicated by the presence of conglomerates west of Kootenai Valley and on the east near Neihart, Mont.[2] The apparent absence of the Belt series from the Bighorn Mountains,[4] in the Black Hills,[5] and

[1] Willis, Bailey, op. cit., p. 325.
[2] Walcott, C. D., Algonkian formations of northwestern Montana: Bull. Geol. Soc. America, vol. 17, 1906, p. 27.
[3] Barrell, Joseph, Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, 1906, p. 566.
[4] Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906.
[5] Darton, N. H., Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: Prof. Paper U. S. Geol. Survey No. 65, 1909.

in parts of the Yellowstone National Park[1] makes it probable that no great thickness of Belt rocks was ever deposited in those regions.

PALEOZOIC RECORD.

The Belt series, at the localities in western Montana where its upper limit is visible, is unconformably overlain by quartzites or sandstones containing a marine littoral fauna of early Cambrian age. It is thus proved that in late Algonkian or early Cambrian time the Belt rocks were uplifted and subjected to widespread erosion, then submerged under a moderate depth of salt water and covered with sea sands. The basal Cambrian fossils are in general older in the more easterly areas, indicating that the invasion of the sea proceeded from that direction.

The chief evidence of the unconformity at the base of the early Cambrian Flathead quartzite is the fact that it lies at different places on Algonkian beds that differ widely in stratigraphic position.[2]

In the Philipsburg quadrangle this is the case to a remarkable degree, but here there is other evidence of unconformity, more vivid and less liable to other interpretation. Cliff exposures display Cambrian quartzite lying on the beveled edges of the Algonkian with an angular discordance as great as 30° (Pl. VII, *A*, p. 50), and in one place the base of the Cambrian is a conglomerate with pebbles of the Algonkian quartzite immediately beneath.

The Paleozoic rocks of the Philipsburg quadrangle consist of a basal Cambrian quartzite, an overlying succession of alternating shales and limestones ranging in age through Cambrian, Silurian (?), Devonian, and lower Carboniferous (Mississippian), and a final layer of upper Carboniferous (Pennsylvanian) quartzite. The region was covered during most of Paleozoic time, therefore, by seas of considerable depth. Marine deposition was not absolutely continuous, however, throughout the region. It was interrupted for a considerable period between the middle of the Cambrian and the Devonian, so that Ordovician and Silurian strata are generally wanting in western Montana. The Devonian Threeforks shale overlies the Jefferson limestone in some sections but is absent in others, and there are indications of slight unconformity at the junction of the lower and upper Carboniferous, which are very different in lithologic character. At no place, however, has any marked angular unconformity been discovered in the Paleozoic rocks of western Montana. No violent disturbances took place during their deposition, but the alternations of shale and limestone indicate changes in conditions dependent on upheaval, subsidence, or gentle tilting of the earth's crust. The more vigorous of these movements resulted in exposure of the sea bottom to erosion. A final shallowing of the sea by upheaval or sedimentation, or otherwise, is indicated by the Carboniferous quartzite at the top of the Paleozoic section.

MESOZOIC RECORD.

An upheaval of the sea bottom put an end to sedimentation in the shallow sea of late Carboniferous time. The earliest Mesozoic rocks are marine, but they are Jurassic; Triassic beds are absent, so that during this period the region was probably dry land. The Jurassic sediments, chiefly shales and impure limestones, locally comprise conglomerates containing pebbles of Carboniferous rocks, proving that these were partly exposed to erosion during Jurassic time. Moreover, they are rich in iron, as sediments might be that were washed from a continent whose rocks had long been exposed to decay but not to vigorous erosion. In the Great Falls region, Fisher[3] has observed marked angular unconformity between the Jurassic and the Carboniferous.

From early Cambrian time the sedimentation that had occurred was virtually all marine, but from the end of the period represented by the Ellis formation (Jurassic) the salt sea only intermittently covered the region. In the Philipsburg district, the marine Jurassic is succeeded by sandstones, shales, and limestones, of Lower Cretaceous (Kootenai) age. The character of these beds indicates that they were in part deposited in fresh water, but they may be in part terrestrial.

[1] Hague, Arnold, Weed, W. H., and Iddings, J. P., Yellowstone National Park folio (No. 30), Geol. Atlas U. S., U. S. Geol. Survey, 1896.
[2] Walcott, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, p. 210.
[3] Fisher, C. A., Geology of the Great Falls coal field, Mont.: Bull. U. S. Geol. Survey No. 356, 1909, p. 27.

The Upper Cretaceous beds occurring in the Philipsburg district are correlated with the marine Colorado formation. The lower part of these beds consists of black shale whose character suggests marine deposition, although it has yielded no fossils, but this shale locally contains thin beds of coal, which indicate deposition on or near a marshy shore.

The time represented by the pre-Tertiary rocks of the quadrangle was notably free from igneous activity, although vulcanism has been shown by Stone and Calvert [1] to have begun in Cretaceous time near the Crazy Mountains. The only igneous rocks in the Philipsburg quadrangle for which a pre-Tertiary age appears more than barely possible are some basic intrusives forming sills in Algonkian, Cambrian, and Cretaceous sediments.

CENOZOIC RECORD.

The pre-Tertiary rocks record the history of sedimentation occasionally interrupted by uplift, slight deformation, erosion, and resubmergence. The Tertiary and post-Tertiary record is by comparison far more complex and records a far more eventful history, involving deformation much more vigorous than any that had occurred since the beginning of the deposition of the Belt series, igneous intrusion on a large scale, volcanic activity, erosion, and deposition. These various activities went on side by side, and in any satisfactory account of the Cenozoic they must be correlated. The task of correlation offers some of the most alluring problems of Montana geology and also some of its greatest difficulties. Owing to the complexity of the problem, the imperfection of the record in the Philipsburg quadrangle, and the fact that certain aspects of the Tertiary and Quaternary geology are not essential to the main purposes of this report, the Cenozoic record, apart from deformation and intrusion, has been less thoroughly studied than that of earlier times. Nothing more can be offered here, therefore, than a very imperfect sketch, which, in regard to some aspects of the later geology, can do little more than suggest problems for future attack.

The effects of deformation are chiefly to be seen in the pre-Tertiary rocks, which have been very complexly faulted and folded, the folds involving the Cretaceous and older rocks being locally overturned or even recumbent, and some faults having throws of several thousand feet. The great unconformity between the Tertiary and pre-Tertiary rocks is partly proved by the relatively slight deformation of the Tertiary beds, which, however, have been tilted and faulted to some extent.

The principal effect of igneous activity has been the intrusion of irregular or domelike masses of magma, which have crystallized as granular rocks belonging to the diorite, granite, and intermediate families. The intrusions, so far as known, seem to have been contemporaneous with or immediately consequent upon the principal deformation. The volcanic rocks within the quadrangle include lavas, tuffs, and volcanic ash. No certain correlation has been made between the extrusive and intrusive phases, but the volcanics are apparently later than the intrusives. One of the volcanic formations consists of fine-grained, light-colored, silty beds, which occur in some of the broader basin-like depressions. Material of this kind is commonly assumed to have been deposited in lakes, but there is no definite proof that it has been so deposited in this locality. However, in a region where wide-spreading showers of volcanic ash were falling, it is almost certain that the drainage would be locally blocked and that lakes would be formed, and it is therefore inherently probable that some of this material is lacustrine.

Among the more interesting features of the land sculpture are certain remnants of old topography that stand high above the present base-level of the streams—remnants of land that have been reduced to low relief by Tertiary erosion. Among the more conspicuous of these are the tops of the hills lying west and north of Philipsburg, above which Henderson Mountain rises like a monadnock. Another is the pair of plateaus that lie north and south of Lost Creek, the surfaces of which truncate the edges of hard and much-deformed rocks which are largely concealed by a mantle of rock waste. The area about Georgetown Lake affords

[1] Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingston formation of Montana: Econ. Geology, vol. 5, 1910, pp. 552-553, 652-669, 741-764.

another example of senile topography at high level, and still another plateau-like surface about 500 feet higher appears just south of the lake. Later physiographic features, in part possibly structural, include the broader valleys like that in which Philipsburg lies.

The high mountains show vividly the erosional effects of alpine glaciers, and the contours on the topographic map (Pl. II, in pocket) indicate in a very striking manner the broad, flat-bottomed amphitheaters of the Anaconda Range. Postglacial erosion has been relatively unimportant, although in the bottoms of some of the glaciated canyons it has excavated trenches which are in places over 100 feet deep.

Those Tertiary deposits that are clearly of detrital rather than volcanic origin are chiefly stream gravels. They are strongly unconformable on the pre-Tertiary rocks and belong to several stages whose exact age is not known. Some of the earliest, which are considerably deformed, are probably Eocene. The latest Tertiary deposits are probably the gravels on terraces in the broad valleys, but it is not possible to discriminate between late Tertiary and early Quaternary gravels.

Glacial deposits of great extent and volume occur in the Flint Creek and Anaconda ranges. Later and older moraines can be very easily distinguished in places. The post-glacial deposits comprise rather extensive areas of bottom land. In part they are lacustrine, and are due to the filling in of hollows dammed by moraines.

Some attempt has been made to construct from the foregoing records of deformation, igneous activity, erosion, and deposition, a chronological account of the Tertiary and Quaternary history which forms a part of the appended tabular summary.

SUMMARY.

The table below gives, in a form convenient for reference, an outline of the geology of the Philipsburg quadrangle.

Tabular résumé of geologic history and stratigraphy of the Philipsburg quadrangle.

Period.	Epoch.	Chief geologic activities.	Geologic record.
Quaternary.	Recent.	Postglacial disintegration by frost, talus formation, stream erosion, chiefly in uplands, with deposition in lower valleys.	Slight modification of glacial sculpture and morainal deposits. Narrow trenches on bottoms of some glaciated canyons. Upper Flint Creek gorge. Alluvial deposits on bottoms of valleys. Enrichment of ores. Placers formed.
	Pleistocene.	Alpine glaciation; at least two stages, separated by an interval in which the ice withdrew. Formation on nearly all peaks 8,200 feet or more in height of alpine glaciers that flowed down the canyons to levels between 6,500 and 4,500 feet.	Sculptural record: Amphitheaters and U-shaped cross sections of high canyons. Deposits: Moraines, mainly of ill-rounded granite bowlders. Secondary effects: Formation of small lakes, of which many have been filled to form meadows, and diversions of drainage.
Tertiary.	Pliocene and Pleistocene.	Slight tilting and probably general uplift, initiating more vigorous erosion; partial removal and redistribution of earlier gravels.	Deep mountain canyons and preglacial terrace gravels. Enrichment of ores. Some placers probably formed.
		Erosion of broad valleys, and filling in of lower parts with gravel.	Deposits: Gravels of sloping terraces in valleys overlying ash-beds. Sculptural record: Elevated remnants of broad valleys with gently sloping sides. Probably enrichment of ores.
	Miocene.	Explosive eruptions whose coarser products fell near the vents, and whose finer products were widely spread by the winds. Lakes probably formed in places.	Valley deposits of pale-tinted, fine-grained volcanic ash, little deformed, which have yielded Miocene vertebrate fossils in lower Flint Creek valley. Thickness, 500 feet. Probably enrichment of ores.
	Eocene to Miocene (?).	Volcanic eruptions; vigorous erosion of uplands; stream deposition in valleys.	Gravels and andesites of Anaconda region. Old stream channels in western part of quadrangle; corresponding topographic facets on uplands, possibly represented by some of the highest plateau surfaces. Rocks considerably deformed, but not metamorphosed by intrusions. Thickness, 1,000 feet. Possibly enrichment of ores.
		Final emergence from the sea; great deformation and extensive intrusion.	Great unconformity; large masses of intrusive igneous rock cut the Cretaceous and earlier sediments, which are strongly folded, locally overturned and much faulted. Deposition of ores.

Tabular résumé of geologic history and stratigraphy of the Philipsburg quadrangle—Continued.

Period.	Epoch.	Chief geologic activities.	Geologic record.
Cretaceous.	Upper Cretaceous.	Marine deposition, probably in part along a low, marshy shore. Possibly succeeded by fresh-water deposition.	*Colorado formation.* Sandstones, 1,000 ± feet, with top removed by erosion; underlain by 500 feet of fissile black shale. A few fossil mollusks in lower part of sandstone and some fossil leaves and bone fragments higher in the section. As here mapped may include some Montana.
		Probably upheaval, followed by submergence beneath the sea.	Hiatus. Dakota sandstone absent.
	Lower Cretaceous.	Deposition in a fresh-water lake.	*Kootenai formation.* Chiefly red and green shale and sandstone. Base generally a conglomeratic sandstone with pebbles of quartzite. Siliceous buff-weathering limestone near base, and gray limestone with abundant gastropods at the top. Total thickness, 1,500 feet.
Jurassic (?).		Upheaval from sea and formation of a great lake basin.	Erosion interval. Morrison formation (late fresh-water deposits of Jurassic (?) age) apparently absent.
Jurassic.		Marine deposition.	*Ellis formation.* Calcareous shale and sandstone; thin beds of impure limestone, and, near the top, conglomerate with pebbles of chert and Jurassic fossils. Thickness, 400 feet.
		Uplift and erosion.	Unconformity indicated by absence of Triassic and by pebbles of Carboniferous rocks in conglomerate of Ellis formation. No angular discordance noted.
Carboniferous.	Pennsylvanian.	Marine deposition.	*Quadrant formation.* Quartzite member: Chiefly vitreous quartzite, generally forming two beds separated by a calcareous layer in which Pennsylvanian fossils occur. Thickness, 400 ± feet. Shale member: Red shales and thin-bedded magnesian limestones with Pennsylvanian fossils. Average thickness about 300 feet.
	Upper Mississippian (?).	Uplift and erosion (?).	Slight unconformity (?), indicated by abrupt change of lithologic character and by marked local variation in thickness of upper Madison.
	Lower Mississippian.	Marine deposition in deep water.	*Madison limestone.* Nonmagnesian limestone, upper part thick bedded, light gray and white; lower part dark-gray shaly limestone. Much chert in all but lowest part. Abundantly fossiliferous. Average thickness, about 1,200 feet.
Devonian.		Marine deposition.	*Jefferson limestone.* Magnesian limestones, thick bedded, white, gray, or black. Has yielded numerous fossils. Thickness, 1,000 feet.
Silurian (?).		Marine deposition (?) (Shallow water).	*Maywood formation.* Flaggy magnesian limestones and shale, largely red, with beds of calcareous sandstone near the base. Thickness, 200 or 300 feet. No fossils found.
		Uplift and erosion.	Unconformity? Abrupt change in lithologic character indicates change of conditions, presence of sandstones pointing to uplift of adjacent land masses. Absence of demonstrably Ordovician or Silurian strata is negative evidence of an erosion interval.
Cambrian.		Marine deposition.	*Red Lion formation.* Limestone member: Limestone with closely spaced siliceous laminæ; contains Cambrian fossils. 250 feet. Shale member: Shale, mostly coal black, intercalated with thin layers of limestone. Average thickness, 20 feet.
			Hasmark formation. Upper magnesian limestone member: Mostly cream-white, 350 feet, magnesian limestone. Shale member: Shale, banded, mostly in shades of chocolate-brown, partly with calcareous nodules and flaggy limestone; contains a few imperfect specimens of *Obolus* (?). Thickness, 10 to 150 feet. Lower magnesian limestone member: Magnesian limestone, mostly pale blue-gray. Thickness, 550 feet.
			Silver Hill formation. Dark, slightly calcareous shales, 120 feet; overlain by 120 feet of limestone with thin brown siliceous laminæ; at top 90 feet of shales and laminated limestones. Average thickness, 400 feet.
			Flathead quartzite. Vitreous quartzite, with local basal conglomerate. Thickness, 5 to 250 feet.
	Early Cambrian (?).	Warping and erosion.	Unconformity, involving angular discordance up to 30°.

Tabular résumé of geologic history and stratigraphy of the Philipsburg quadrangle—Continued.

Period.	Epoch.	Chief geologic activities.	Geologic record.
Algonkian.	Belt.	Flood-plain deposition.	*Spokane formation.* Sandstones and shales, mostly deep red, the shales dominant in the lower, sandstones in the upper portion. Thickness, 5,000 feet.
		Deposition in sea or estuary. This is intended to apply to all formations from Neihart to Greyson (?).	*Greyson shale* may be represented by several hundred feet of greenish gray shale, mapped as upper part of Newland formation.
			Newland formation. Calcareous rocks, containing carbonates of magnesia and iron in considerable quantity; chiefly shale, which grades into calcareous sandstone and impure limestone. Thickness, 4,000 feet.
			Ravalli formation. Sericitic banded quartzite and dark shales, the latter dominant in the upper part. Thickness, 2,000 feet.
			Prichard formation. Bluish argillites with some interbedded quartzite. Thickness, 5,000± feet.
			Neihart quartzite. Pure, generally coarse-grained quartzite. Thickness, 1,000+ feet. Base not exposed.

CHAPTER III.

ALGONKIAN SEDIMENTARY ROCKS.

BELT SERIES.

DISTRIBUTION.

The Algonkian rocks occupy the greater part of the western half of the quadrangle in an area bounded on the east by the central fault zone. Here only the upper formations, Spokane, Greyson(?), and Newland, occur, and, as the area contains only small outcrops of intrusive rock, they are for the most part only slightly altered.

In the Anaconda Range all the Algonkian formations are exposed. Here they have been invaded by a very great volume of igneous intrusives and show much contact metamorphism. Their deformation has also been more complex in this range than in the western part of the quadrangle.

CORRELATION.

The correlation of these rocks collectively with the Belt series depends on their general character and their unconformable relation to the Cambrian. The correlation of the several formations depends on a similarity of the succession and lithology in the Philipsburg district with that in sections previously studied. This is exhibited in the following table,[1] in which the order of the sections is that of relative position, the first being the most southeasterly.

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

Belt Mountains (Walcott).[a]	Philipsburg district (Calkins).	Mission Range (Walcott).[b]	Cœur d'Alene district (Calkins).[c]
Cambrian.	Cambrian.	Cambrian.	
Unconformity		Unconformity	
Marsh. Shale, red, 800 feet.		*Camp Creek.* Sandstones, gray, rather thin bedded, 1,762 feet.	
Helena. Limestone, with some shale, 2,400 feet.		Shales, sandstones, and limestones, 1,560 feet.	
Empire. Shales, greenish-gray, 600 feet.		Sandstones, mostly reddish, 4,491 feet.	
	Unconformity		
Spokane. Shales, with thin beds of sandstone; deep red, 1,500 feet.	*Spokane.* Shale and sandstone, the latter prevailing in upper portion. Color chiefly red, 5,000 feet.	Sandstones, largely shaly, colors red and gray, with 198 feet of limestone 700 feet below top, 3,887 feet.	*Striped Peak.* Shales and sandstone, red and green, 1,000 feet.
Greyson. Shales mostly dark gray, 3,000 feet.	*Greyson* may be included in Newland.		
Newland. Limestone impure, weathering buff, with interbedded shale, 2,200 feet.	*Newland.* Limestone thin bedded, more or less siliceous and ferruginous, passing into shale; generally buff on weathered surface, 4,000 feet.	*Blackfoot.* Limestone, thin bedded, more or less siliceous; siliceous layers, weathering buff, interbedded with calcareo-arenaceous shales, 4,805 feet.	*Wallace.* Shales more or less calcareous, interbedded with thin layers of siliceous and ferruginous limestones and calcareous sandstone. Limestones and calcareous shales weather buff, 4,000 feet.

[a] Walcott, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244.
[b] Walcott, C. D., Algonkian formations of northwestern Montana: Bull. Geol. Soc. America, vol. 17, 1906, pp. 1–28.
[c] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.

[1] More complete sections are made by Walcott and Calkins in The geology and ore deposits of the Cœur d'Alene district, Idaho, by F. L. Ransome and F. C. Calkins: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 27 and 40.

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

Belt Mountain (Walcott).	Philipsburg district (Calkins).	Mission Range (Walcott).	Cœur d'Alene district (Calkins).
Chamberlain. Shale, mostly black, with some sandstone, 1,500 feet.	*Ravalli.* Quartzite, gray with some dark bluish and greenish shale, 2,000 feet.	*Ravalli.* Sandstones, quartzitic, fine grained, purplish gray and gray, 2,550 feet.	*St. Regis.* Shales and sandstones, purple and green, 1,000 feet.
		Sandstones, compact, gray, 1,060 feet.	*Revett.* White quartzite, partly sericitic, 1,200 feet.
		Sandstones, greenish gray, fine grained, in layers 4 inches to 2 feet thick, 4,645 feet. Base not seen. Total thickness of Ravalli, 8,255 feet.	*Burke.* Indurated siliceous shales with sandstones and quartzites, prevailingly gray-green, 2,000 feet.
	Prichard. Shales, dark-bluish, interbedded with sandstone; rusty brown on weathered surface, 5,000 ± feet.		*Prichard.* Argillite, blue-gray to black, with distinct and regular banding, interbedded with a subordinate amount of gray sandstone. Uppermost part arenaceous and marked with shallow-water features. Base not exposed. 8,000 feet.
Neihart. Quartzite with some shale in upper part, 700 feet.	*Neihart.* Quartzite, light-colored. Base not exposed. 1,000± feet.		
Total Belt series, 12,700 feet.	15,000 feet.		
Archean.			

The correlations involve the assumption that the formations do not rapidly thin out or change character horizontally. The evidence that they do not do so must of course be partly negative, for very little of the region has been mapped in detail. On the other hand much of the Algonkian section in western Montana and the adjacent parts of Canada and Idaho has been the subject of geologic reconnaissance, and the resulting stratigraphic observations are hardly consistent with rapid horizontal variations. Evidence of great positive value is afforded by the occurrence of the fossil *Beltina danai* Walcott near the top of the calcareous beds correlated with the Newland limestone in the Belt Mountains and in the Lewis and Clark ranges near the international boundary.

Certain differences in the sections are explainable as the result of gradual variation. This is notably the case with the siliceous beds of the Ravalli formation and its equivalents, which may be represented by the upper part of the Chamberlain shale of the Belt Mountains.

The weakest point in the correlation proposed is the absence from the Philipsburg quadrangle of any distinct lithologic unit corresponding to the Greyson shale. It is possible that this formation thins out westward or grades horizontally into beds of different character. If the latter supposition be correct, the Greyson shale is more likely to be represented by the upper part of the Newland formation, to which it shows some lithologic resemblance, than by any part of the Spokane formation with its prevailingly deep-red rocks, which it does not in the least resemble.

NEIHART QUARTZITE.

GENERAL CHARACTER AND DISTRIBUTION.

The exposures of Neihart quartzite in the Philipsburg quadrangle are all in the southeastern part of the Anaconda Range.

The largest area affords a good section along the east side of Sullivan Creek. The quartzite beds, which form a cliff and talus conspicuously light in color by contrast with the dark rusty rocks of the Prichard to the north, can be seen to form a flat-topped arch, with the north side steep and the south side very gently sloping where it disappears beneath the moraine. There is no indication of appreciable faulting, so that a section constructed from observed dips may be relied on to give the exposed thickness with fairly close approximation. This is found to be in round numbers 1,000 feet—a minimum, of course, for the base is concealed.

The lowest beds exposed are of very pure white or pale-drab quartzite. The bedding is fairly well shown by banding, but there are no distinct partings. Farther up in the section the prevailing rock is grayish quartzite, with faint but distinct bands about half an inch thick and very thin micaceous partings from 6 inches to 3 feet apart. Within a few rods of the top there are numerous interbedded layers of dark mica schist a few inches or feet in thickness. The horizon where schist predominates over quartzites is taken as the top of the Neihart, and although the transition to the Prichard is gradual it can be located within a few yards.

LITHOLOGY.

The rock most abundant in the main body of the formation is very pure or moderately pure quartzite, which, through pressure and cementation, has become vitreous and perfectly compact. A very little mica, chiefly muscovite, can be detected even in the purest. It forms tiny flakes having parallel arrangement. The most striking feature of the purer quartzites is a peculiar faint striping, most evident on the finely fluted weathered surfaces, suggesting that of fossil wood. The constituent grains of this rock are greatly elongated and larger in average diameter than those of most quartzites. The microscope shows that they are overlapping, rudely lenticular pieces of quartz, showing remarkable development of the "strain shadows" that indicate strain due to pressure. The average size of the grains has probably been much increased by recrystallization, so that it does not truly indicate the coarseness of the sands from which the rocks were formed.

The pure quartzites grade into the grayish banded quartzites, which contain more mica, and relatively more biotite as compared with muscovite; these again grade into the siliceous mica schists that occur in the upper part of the formation. Sillimanite, which forms very sparsely disseminated microscopic needles in the purest quartzites, increases in amount concomitantly with the micas, but can not be identified without the aid of the microscope. In the mica schists, which are of medium grain and dark-gray to dull dark-green in color, and which are not marked by any unusual megascopic features, the microscope shows muscovite, biotite, and sillimanite to be nearly of the same order of abundance as quartz. The quartz grains in these rocks are much smaller than in the quartzites and show far less evidence of strain. The green color in certain beds is due to chlorite, which has partially replaced biotite.

PRICHARD FORMATION.

DISTRIBUTION AND PRINCIPAL FEATURES.

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

The most striking characteristic of the Prichard formation as seen in the field is the deep reddish-brown color of the weathered outcrops. Abundant ocher formed in the decomposition of the Prichard rocks is taken up by the intermittent rivulets on the steep slopes of Mount Evans and deposited in little deltas at the borders of the amphitheaters and on the banks of the brooks that meander across their floors.

Although the formation contains some quartzite, mostly near the top and bottom, it consists mainly of aluminous rocks which are generally bluish on fresh fracture. If they had suffered no igneous metamorphism, the rocks of the formation would be chiefly shales with occasional beds of sandstone, but they have been penetrated and greatly altered by repeated intrusions, to whose effects they are more susceptible than the underlying quartzites, and metamorphism has rendered them so tough and resistant to erosion that they form the culminating peaks of the Anaconda Range. The least-altered phase of the dominant argillaceous beds is fine-grained gray mica schist, in which the bedding is but little obscured. Commonly, however, the Prichard rocks exhibit coarse crystalline textures and contain large flakes of mica, crystals of wine-red garnet, and "knots" of andalusite or sillimanite. In part they are cordierite gneisses with contorted lamination.

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

LITHOLOGIC DETAILS.

MINERALS.

The minerals identified in rocks of the Prichard formation are quartz, biotite (nearly always red-brown in color), muscovite, sillimanite, andalusite, orthoclase, plagioclase, cordierite, pyroxene, amphibole, titanite, magnetite, pyrrhotite, pyrite (?), apatite, zircon, rutile, chlorite, garnet, spinel, and tourmaline. No one specimen contains them all, though many contain all but three or four.

PRINCIPAL ROCK TYPES.

Fine-grained biotite schist.—A specimen of rock whose alteration has been relatively inconspicuous and which resembles typical Prichard slate of the Cœur d'Alene district, Idaho, is dark blue-gray, homogeneous, and fine grained. It has a rather obscure cleavage, to which most of the minute sparkling grains of mica in which the rock abounds lie parallel. An unusual feature revealed by close inspection, is the presence of abundant small yellow grains of iron sulphide, probably the chief source of the ocher that covers the weathered surface of the rock. Chemical tests indicate that most, if not all, of this sulphide is pyrrhotite.

Microscopic examination shows that quartz and reddish biotite are the chief constituents, that iron sulphide, magnetite, and titantite are rather abundant, and that lime-rich feldspar and apatite are present in small amount. The rock evidently contains a good deal of calcium and magnesium.

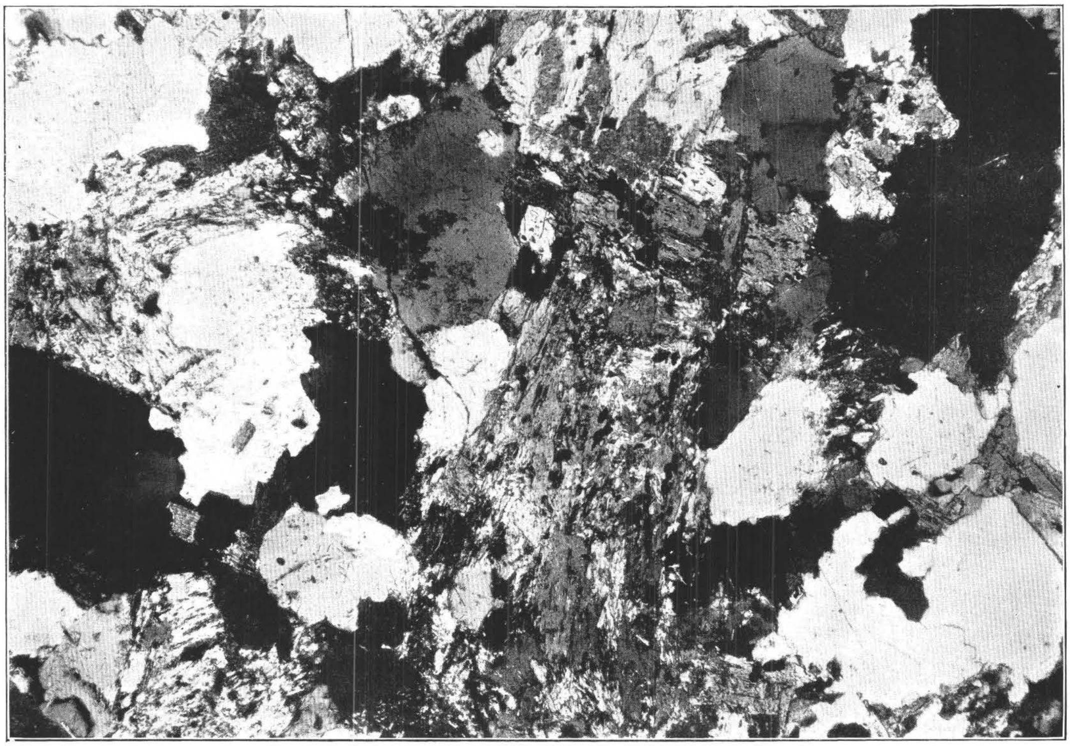
Andalusite-mica schist.—A specimen rich in andalusite, from the western slope of Mount Howe, is coarser grained than the biotite schist, is gray in color, with a tinge of pink, and contains conspicuous grains of muscovite about 1 millimeter in diameter. The rock splits on irregular lumpy cleavage faces.

The thin section reveals quartz, muscovite, reddish biotite, and andalusite as the chief minerals. Cordierite occurs in subordinate amount, and small individuals of sillimanite, zircon, tourmaline, and rutile are abundant. The muscovite occurs partly in relatively large poikilitic equant individuals, but also in small flakes similar in form and size to those of the deep red-brown biotite. The andalusite in rudely prismoidal individuals is crowded with inclusions of all the other minerals except sillimanite. Cordierite forms a few inconspicuous individuals, extremely poikilitic, and larger than those of quartz, from which mineral it is most readily distinguished by the vivid golden-yellow halos around the inclusions of zircon.

Knotted sillimanite-mica schist.—Another rock in which sillimanite and andalusite are both present, but in which the former predominates, is a dark-gray mica schist containing abundant white lenticular masses 2 or 3 millimeters in average diameter.

The constituents identified microscopically are the same as in the rock just described, with the exception of cordierite, but red-brown biotite predominates over muscovite, and sillimanite is extremely abundant, amounting to probably 25 per cent of the rock. Much of the sillimanite forms fagot-like bundles that in some irregular or lenticular masses are packed together in haphazard orientation, with only a subordinate admixture of other constituents. Elsewhere it is more thinly strewn, but hardly a grain of quartz or flake of mica is not transfixed by its delicate needles, whose average diameter is about 0.002 millimeter.

Garnetiferous mica schist.—At the head of Tenmile Creek a very prevalent facies is a dark, rather coarse grained blue-gray mica schist, somewhat similar to the preceding types in general appearance, but characterized by the presence of many pink garnets about 2 millimeters in diameter.



A. CORDIERITE GNEISS.

The chief constituents are quartz in irregular grains with few inclusions, mica, and cordierite (oblong crystal in center, with numerous inclusions).

B. METAMORPHOSED MUD-SAND ROCK CONTAINING SCAPOLITE.

Shows texture of argillaceous sandstone inclosing a mud fragment penetrated by a sun crack. Scapolite with abundant inclusions forms the light spots in the dark mudstone.

The constituents identified in thin section are quartz, muscovite, biotite, sillimanite, cordierite, feldspar, garnet, magnetite, zircon, chlorite, and apatite. The biotite, unlike that of most specimens from this formation, is chestnut brown, untinged with red. The cordierite locally seems to be in pegmatitic intergrowth with quartz. The garnet has irregular boundaries.

Cordierite gneiss.—The most metamorphosed rocks of the Prichard formation, which occur at the head of Twin Lakes Creek, have been affected by several successive intrusions. These are tough massive gneisses, which, on glaciated outcrops, show highly contorted banding. Their general hue is rather dark brownish gray, and they are obscurely mottled, owing to the uneven distribution of biotite. The micas, of which biotite generally predominates, quartz, and occasional pale purplish-red garnets, are the only constituents that can readily be identified by the naked eye. The cordierite might well be overlooked, and was, indeed, first identified under the microscope, but when carefully searched for it may be distinguished from quartz by its inferior transparency, its duller and somewhat greasy luster, and its pale gray-green color. The individuals are not well defined because of their irregular outlines and abundant inclusions.

A thin section is depicted in Plate V, *A*. The constituents identified under the microscope are quartz, reddish-brown biotite, muscovite, cordierite, sillimanite, garnet, green spinel, and feldspar, with small quantities of rutile, apatite, zircon, magnetite, iron sulphide, secondary chlorite, and micaceous decomposition products of cordierite. The most interesting mineral is cordierite, which is more abundant than in the other rocks. It is crowded with inclusions of all the other minerals, among which needles of sillimanite arranged in wavy lines parallel to the lamination of the rock are conspicuous. The feldspars, which occur in moderate abundance, are microcline and sodic plagioclase.

Rocks containing amphibole and pyroxene.—A rock from the immediate contact with the granite on the west slope of Mount Howe is built up of rather irregular laminæ, of which the thicker appear to consist mostly of minute crystals of dark-green hornblende, and the thinner of dull-white material, proved microscopically to be chiefly quartz. The microscope also reveals the presence of considerable biotite, diopsidic pyroxene, and feldspar, with subordinate amounts of titanite and zircon.

A specimen of quartzite from the head of the East Fork of Twin Lakes Creek is light gray, of moderately fine texture, and shows numerous minute splinters of dark greenish-gray amphibole and paler pyroxene. The microscope shows the most abundant constituent to be quartz in irregular interlocking grains. A lime-rich plagioclase occurs in similar habit. The amphibole and pyroxene develop imperfect prisms with abundant inclusions of quartz. Biotite, pale garnet, iron ore, zircon, titanite, and chlorite are present in small amounts.

RAVALLI FORMATION.

PRINCIPAL FEATURES AND DISTRIBUTION.

The Ravalli formation, which is about 2,000 feet thick in the Philipsburg district, is composed mainly of light-gray quartzite less pure than the Neihart quartzite. This rock constitutes almost exclusively the lower two-thirds of the formation; the upper third comprises a good deal of dark-bluish and greenish shale, interbedded with dark quartzitic sandstone and with quartzite like that in the lower part. Near the base, too, considerable shale occurs, so that there is a gradation, though a rapid one, between the Ravalli and the Prichard. At the top there is a similar gradation to the Newland formation, which is regarded as beginning with the lowest markedly calcareous beds.

The formation occurs in a northeast-southwest zone crossing the crest of the Anaconda Range near the central meridian of the quadrangle, and as its rocks are resistant it is well exposed. The only complete and continuous section is displayed in the cliffs north of the Continental Divide, west of Mount Howe, where the approximate thickness has been measured. The area crossed by the divide between Twin Lakes and Barker Creek, however, displays almost the entire thickness of the formation and is interesting because it shows intense contact metamorphism, probably due in the main to batholithic intrusions not far beneath the surface.

LITHOLOGIC DETAILS.

LITTLE-ALTERED ROCKS.

The rocks of the Ravalli formation range from a fairly pure light-gray quartzite to a dark-bluish or greenish fissile shale. The intermediate types comprise sandy shales and dark quartzitic sandstones.

In the quartzites the bedding is marked more or less distinctly by narrow stripes of lighter and darker gray, parallel in part to the general attitude of the beds, but in part so inclined as to form a cross-bedded structure. The quartzites are invariably rather fine grained, and, owing to the presence of finely divided mica, are duller, less vitreous, and softer than the typical Neihart rock.

The shales are dark, dull greenish blue or bluish green, with bedding marked by obscure bands in slightly differing tones and, usually inclined to these, a slightly developed secondary cleavage.

Study of microscopic sections proves that the quartzites, quartzitic sandstones, and shales in their little-altered condition consist mainly of quartz and light and dark micas, variation in texture and in amount of mica constituting the principal differences between the several types. A constant and characteristic feature is the greenish hue of the biotite, in contrast to the almost invariably reddish hue of the biotite in the Prichard rocks. The purest quartzite shows angular to subangular grains of quartz and feldspar about 0.1 millimeter in diameter, somewhat modified by secondary growth. A few flakes of presumably clastic muscovite, similar in size to the quartz grains, also appear. The interstices between these grains are filled with a rather abundant cement composed mainly of very minute irregularly oriented flakes of sericite and biotite.

A section of a dark greenish-gray argillite with slaty cleavage shows it to consist, like the quartzites, chiefly of quartz, sericite, and greenish-brown biotite. The micas are, however, relatively abundant, and have in great part a nearly common orientation oblique to the bands that mark the bedding and doubtless parallel to the cleavage. Tourmaline is notably abundant in this rock; it forms prisms about as thick as the quartz grains and about five times as long. The relatively large size and sharp development of the crystals indicate clearly that they are secondary and not clastic. Most of them lie nearly parallel to the schistosity. Epidote is developed in much the same fashion as tourmaline.

MUCH-ALTERED ROCKS.

Strong contact metamorphism of the more siliceous Ravalli rocks commonly results in recrystallization unaccompanied by much change in the mineral composition. A clastic texture, in which the larger particles of sand can be distinguished microscopically from a turbid cement, gives way to a mosaic texture, in which the principal constituents form interlocking grains of roughly equal size. Mineralogical changes are more marked in the argillaceous rocks. Some of these contain andalusite, but this mineral is not characteristic of the formation. Cordierite seems to have been developed locally, but if so it has been replaced by micaceous alteration products in all the specimens examined. A relatively pure metamorphosed quartzite from a bed not far from the top of the formation is exceptional in containing amphibole and pyroxene.

The more usual types of highly altered quartzitic rocks, abundantly represented in the Barker Creek area, are chiefly gneissoid, and are composed in the main of light-gray sugary quartzitic material, coarser than the little-altered quartzites and evidently recrystallized, with distinct banding, due to the coloration of certain layers or lenses with biotite.

The constituents identifiable under the microscope are quartz, muscovite, brown biotite, green biotite, chlorite, feldspars, and, in subordinate amounts, zircon, epidote, tourmaline, sillimanite, magnetite, pyrite, apatite, and rutile.

A knotted structure is commonly developed in the slightly argillaceous phases of the formation. Eye-shaped dark brownish-gray lenses about 1 centimeter in breadth, some of them elongated with an approach to prismatic form, are embedded in a light-gray, moderately fine grained schistose matrix consisting of quartz with less mica. Microscopic examination shows the knots to consist of a very fine grained aggregate of white and brown micas mingled with small amounts of quartz and the other constituents, and it seems probable that they are pinite pseudomorphs after cordierite.

An extremely metamorphosed aluminous rock from near the top of the Ravalli was collected near the granite contact on the east slope of the peak marked "9814" on the topographic map at the head of East Fork of Rock Creek. It is tough, compact, and of a grayish color in mass, with very distinct bands a few centimeters broad, parallel to the bedding planes. The lighter bands resemble fine-grained granite. The most remarkable feature of the rock is a cross lamination in some of the layers; the cross laminæ, about 1 or 2 millimeters thick, and inclined at 30° to the bedding, appear in a cross section as parallel light and dark stripes. This structure, which is developed at the same locality in Newland rocks, is evidently secondary, and seems to be in the nature of a thoroughly healed cross fissility or fracture cleavage. Similar bands, much more persistent but less numerous, which traverse the specimen in several directions, are evidently joint fissures similarly healed.

The microscope reveals as the constituents quartz, muscovite, brown and green mica, orthoclase, plagioclase, chlorite, epidote, magnetite, tourmaline, apatite, andalusite, sillimanite, zircon, rutile, and a secondary sericitic substance formed at the expense of andalusite. Aggregates of sericite and green biotite which may have been derived from cordierite are present. The clastic texture of the rock has been thoroughly obliterated, and the minerals interlock irregularly.

NEWLAND FORMATION AND GREYSON (?) SHALE.

PRINCIPAL FEATURES AND DISTRIBUTION.

The great bulk of the Newland formation as represented in the Philipsburg district consists of thin-bedded calcareous rocks which may with almost equal propriety be called siliceous impure limestones or calcareous argillites. The name Newland limestone, applied to the formation in the type area, is not wholly appropriate in the Philipsburg region or the areas farther west, where the most abundant rocks in the formation are about half carbonate fairly rich in magnesia and iron, the remainder being chiefly quartz. Judging from the original description of the Newland limestone, the formation as here represented is more calcareous on the whole than in the Cœur d'Alene district of Idaho, where it was formerly called the "Wallace formation," and it appears that the proportion of carbonate continues to increase toward the east. Shallow-water markings found throughout the formation in the Cœur d'Alene district were here noted only in its upper part. This upper part, consisting of drab to greenish-gray calcareous shale, may be the equivalent of the Greyson shale.

The general appearance and the degree of resistance to erosion of the Newland rocks depends in a remarkable degree on the extent to which they have been metamorphosed. Where it is little metamorphosed, as in the softly contoured hills west of Philipsburg Valley, the formation offers relatively slight resistance to erosion (Pl. III, p. 20). The rocks in their little-altered state are mostly gray on fresh fracture, but their weathered surfaces are deeply stained with yellow ocher derived from iron-bearing carbonates, a coloration which differentiates the unaltered Newland from all other formations of the region and makes it easily recognizable from a distance.

Contact metamorphism transforms these soft and easily decomposed rocks to tough diopsidic hornstones, prevailingly light greenish gray, whose weathered surfaces are almost free from limonite, and which resist erosion almost as effectively as quartzite. These altered rocks form steep cliffs and lofty peaks in the Anaconda Range. The increase of hardness effected by metamorphism is perhaps most clearly demonstrated, however, by Henderson Mountain, north of Philipsburg. This eminence, carved from hornstones produced by the metamorphic action of a porphyry intrusion, rises abruptly above the flat surrounding hills, whose country rock is little-altered shale of the Newland and Spokane formations.

The most nearly continuous and complete sections are to be found in the strip southwest of Storm Lake, in the Anaconda Range, from which the thickness, approximately 4,000 feet, has been deduced.

LITHOLOGIC DETAILS.

LITTLE-ALTERED ROCKS.

Megascopic features.—The basal part of the Newland formation, as exposed near the head of Seymour Creek, is transitional to the Ravalli. It consists of dark argillaceous rocks in rather thick beds, intercalated with beds of yellow-weathering gray impure limestone a few inches thick. The argillites are not essentially different from the dark shales in the upper part of the Ravalli, described on page 40.

The fine-grained calcareous rocks that constitute most of the main body of the formation generally break down into thin flags or slabs not more than a foot thick. The bedding is marked in addition by ill-defined bands of different colors, one-eighth to one-half inch thick.

These dominant rocks vary in color on fresh fracture from very dark bluish gray to light blue-gray, pale gray-green, drab, or cream-white. They invariably have a fine, somewhat horny or waxy texture.

Many weathered blocks show deep grooving parallel to the bedding, caused by the etching out of less resistant calcareous laminæ, and therefore have a superficial resemblance to dead wood long exposed to the weather. All these rocks effervesce when cold dilute hydrochloric acid is applied to fresh surfaces, but not, as a rule, very briskly. The outer crust of weathered material does not generally effervesce with acid, because the carbonates have been decomposed or dissolved. At certain horizons in the middle and upper parts of the formation, however, the purer limestone forms discontinuous layers, thin lenses, and nodules flattened parallel to the bedding planes. These are especially conspicuous on weathered surfaces, where they show a bluish-gray color, and are deeply sunken because of their relatively easy solubility. A little fine calcareous quartzite or sandstone in layers a few inches thick is interbedded with the other rocks. Drab to greenish-gray calcareous shales, more fissile than those in the middle part of the Newland formation and consequently more deeply weathered, are exposed for a few hundred feet below the overlying red shale (Spokane) in the gorge below the dam of Georgetown Lake. These beds are possibly equivalent to the Greyson shale of the Belt Mountains. They are marked by sun cracks and other features indicating deposition in very shallow water with frequent exposure to the atmosphere.

Microscopic features.—The unaltered Newland rocks, when examined in thin section, prove to consist in the main of quartz and carbonate; the latter, which is largely in the form of rhombohedra, being somewhat the more abundant. The diameters of the grains are measurable in hundredths or thousandths of a millimeter. Feldspar can always be detected where the grain of the rock is not too fine, and sericite is invariably present. Biotite partly altered to chlorite occurs in some specimens, but is on the whole very rare. Chlorite, that does not seem to be secondary, probably forms the coloring matter of the distinctly greenish beds, and in some specimens can be readily identified, but in the extremely fine textured rocks its low double refraction renders it likely to be overlooked. Minor constituents generally present are zircon, carbonaceous dust (in the dark layers), and white, cloudy particles probably rich in titanium, for their transparent portions exhibit a high double refraction that may be due to rutile, although good crystals of that mineral have not been observed. Tourmaline occurs sporadically and in very small amount. Pyrite is rare and is not the source of the prevailing ocherous stain on the weathered surfaces.

The effect of weathering first appears in the impregnation of isolated rhombohedra of carbonate with iron oxide. In thoroughly weathered specimens nearly all the grains except those of the soft gray nodules are similarly impregnated, a condition which indicates that all the carbonate in the body of the rock is somewhat ferruginous. Some specimens of shale more than ordinarily siliceous contain scattered rhombohedra of rusty carbonate about 0.5 millimeter in diameter, about 10 times the size of the associated quartz grains, some of which they inclose. These must have grown by a metasomatic replacement of the rock substance, like the siderite grains that are locally so abundant in the siliceous sediments of the Cœur d'Alene district.[1]

MUCH-ALTERED ROCKS.

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

These rocks are more or less distinctly banded, in white, grayish-green, chocolate-brown, and intermediate hues, by layers that are generally from 1 millimeter to 1 centimeter thick. The texture is in some specimens perceptibly crystalline (Pl. VI, *A*), but is more commonly very fine and dense, like that of porcelain, so that the constituent minerals can rarely be identified megascopically. Nevertheless, with the aid of information derived from microscopic study of thin sections, the mineral composition of the layers can be judged to some extent by their color. A brown hue indicates the presence of biotite, and dark gray-green that of amphibole; very pale green layers are likely to be rich in diopside, and pure-white layers to consist mainly of quartz and feldspar, with more or less carbonate. Weathered surfaces are generally somewhat ridged, layers or nodules rich in carbonate being deeply etched. They are commonly lighter than the fresh rock, and are discolored a little in places with orange or yellow iron oxide.

Thin sections examined under the microscope usually reveal a fine granular fabric, sometimes modified by a poikilitic development of amphibole or pyroxene. The grain is more uneven and in general coarser than that of the unaltered rocks, the diameter of the individuals being generally between 0.02 and 0.5 millimeter, although the poikilitic crystals attain diameters of 1 or 2 millimeters. Diopside and amphibole, occurring as they do side by side in crystals of different habit, are evidently contemporaneous or nearly so, and alteration of one to the other is rarely observed.

As a rule the magnesian constituents roughly equal or exceed in quantity the limpid quartz and feldspar which are intimately mingled with them or form multitudinous inclusions in the spongiform individuals of pyroxene and amphibole. The feldspar is commonly more abundant than the quartz and, indeed, some slides contain much orthoclase and no quartz whatever. Most of the feldspar is alkalic and as a rule either potash feldspar or albite occurs almost exclusively in a single specimen. Occasionally potash feldspar and a lime-rich plagioclase occur in the same specimen, the lime feldspar being mainly in the biotitic portions. Where alkalic feldspar is abundant, it probably has been introduced in part by hot solutions from the intrusive magmas, a probability which is strengthened by the predominance of one or the other. Lime feldspar may well have been formed from the original calcium of the rock, its presence in certain layers being determined, like that of the associated biotite, by relatively abundant aluminous material in the original sediment.

Titanite occurs as a rather abundant accessory in all sections. Other constituents more or less commonly present in small quantity are zircon, pyrite, and green or brown tourmaline, the mineral last named being in general much scarcer than in noncalcareous rocks altered to the same extent.

Scapolite rocks.—The scapolite-bearing rocks northwest of Cable Mountain are not very different in general appearance from the rocks just described, but they are less distinctly banded and comprise very little brown biotitic material. Generally the scapolite is so intimately mingled with the green silicates that give color to the rock that it can not be seen with the naked eye, but in some of the more coarsely crystalline specimens, especially on weathered surfaces, it is clearly visible in the form of grayish-white semitransparent prisms as much as 1 centimeter long.

[1] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 95, Pls. XI and XII.

Microscopic examination shows that the minerals most common in these rocks are scapolite and pale-green diopside, the proportion in which either mineral is present ranging roughly from 25 to 50 per cent. Quartz and calcite are generally important, but their amount varies greatly. Amphibole is absent or scarce in most specimens, although deep-green hornblende is the only magnesian mineral in some beds at the top of the formation. The most common amphibole in the body of the formation is pale actinolite. A soda-rich feldspar (albite or sodic anorthoclase) is locally abundant, but orthoclase and microcline are of merely sporadic occurrence. Zircon, pyrite, and epidote occur in very small quantities, as in the hornstones free from scapolite, and tourmaline is very scarce. A few minute crystals of birefringent garnet were seen in one specimen and a few grains of allanite and much phlogopite in another. Mica is generally absent, the alumina having gone to the formation of scapolite.

The scapolite in most specimens has a double refraction of approximately 0.022 to 0.025, which indicates a composition near Me_2Ma_1. In the specimen where the mineral is most abundant, however, its double refraction is about 0.013, a fact which proves that it is very poor in lime and that much soda has been added to the rock by magmatic solutions.

The grain of the scapolite rocks is highly variable but in general is coarser than that of the scapolite-free hornstones. The fabric—that is, the form and relations of the constituent crystals—is also diverse, the variation depending chiefly on the way in which the scapolite is developed. Ordinarily it forms larger crystals than the other constituents and incloses them. The poikilitic habit is generally most pronounced where the crystal form is least developed. An exceptional "panallotriomorphic" structure is exemplified in a fine-grained rock composed essentially of diopside and scapolite in rudely prismoid grains of about equal size.

Rocks rich in epidote.—Epidote in small quantities has been found in limestone specimens from the Newland taken at many places, but is not abundant except about the granite porphyry intrusion in Henderson Gulch and near the mouth of Sluice Gulch, at the western border of the quadrangle, where it is commonly accompanied by garnet—a mineral also scarce in this formation elsewhere in the quadrangle. The garnet and epidote are irregularly distributed in the contact zones and seem to be generally in or near fissures which contain fairly well-developed crystals of both. They are accompanied by other minerals characteristic of the metamorphosed Newland, such as calcite, quartz, diopside, titanite, actinolite, and albite. The reddish-brown color of the garnet and the characteristic yellowish green of the epidote make these minerals easy to recognize.

Rocks containing tremolite and vesuvianite.—Some exceptionally iron-poor rocks of the Newland formation contain tremolite and phlogopite instead of green amphibole and biotite. A rock from Sunrise Mountain consists essentially of tremolite, diopside, calcite, quartz, iron-poor epidote, and abundant vesuvianite. Vesuvanite has not been found in the formation at any other place in the quadrangle.

CHEMICAL FEATURES OF ALTERED AND UNALTERED ROCKS.

A chemical analysis was made of an unmetamorphosed rock from the Newland formation, and the alkali and silica contents of two metamorphosed specimens were determined in the hope of obtaining evidence as to whether or not these substances are added in the process of metamorphism. The unmetamorphosed rock, a dark impure limestone from the gorge below Georgetown Lake, is fine grained, not appreciably metamorphosed, and is stained with yellowish-brown ocher on the weathered surface. The microscope shows that it consists mainly of carbonate (partly rhombohedral), and quartz, with subordinate sericite, possibly a little feldspar, yellowish-white flocks of leucoxene, and some opaque carbonaceous dust. Of the metamorphosed rocks that were partially analyzed, one (2) consists chiefly of diopside, actinolite, and orthoclase, another (3) chiefly of diopside, quartz, and feldspar which is in small part striated and shows the extinction angles of albite, though most of it is unstriated. The results of the analyses follow:

Analyses of rocks from the Newland formation.

[W. T. Schaller, analyst.]

	1	2	3
SiO_2	44.80	56.27	58.52
Al_2O_3	8.96		
Total iron as FeO	2.85		
TiO_2	.37		
MgO	5.90		
CaO	16.42		
K_2O	2.14	3.63	4.91
Na_2O	.43	.86	1.00
H_2O [a]	3.33		
CO_2 [b]	15.42		
	100.62		

[a] Determined by loss on ignition, corrected for CO_2 and oxidation of ferrous iron.
[b] The presence of a small amount of carbonaceous matter was determined qualitatively.

1. Impure limestone from gorge below Georgetown Lake.
2. Hornstone from Rumsey Mountain.
3. Hornstone from Sunrise Mountain.

These analyses, so far as they go, indicate enrichment in silica and alkalies. With respect to silica, the evidence has little value, for that substance is present in widely varying amounts in the Newland rocks. But the great excess of potash in the metamorphosed rocks, where it is from 50 to 100 per cent more abundant than in the unmetamorphosed one, strongly suggests enrichment by metamorphic agencies.

The apparent increase of soda by metamorphism is less significant because the amount of that oxide is small in any of the specimens. There can be no doubt, however, that soda was added to the Newland rocks when scapolite was developed in them. The scapolite that they contain is, on the average, fairly rich in soda, and is most sodic in the rocks where it is most abundant.

SPOKANE FORMATION.

PRINCIPAL FEATURES AND DISTRIBUTION.

The Spokane formation is represented in the Philipsburg quadrangle by a great thickness of shale and sandstone, prevailingly red where unaltered and characterized as a whole by sun cracks and ripple marks. The lowest red shale overlying the calcareous buff-weathering rocks of the Newland is regarded as the base of the Spokane, whose lowest part comprises some rock like that constituting the upper part of the Newland. The lower red shales locally contain a little carbonate, but carbonate is virtually absent from the main body of the formation. In most sections the transitional basal phase is succeeded by 2,000 or 3,000 feet of shale with subordinate sandstone. The amount of sandstone varies locally, and in some sections the lower part of the formation is chiefly arenaceous. The upper part everywhere consists chiefly of sandstone with subordinate shale, and in many places it could be delimited on the map from the lower dominantly shaly part by a fairly definite line. Owing, however, to the horizontal variation in the character of the lower part, to the more or less gradational character of the contact, and to the fact that both parts consist of the same kinds of rock, it would be impracticable to map two subdivisions of the formation in all parts of the quadrangle. In places a thin conglomeratic bed appears a few hundred feet from the top of the formation.

The most nearly complete cross section of the Spokane formation is displayed in the canyon of Flint Creek between Georgetown Lake and Philipsburg Valley. If the structure is simply monoclinal, as it appears to be, the thickness here developed is nearly 10,000 feet. This enormous apparent thickness may be due in part to repetition by strike faults, but of these there is no clear evidence.

The most prominent feature of the unaltered Spokane rocks is their deep-red color, but this color is radically changed by contact metamorphism. Slight metamorphism changes the warm reds to duller purplish hues; thorough metamorphism changes the purples to grays, greens, and browns. The metamorphic representatives of the Spokane formation are chiefly quartz-muscovite-biotite rocks and cordierite-bearing hornstones. Where this formation has lost its red color through metamorphism it is difficult to fix accurately the boundaries between it and the Newland. Deep-green flaggy rocks, rich in hornblende and more rusty on weathered surfaces than the metamorphosed Newland, are taken to represent the transitional partly calcareous beds.

The shaly parts of the Spokane are easily eroded, and their characteristic topography is that of the rather gentle slopes along the northwest side of Philipsburg Valley. The upper, sandy part, however, is much more resistant. The prominence of Cable Mountain, Twin Peaks, and the ridge between the two Willow creeks, as well as the ridge northeast of the Carp mine, is due to the hardness of the upper, sandy part as compared with the associated limestones and shales. Slopes carved from it are generally mantled by heavy sandstone talus. Metamorphism increases somewhat the resistance of the sandstones and in greater degree that of the shales.

The distribution of the Spokane is much the same as that of the Newland. Most of the area in which the formation occurs unmetamorphosed lies west, and most of that in which it is much altered lies east of a line joining the northeast and southwest corners of the quadrangle. The Cable Mountain area and the vicinity of Rumsey Mountain near the center of the quadrangle afford opportunity to observe progressive metamorphism. In these areas scapolite is locally developed to some extent in the argillaceous beds, as it is in the Newland.

LITHOLOGIC DETAILS.

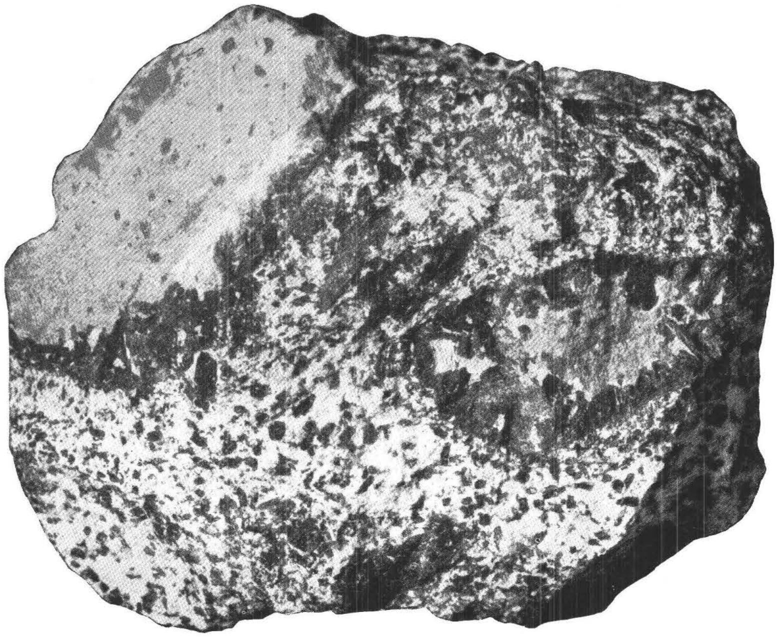
LITTLE-ALTERED ROCKS.

The most interesting feature of the Spokane formation is the abundance of well-preserved shallow-water markings that it contains. Everywhere it displays fine examples of sun cracks, ripple marks, and mud breccias, and at one point in the Flint Creek gorge raindrop impressions were noted.

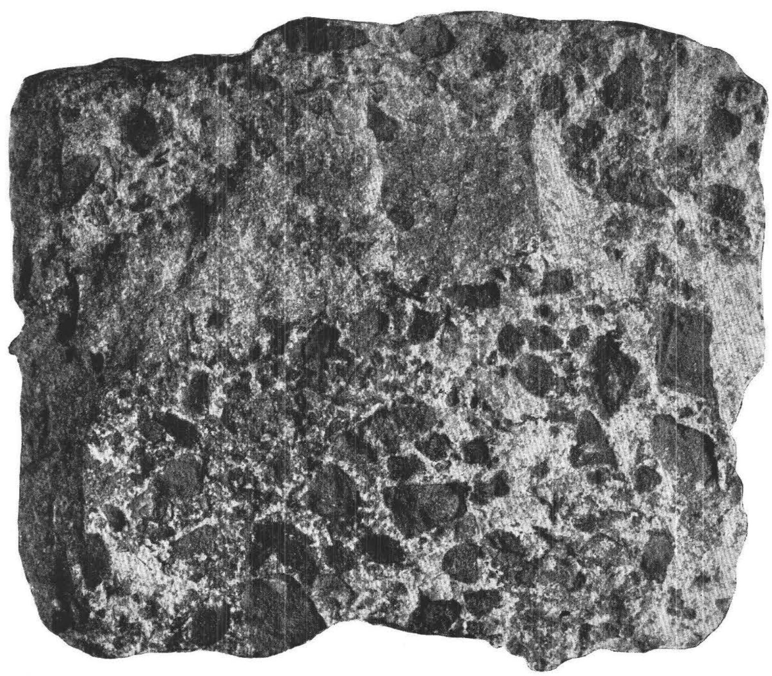
The shales, which are in general more or less sandy, are built up of alternating thin laminæ of comparatively dark fine-grained material and of light coarse-grained material. Some of the finer-grained material is very fissile. Parting takes place along the finer layers, and the surfaces of the flags into which the rock splits are as glossy as if they were newly painted. The prevailing color, a deep rich red, is sometimes relieved by a contrasting pale olive-green. Sun cracks are naturally most developed in the finer argillite, and ripple marks in the layers of flaggy sandstone.

The sandstone of the formation, into which the shale grades in many places, has generally a tinge of red, locally almost as deep as that of the shale. There is commonly more or less color lamination in red and white, locally inclined to the stratification. The texture varies from fine to moderately coarse, the diameter of the grains rarely exceeding a millimeter. Like many other red sediments, the red sandstones, and less commonly the shales, contain pale-green or nearly white spots, generally between 1 and 5 millimeters in diameter, probably due to reduction of the iron about organic particles of which no other trace remains.

A prominent characteristic of the sandstone of the Spokane formation is the presence in many layers of abundant flat masses of dark argillite from a small fraction of an inch to 2 inches in diameter, similar to the finest-grained portion of the shales. (See Pl. VI.) Commonly these masses, whose larger dimensions are in the bedding planes, are smooth and well-rounded, like pebbles. The rock containing them differs in two respects from typical conglomerate, however; first, the volume of the matrix of sandstone greatly exceeds that of the pebbles, and, second, the pebbles are virtually homogeneous in composition and consist of a kind of material abundantly interbedded with the sandstone. These beds grade into others in which the argillaceous particles are sharply angular. It is believed, in view of the common association of these rocks with mud cracks, that the argillaceous fragments were derived from mud flakes curled up and loosened in the process of drying and buried by the next deposit of sand. The rounding of the fragments in certain beds is evidently the result of attrition, but as fragments



A. INCLUSIONS OF CALCAREOUS HORNFELS, WITH DARK REACTION RIMS OF HORNBLENDE, IN DIORITE AT HEAD OF FOURMILE BASIN.



B. SANDSTONE WITH MUD FLAKES (SPOKANE FORMATION).

Frequently observed in the Belt series in sandstones of formations whose shales are sun cracked.

of mud could hardly survive transportation by water for any considerable distance it is probable that some of them were rolled by wind after drying.

Wholly distinct from these beds in character and origin are certain thin beds of conglomerate or pebbly sandstone which occur well up in the succession, and which are found, for example, on Cable Mountain and the spurs southwest of Twin Peaks. These beds contain well-rounded pebbles, chiefly of quartz, but with some of feldspar and quartzite, an inch or less in diameter, evidently formed by the long-continued attrition of fragments of rocks much older than the Spokane formation.

The microscope shows that the sand grains of both shales and sandstones, although mostly quartz, comprise a good deal of feldspar, chiefly potassic. The grains are angular in the shales but fairly well rounded in the sandstones.

MUCH-ALTERED ROCKS.

Rocks containing amphibole, with or without scapolite.—The flaggy, distinctly banded, green hornstones found near the base of the Spokane formation in most areas where it is affected by strong contact metamorphism are like the most common phase of the altered Newland, except that they contain more amphibole.

Southwest of Twin Peaks and near the junction with the scapolite-bearing Newland rocks east of Rumsey Mountain, the lower argillaceous part of the formation has been altered to hornstones banded in gray-green and dull purple. All of these hornstones contain poikilitic amphibole and are free from diopside. Most of them contain scapolite. The coloring matter of the purplish layers is hematite dust, not biotite, which is the pigment of the chocolate-colored or purplish-brown hornstones derived from many argillites. The biotite present in these rocks is green. The abundance of hematite is one of the chief reasons for assigning these rocks to the Spokane rather than to the Newland. Epidote is plentiful; the other constituents are those of the scapolite rocks derived from the Newland. Scapolite has not been found elsewhere in the formation, and its development here obviously depends on the same local conditions that determined its development in the Newland formation near by.

A thin section of a specimen of these rocks is illustrated in Plate V, *B* (p. 38).

Rocks characterized by primary chlorite.—In a rudely circular area about a mile in diameter, whose center lies near a point 1½ miles west of Flint Creek and about the same distance south of the north boundary of the quadrangle, the color of the upper Spokane beds changes along the strike from red to green through an alteration not elsewhere observed.

A thin section from a fine-grained specimen shows the usual textural features of the unaltered Spokane shale, although the rock is somewhat rich in carbonate. It is peculiar also in containing very abundant chlorite, evidently not derived from the fresh green biotite, which is associated with it in subordinate amount. Considerable tourmaline is present.

The development of chlorite is ascribed to contact metamorphism by some concealed intrusive mass, possibly similar to that exposed in the ravine that separates Henderson and Sunrise mountains.

Rocks composed essentially of quartz and mica.—The usual alteration of shaly rocks in the Spokane formation is to micaceous schists or hornstones similar to the common moderately altered phase of the argillaceous part of the Ravalli, though generally finer grained and colored in somewhat lighter tones of dull olive-green or gray.

The microscope shows the chief constituents to be quartz, colorless mica, and brown or greenish biotite. Feldspar, mostly orthoclase or microcline, occurs in about the same amount as in the unaltered rocks, and magnetite, apatite, zircon, leucoxene, rutile, and tourmaline are universally present. In some specimens nearly all the mica is colorless, but usually about half of it is greenish biotite. Among the minor constituents tourmaline and rutile are especially characteristic.

Locally the quartz-sericite rocks contain a ferruginous carbonate, which is abundantly developed in evenly disseminated imperfect rhombohedra several times larger than the quartz grains. They readily decompose, and their presence is indicated on weathered surfaces by little holes or flecks of limonite.

In the same way that the sandy shales grade into quartzose sandstones, the quartz-mica schists derived from the one grade into the slightly micaceous quartzites derived from the other. The moderately metamorphosed sandstone ranges in color from pale gray to dull greenish brown. A prevalent and characteristic feature of these rocks, especially common in the more micaceous types, is a more or less obscure dappling with dark-greenish spots about 2 millimeters in diameter.

Microscopic study shows that the metamorphosed sandstones contain the same minerals as the less siliceous rocks just described. The dappling is due to complete or partial segregation of brown or green biotite in the cement of certain portions.

Cordierite-bearing rocks.—Among the most characteristic rocks of the altered Spokane are those that contain cordierite. This mineral is developed in rather argillaceous beds, and is usually accompanied by andalusite; indeed, andalusite-bearing rocks without cordierite or some secondary material that has replaced it have not been found in this formation.

The cordierite rocks are gray and are thickly dappled with roundish darker spots a few millimeters in diameter—cross sections of cordierite and andalusite grains—which form warty protuberances on weathered surfaces. Some specimens are distinctly crystalline and contain large crystals of mica. Others are not distinctly crystalline, for cordierite may develop, like scapolite, in rocks whose original texture has not been obscured.

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

CHAPTER IV.

PALEOZOIC ROCKS.

CAMBRIAN SYSTEM.

GENERAL STRATIGRAPHY AND DISTRIBUTION.

The main lithologic features of the Cambrian rocks and their relative resistance to weathering and erosion are shown in the generalized section in figure 2. The distribution of the series and the location of the better exposures are briefly stated below.

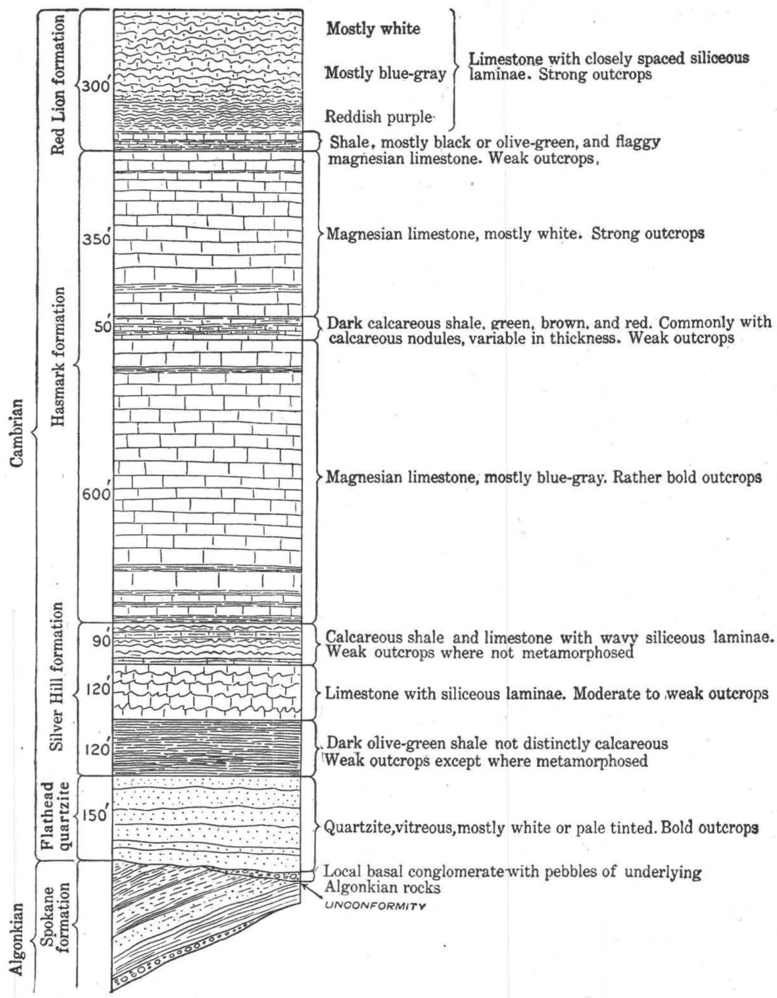


FIGURE 2.—Columnar section of Cambrian rocks.

The northernmost tract in which these rocks occur—that comprising Princeton and Flint—affords good sections of the Hasmark and Red Lion formations on the slopes north and south of Boulder Creek, just above its south fork.

In the anticlinal area east of Philipsburg there are excellent exposures of all the Cambrian formations. The area is of special interest because of the intense metamorphism there developed in the Paleozoic rocks, particularly in the Silver Hill formation. Metamorphosed Cambrian rocks are well exposed in the long strip flanking the Cable Mountain anticline, although some of the Hasmark is possibly cut out by faulting near the Red Lion mine. The exposures are good in the hills about Gold Coin, but the sections are not extensive. Toward the southeast the best exposures are in the bend of Warm Spring Creek. The southward-facing cliff west of the mouth of Foster Creek displays a fine section of the Flathead quartzite and the Silver Hill formation, with part of the rocks immediately above and below, and a mile or two farther north a steep westward-facing slope displays all but the lowest part of the Hasmark formation overlain by the Red Lion. In the area of complex faulting traversed by Lost Creek the Red Lion is wanting, and the Hasmark is so much deformed that its several members can not generally be distinguished. The lower part of the series, however, is well exposed in many places. In particular, the fine exposure of the Flathead northeast of the peak marked "8861" on the topographic map (Pl. II, in pocket) is worthy of note. Contact metamorphism is general in this tract, and on the borders of the porphyritic granite north of Lost Creek the Silver Hill and Hasmark are intensely metamorphosed.

The Cambrian occupies a considerable area in the western part of the Anaconda Range. The eastern slope of Silver Hill gives perhaps the best section in the quadrangle of the Hasmark and underlying formations. Other good sections occur in the drainage basin of the East Fork of Rock Creek and along the ridge about 2 miles northeast of the Carp mine. In a somewhat isolated tract about Mount Haggin the lower Hasmark occurs, underlain by the Silver Hill and the Flathead, both of which vary much in thickness in this vicinity, possibly owing in part to the intense shearing forces that have given rise to a great thrust fault on the south side of Mount Haggin.

UNCONFORMITY AT THE BASE OF THE CAMBRIAN.

An important unconformity between the Belt series and the Cambrian was long ago recognized by Walcott.[1] In the parts of Montana previously explored the chief evidence of this relation is the fact that at points not widely separated sandstone or quartzite lies upon beds of widely different position in the pre-Cambrian stratigraphic column. In the Philipsburg quadrangle this evidence of unconformity is also found, and in addition clear proof is given by visible angular discordance between Cambrian and Algonkian beds (Pl. VII) and by local development of a Cambrian basal conglomerate with pebbles derived from the Belt series.

The base of the Flathead quartzite lies on the Spokane formation everywhere in the Philipsburg quadrangle, but the thickness of red beds between the Newland formation and the Flathead varies from less than a hundred to several thousand feet.

The great thicknesses are developed mainly in the western part of the quadrangle. In the Anaconda Range and the southern part of the Flint Creek Range there is, broadly speaking, a rapid diminution in thickness toward the east and a less marked diminution to the south, but the same rule does not hold good for the northern part of the quadrangle. The Spokane appears to be at least 5,000 feet thick between the two Willow creeks but has been reduced to some 200 or 300 feet just west of Flint. From this point eastward it again rapidly thickens, and attains several thousand feet in the drainage basin of Boulder Creek.

In two cliff exposures first observed by MacDonald the Flathead lies upon the beveled edges of the Spokane. One is in the western part of the Anaconda Range, 1½ miles due east of the Carp mine; the other is half a mile northeast of the quartzite peak, 8,861 feet high, on the southern rim of Lost Creek drainage basin.

A photograph of the exposure east of the Carp mine is reproduced in Plate VII, *A*. The Spokane here strikes north-northeast and dips 50° or 60° W.; the Flathead strikes nearly north-south and dips 25° W. The contact is nearly plane.

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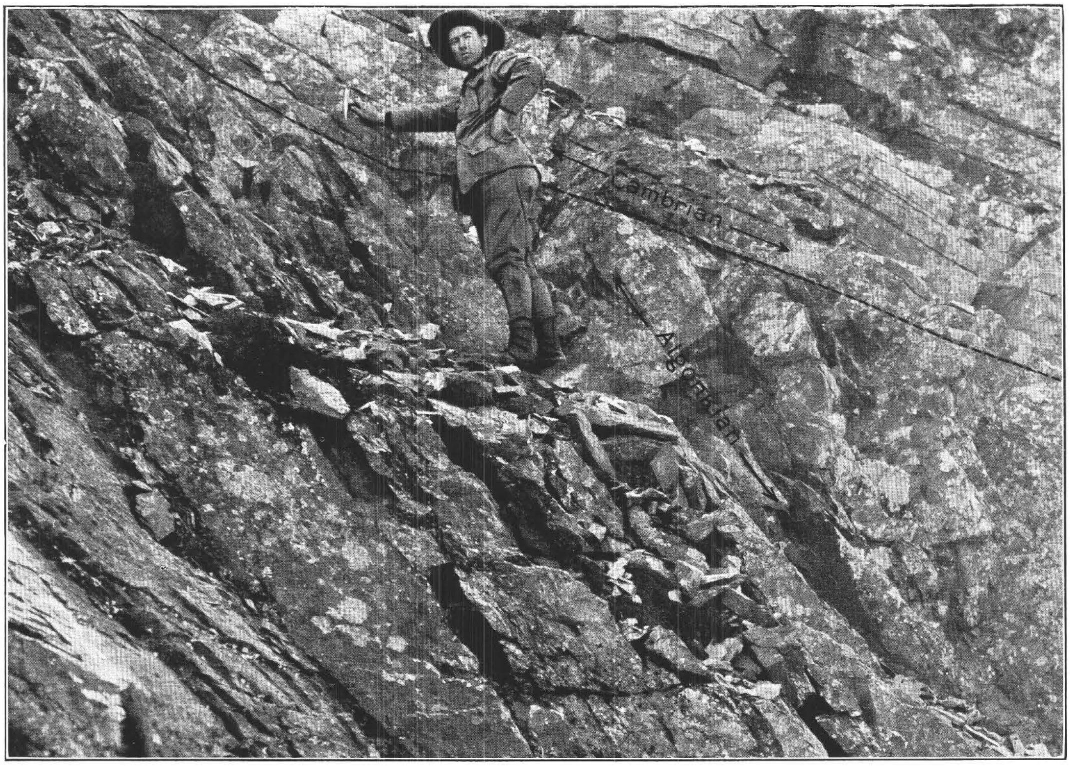
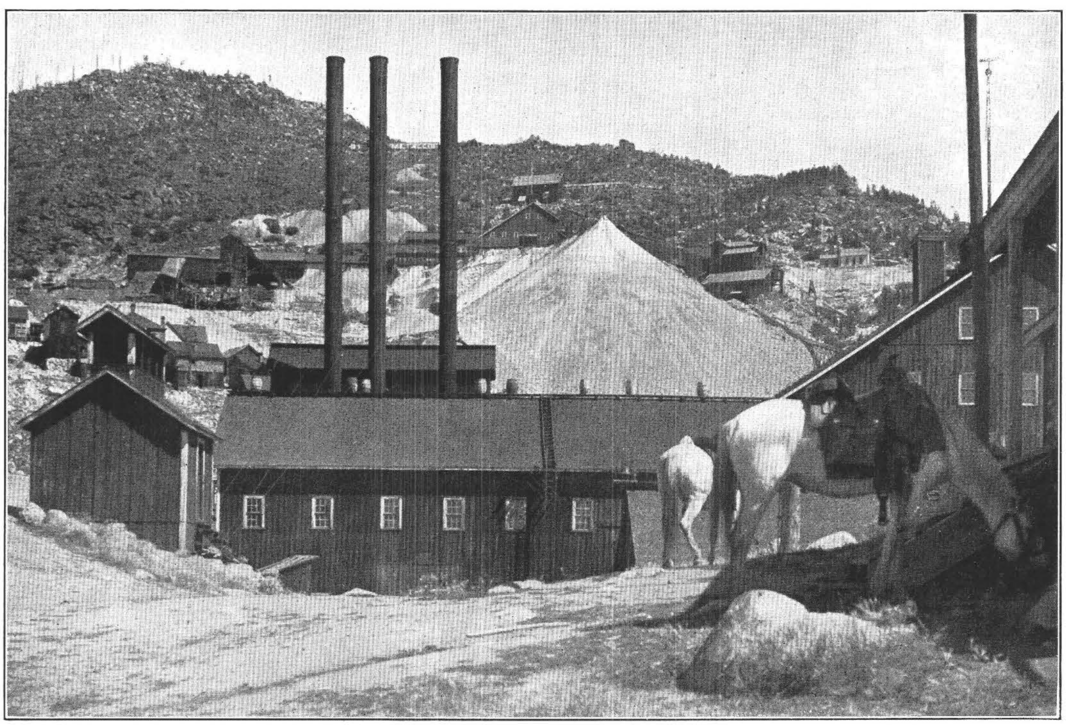
[1] Walcott, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199-244.



A. UNCONFORMABLE CONTACT OF CAMBRIAN FLATHEAD QUARTZITE ON ALGONKIAN SPOKANE FORMATION.



B. GRANITE-BIMETALLIC MINE, SHOWING WEATHERING OF GRANITE.

The relations in the exposure south of Lost Creek are shown in figure 3 from a sketch made on the ground. The discordance here is much less than at the locality shown in Plate VII, *A*. The Flathead quartzite strikes N. 60° E. and dips 21° W.; the sandstone of the Spokane formation immediately below strikes N. 58° E. and dips 25° W. The sandstone tapers to an edge near the crest of the divide between Lost Creek and Warm Spring Creek.

The main body of the Flathead on this cliff is a remarkably pure and massive quartzite, but at the base there is a lens of conglomerate whose relations at the northern end are shown

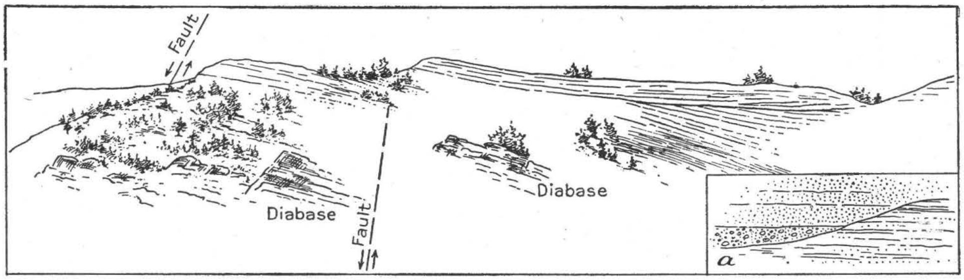


FIGURE 3.—Unconformable contact of Cambrian and Algonkian rocks south of Lost Creek.

diagrammatically in figure 3, *a*. It has been traced southward for a few rods, where it disappears under talus. No conglomerate has been found elsewhere in the quadrangle in beds known to be Flathead. The pebbles of this conglomerate, which has a rather sparse dark sandy matrix, are subangular to fairly well rounded; the largest are about 6 inches in diameter. They are all of light-gray quartzitic sandstone identical with that of the Spokane formation immediately underneath.

FLATHEAD QUARTZITE.

GENERAL CHARACTER AND THICKNESS.

The most characteristic rock of the Flathead in the Philipsburg quadrangle is vitreous white, gray, and drab quartzite. Its lower part, however, locally contains quartzitic sandstone not unlike some beds in the Spokane formation. For example, in the exposure that forms the subject of Plate VII, *A*, the two are in juxtaposition and are sharply delimited by the plane of unconformity, but lithologically they are not in striking contrast; the basal sandstones of the Flathead are only a little thicker bedded than those of the Spokane formation, but not much more quartzitic, and both have shallow-water markings. At the exposure south of Lost Creek, however (fig. 3), the white vitreous quartzite which constitutes most of the Flathead is in sharp contrast with the gray quartzitic sandstone of the Spokane just beneath it.

It is evident from these exposures that despite the great unconformity between them difficulty will often arise in exactly defining the limit between the Flathead and the Spokane. A sharp boundary can be drawn only where the unconformity is visible, or where the Flathead rests on shaly Spokane strata and the contact is marked by an abrupt lithologic change.

Accurate measures of thickness naturally can not be made except where one or the other of these conditions exists. The most reliable determination was made south of Lost Creek, where two independent observations gave 165 and 170 feet. The Silver Hill section and that west of Foster Creek give 140 to 150 feet, but these measurements are of less value, because the base is not so well defined. Rougher estimates of the thickness in the southwest quarter of the quadrangle range from 100 to 200 feet. The base of the formation just east of Philipsburg is not accurately located. About 250 feet of more or less quartzitic rock underlies the Silver Hill formation in this vicinity, but some of this rock is dappled and is probably Spokane.

In the vicinity of Flint and Princeton the apparent thickness of the Flathead is less than elsewhere in the quadrangle, and varies considerably—approximately between 20 and 100 feet—but strike faults are so prevalent as to make the observations of doubtful value. In the vicinity of Mount Haggin the thickness of the Flathead is extremely variable. It is about 50 feet in the pass at the head of Mill Creek, but on the ridge west of Mount Haggin it tapers out rather abruptly between the Spokane and Silver Hill formations. The exposure at this locality is good, and field examination indicated that the disappearance was due to overlap. On successive spurs to the southeast the quartzite is 5 to 75 feet thick, but near the east end of the exposure it expands to a thickness near 200 feet.

The following section illustrates the general sequence of beds in the Flathead quartzite:

Section of Flathead quartzite, east slope of Silver Hill.

Shaly quartzitic sandstone, light gray, with dark micaceous partings (base of Silver Hill formation).

Flathead quartzite.

	Feet.
Quartzitic sandstone, pale green	$1\frac{1}{2}$
Quartzite, drab, rusty weathering, comparatively thin bedded	20
Quartzite, pure and vitreous, drab to gray and white, thick bedded, passing near base into darker, impure quartzite	110
Quartzite, somewhat vitreous, rather thin bedded, banded and cross laminated with local unconformities, rusty on weathered surface	15
Thickness of Flathead quartzite	$146\frac{1}{2}$

Spokane formation (Algonkian).

Sandy shale and indurated flaggy sandstone, ripple marked, gray-green, weathering slightly rusty	100

LITHOLOGIC DETAILS.

The less purely siliceous parts of the Flathead quartzite are very like the more siliceous beds of the Spokane formation. As they have not been seen in wholly unaltered condition it is not known whether they are reddish when metamorphosed. They do not often show the dappling that is characteristic of metamorphosed Spokane sandstone.

More noteworthy, because more characteristic, is the purer quartzite. Some of this, on fresh fracture, is nearly white, and is evidently composed almost wholly of glassy quartz grains, considerably less than 1 millimeter in average diameter.

Microscopic examination shows that the boundaries of the clastic grains are more readily obliterated in the pure quartzites than in the quartizitic sandstones characteristic of the Spokane formation, where the sericitic cement remains distinguishable as such even when much recrystalized; for example, a thin section from a specimen taken west of Barker Creek, where all the rocks are moderately metamorphosed, shows that the prevailing constituent is quartz in irregular interlocking grains averaging 2 millimeters in diameter and attaining a maximum of 4 millimeters. A specimen containing a good deal of orthoclase, obtained northeast of Rumsey Mountain, gives clearer evidence that certain quartz individuals may annex much of the substance of neighboring grains. The original diameter of the sand grains is about that of the isolated feldspar grains, or between 0.25 and 1 millimeter. Many individuals of quartz, however, are as much as 5 millimeters in diameter and have boundaries intricately embayed; a cross section like a clumsy S or L is not uncommon. These larger individuals, which enwrap or inclose feldspars and smaller grains of quartz and tourmaline, have evidently been enlarged in a way that involves a far more thorough rearrangement of material than that involved in the type of secondary enlargement usually figured in textbooks.

The coarser and purer of the two specimens described resembles greatly the typical Neihart quartzite except that the grains are not flattened and are little strained.

SILVER HILL FORMATION.

PRINCIPAL FEATURES.

The name Silver Hill formation is new and is taken from the eminence south of Silver Lake, on whose steep east face the best section is displayed.

The formation as exposed in this type section may be considered as formed of three members, which are, in descending order, as follows:

Generalized section of Silver Hill formation.

	Feet.
Shales, calcareous, strongly banded in brown, white, and green, interbedded with laminated limestone	90
Limestone with thin brown siliceous laminæ	120±
Shale, dark green, not notably calcareous, with a 3-foot sheet of dark intrusive igneous rock near the base	120
	330±

The highest and middle members are not distinct, for they are composed of similar materials, but they show rather sharp lithological contrast with the lowest member, and it would be more strictly logical to map the dark-green shales as one formation and the overlying rocks as another, or even to make a threefold subdivision. The mapping of all these strata as a unit was determined by two considerations: First, the representation of smaller units on the map would be mechanically difficult and would obscure rather than elucidate the structure; second, all the rocks of the formation as mapped are alike in the characteristic most obvious in the field—they are much more susceptible to erosion than the Flathead quartzite below and the dolomitic Hasmark formation above—and they therefore usually occupy topographic depressions and are poorly exposed; about Princeton, indeed, exposures are entirely wanting. For this reason the discrimination of the three members is impracticable in many places.

Despite their comparative weakness, the rocks of the Silver Hill formation in a virtually unaltered state are well exposed in the drainage basin of the East Fork of Rock Creek. In most good exposures, however, including that on Silver Hill, these rocks are noticeably affected by igneous metamorphism, by which, like the somewhat similar rocks of the Newland formation, they are greatly indurated.

The thickness of the Silver Hill formation appears to be fairly uniform in the northern and middle parts of the quadrangle, but varies considerably in the Anaconda Range. At the Carp mine it is inconspicuous and apparently thinner than in most places, but 3 miles northeast, in a section which does not appear to be faulted, both the calcareous and noncalcareous parts are of about twice their normal thickness. On the bank of the East Fork of Rock Creek the Hasmark rests on the Flathead, but there are evidences of faulting, which may account for the absence of the Silver Hill. A few rods east of the creek its apparent thickness is about 100 feet. The fine section northwest of the peak, 10,005 feet high, east of Rock Creek, is similar in character and thickness to the Silver Hill section. In the vicinity of Mount Haggin, the Silver Hill formation is generally not more than 100 feet thick, and apparently transgresses the Flathead, so that its upper, limy portion rests on the Spokane.

LITHOLOGIC DETAILS.

LOWER PART.

The shales of the lower part are mostly of a remarkably uniform olive-green color, without distinct banding. The bedding is accentuated, however, by thin sharp-edged whitish lenses, generally a few millimeters thick and a few centimeters broad, forming a rather small proportion of the mass. The presence of these lenses is a distinctive feature of this member. The unmetamorphosed shale is very fissile and may be split into plates no thicker than ordinary pasteboard. The visible effects of incipient metamorphism are darkening and induration; the altered shales are not so fissile and may be broken across the bedding almost as readily as parallel to it. Microscopic sections from slightly altered specimens of the lower green shales reveal textures like those of the finer phases of the Spokane. The coarser parts include angular to subangular grains of quartz and subordinate feldspar, about 0.1 millimeter in maximum diameter, in a groundmass very rich in sericite and green biotite. The finer parts are essentially an almost cryptocrystalline mixture of these three constituents. A little epidote and tourmaline commonly occur in grains or crystals up to several tenths of a millimeter in diameter, and are evidently of contact-metamorphic origin. When considerably metamorphosed, the lower shales are changed to cordierite hornstones like those described in connection with the Spokane. Megascopically they are gray, more or less distinctly "knotty," and dappled with dark spots, commonly 1 millimeter to 3 millimeters across. In some specimens grains of mica 1 millimeter or more in diameter are conspicuous.

A microscopic section of a highly altered specimen from the south end of Cable Mountain shows highly poikilitic grains of cordierite and smaller imperfect prisms of andalusite in a matrix composed for the most part of limpid polyhedral grains of orthoclase. Quartz occurs only in very small amount, forming one or two lenticular aggregates of coarser texture than the orthoclase and a sort of graphic intergrowth with andalusite. Other constituents are biotite, tourmaline, sillimanite, magnetite, and zircon. The tourmaline is exceptionally abundant and well crystallized. (See Pl. XV, *A*, p. 130.)

In most specimens cordierite and andalusite have been more or less completely altered to fine-grained aggregates of mica. The pseudomorphs after andalusite consist wholly of colorless mica; those after cordierite of mingled colorless and greenish-brown varieties.

MIDDLE PART.

The general appearance of the laminated limestone characteristic of the middle division of the Silver Hill formation is remarkably similar to that of the rock forming most of the Red Lion formation, an outcrop of which is shown in Plate X, *A* (p. 61). The rock as a whole is moderately thick bedded, but its most conspicuous feature is the alternation of thin laminæ markedly different in relief. The greater part of the rock is nearly pure limestone of white, pale gray, or pale drab tint. The thinner laminæ alternating with those of limestone are of a darker siliceous material, gray or brown in color, resembling chert, and project in relief on weathered surfaces. They average somewhat less than 0.5 centimeter in thickness and are spaced at intervals of about 1 or 2 centimeters. This description applies to the slightly metamorphosed condition that the rock has in its type exposure. Where there is no appreciable contact metamorphism, as in the vicinity of Princeton and in the best exposures in the basin of the East Fork of Rock Creek, the limestone parts more readily, and weathered surfaces of the siliceous layers are dull and stained with ocher, the appearance of the rock then recalling the description of the "mottled limestones" of the Cambrian in the earlier Montana folios, although these publications do not emphasize a laminated character. The limy layers are not very magnesian—distinctly less so than the limestones of the overlying Hasmark. They contain a little quartz, apparently clastic, and the siliceous layers contain some carbonate.

UPPER PART.

The banded shales predominant in the uppermost part of the Silver Hill formation are interbedded with the laminated limestones and grade into them; indeed, the limestones pass to the shales by diminution of the calcite layers in purity and thickness. The least limy rock of the uppermost division in the Silver Hill section of the formation is a brownish calcareous shale with thin whitish or greenish layers. The color in the chocolate-brown layers of the slightly metamorphosed limy rocks is due to biotite, and that of green layers to amphibole or pyroxene developed by metamorphism. The unmetamorphosed shale would probably be of a drab or a dull olive-green hue.

The calcareous beds in the upper part can suffer considerable contact metamorphism without conspicuous change in megascopic appearance. This is illustrated by a specimen of the laminated limestone from the section west of Foster Creek. Megascopically metamorphism is suggested merely by a slight coarsening of texture, but the microscope reveals very considerable alteration. The brown siliceous laminæ consist principally of potash feldspar, reddish-brown biotite, and diopside, with a little calcite, epidote, titanite, and lime-rich feldspar, and a few relatively large crystals of greenish-brown tourmaline crowded with inclusions of the other minerals. Quartz is absent. Except for the tourmaline crystals, which may be several millimeters in diameter, the minerals occur in minute grains measurable in fractions of a millimeter.

A specimen of calcareous shale of the uppermost division found northeast of the Red Lion mine resembles the amphibole-bearing hornstones derived from the Spokane a little farther west (p. 47) but contains no scapolite.

Extremely powerful metamorphism of the Silver Hill formation is exemplified at Philipsburg. Here the calcareous shales and limestones are altered to rocks of irregular and, as a rule, coarse texture, characterized by garnet, pyroxene, amphibole, scapolite, epidote, and magnetite. Most of them may be roughly grouped as rocks rich in garnet and rocks rich in scapolite. None contain both minerals abundantly. Rocks rich in magnetite occur in smaller amounts.

In the rocks of the first class the chief constituent is a dark reddish-brown garnet, with which is mingled irregularly in thin, ill-defined subparallel layers a green microcrystalline substance consisting mainly of pyroxene with more or less epidote. A little calcite can usually be detected by turning the specimen about in a good light to catch reflections from the bright cleavage faces broken by inclusions. These reflections show the calcite to be crystallographically continuous in places over a diameter of several inches. Other constituents visible microscropically are amphibole, titanite, chlorite, quartz, and zircon.

The scapolite rocks that do not contain magnetite are light to dark greenish gray and contain the same minerals as the scapolite rocks derived from the Newland (p. 43), but their texture is coarser. Poikilitic development of calcite is beautifully exemplified in some specimens where the lacelike mottled reflections are continuous over diameters of 2 or 3 inches. The scapolite in these specimens forms clear, slender striated prisms about 1 centimeter long, not conspicuous except on weathered surfaces. Amphibole and pyroxene form relatively minute crystals. In other specimens where calcite is scarce the scapolite forms more irregular and very much larger individuals, some of them an inch or two long, inclosing the green silicates. Minor constituents of these rocks are titanite, quartz, epidote, and pyrite.

Magnetite has been formed locally by partial replacement of the constituents of the Silver Hill formation, and is intimately associated with some of the metamorphic minerals occurring in the rocks just described. The replacement is in some degree selective and follows certain beds, presumably the more calcareous, so that the magnetite rocks are in part distinctly banded. Alternate layers are chiefly magnetite in granules less than 1 millimeter across, with some interstitial amphibole, iron-poor epidote, and quartz; the layers between are chiefly of finely divided amphibole, epidote, and calcite.

In another type scapolite is abundant. White strips of the mineral about 1 centimeter long, lying in all positions, are conspicuous in a matrix chiefly magnetite, mixed with some finely divided green amphibole and poikilitic calcite. Under the microscope some epidote and a little titanite appear. The textural relations indicate a simultaneous growth of magnetite, amphibole, and scapolite.

In the contact zone of the porphyritic granite north of Lost Creek, the upper Silver Hill is largely altered to obscurely laminated rocks rich in greenish to brownish yellow vesuvianite and containing also diopside, epidote, calcite, quartz, and a very little scapolite.

TYPICAL SECTION.

The following detailed section illustrates the sequence of strata of the Silver Hill formation and its transition to the Flathead below and the Hasmark above. As these transitions are gradual, it is in some degree a matter of arbitrary choice where the limits of the formation shall be fixed, but the lowest dolomite above is called the base of the Hasmark. and the highest vitreous quartzite below is called the top of the Flathead. The section is composite, the part above the main body of laminated limestone being exposed on the cliff west of the mouth of Foster Creek and the remainder on Silver Hill. Slight metamorphism exists at both localities.

Section of Silver Hill and contiguous formations, from exposures at Silver Hill and at the cliff west of the mouth of Foster Creek.

Hasmark formation (lower part).

	Feet.
White and gray dolomite, such as constitutes most of the Hasmark formation.	
Dolomite, blue-gray to white, more or less tinged with buff on weathered surfaces; lower part thin bedded	33
Dolomite, drab, yellow on weathered surface, very fine grained	$\frac{1}{2}$
Impure shaly magnesian limestone, pale green to white	5
Shale. calcareous, very fine grained, banded in gray-brown to greenish white, alternating with very fine grained pale gray-green siliceous dolomite or magnesian limestone	3
Dolomite, shaly, medium grained, blue-gray to white on fresh fracture, gritty and more or less stained with yellow on weathered surface	4

Silver Hill formation.

Shale, calcareous, banded in white, pale green, and brown, with white predominating; weathered surface much stained with limonite	7
Shale, calcareous, banded in chocolate-brown to white, with brown predominating; less fine grained than that above; contains bunches of black tourmaline	8
Magnesian limestone, shaly, interbedded with calcareous shale, drab to brown on fresh fracture; stained with limonite on weathered surface	10
Impure limestone banded in chocolate-brown to white; most laminæ one-fourth inch to 1 inch; darker laminæ weather very slightly in relief; an undivided bed	$1\frac{1}{2}$
Green and brown fine-grained shale, grading into laminated impure limestone; like the bed above, but more conspicuously banded; contains bunches of tourmaline	5
Grades into fine-grained, less calcareous, very strongly banded shale; laminæ average about one-half inch in thickness; color, very dark grayish green with a tinge of brown to nearly white or greenish, the dark predominating	$5\frac{1}{2}$
Rock similar to the above bed, almost entirely dark	2
Rock composed of laminæ $1\frac{1}{2}$ inches in average thickness, of fairly pure light-gray limestone and the dark brownish-green material of the above beds; the latter weathers in relief	$1\frac{1}{2}$
Grayish-green shale	2
Laminated limestone, with very fine grained dark-green siliceous layers	$1\frac{1}{2}$
Laminated limestone in which the dark layers are coarse, and evidently rich in biotite; contains bunches of tourmaline; calcareous and siliceous layers about equal in volume; grades into rocks above and below	7
Shale, distinctly banded, fine grained, composed of chocolate-brown laminæ about one-half inch in average thickness, alternating with thinner, less continuous, nearly white laminæ	12
Laminated limestone, with more calcareous material than siliceous material	6
Laminated limestone, with more siliceous material than calcareous material	1
Limestone, impure but not distinctly laminated	$1\frac{1}{2}$
Shale, chocolate-brown, with white to pale-green bands; has a thin layer of impure limestone near top	9
Impure laminated limestone, white, gray, and drab, with irregular wavy anastomosing layers of chocolate-brown siliceous material one-fourth inch to 1 inch apart	120
Shale, greenish black, with thin lenticular laminæ of whitish material a fraction of an inch thick, and a layer of lighter green and more distinctly banded shale near base	120

Flathead quartzite (upper part).

Shaly quartzitic sandstone, light gray, with dark micaceous partings	$2\frac{1}{2}$
Quartzitic sandstone, pale green	$1\frac{1}{2}$

CHEMICAL CHARACTER OF LOWER PART OF THE SILVER HILL FORMATION.

The orthoclase-rich cordierite-bearing hornstone described on page 54 must evidently be richer in potash than most sedimentary rocks. As some evidence was obtained that alkalies were added to the Newland rocks by magmatic solutions, it was surmised that the potash of the rock in question might have had in part a similar source. To test this hypothesis, analyses were made of this rock and of apparently unmetamorphosed lower shale of the Silver Hill formation from the southwest slope of Cable Mountains. The less-altered rock is fine grained, fissile, and olive-green in color. A thin section shows the main constituents to be quartz, sericite, and a green mica. Little nests of chlorite, grains and crystals of magnetite, and numerous slender prisms of tourmaline also appear. Most of the mineral particles range in diameter from 0.01 millimeter to 0.1 millimeter. The tourmaline is evidently not clastic, and is probably to be considered an evidence of slight contact metamorphism. The metamorphism, however, is obviously very much less than that undergone by the orthoclase-rich hornstone described on page 54 and illustrated in Plate XV, *A*, page 130. The analyses of the two rocks, however, show remarkable similarity, especially as regards the potash content, which is slightly greater in the less-altered rock. The analyses, therefore, give no evidence that metamorphism has been attended by addition of potash. They indicate, however, that the original rock is remarkably rich in potash and that the deposits from which it was formed may have been glauconitic.

In these analyses specimen 1 is slightly altered shale from the southwest slope of Cable Mountain, and specimen 2 is orthoclase-rich cordierite hornstone from a prospect northeast of Cable.

Analyses of rocks from lower part of Silver Hill formation.

[Analyses by W. T. Schaller.]

	1	2
SiO_2	53.29	63.47
Al_2O_3	22.38	17.33
Total iron as FeO	6.57	5.09
TiO_2	.91	.96
MgO	2.10	1.32
CaO	.53	.64
K_2O	7.43	7.09
Na_2O	1.11	.50
H_2O [a]	4.12	2.66
CO_2	.58	.36
	99.02	99.42

[a] Determined by loss on ignition, corrected for CO_2 and oxidation of ferrous iron.

HASMARK FORMATION.

PRINCIPAL FEATURES.

The Hasmark formation is named for an abandoned settlement southeast of Philipsburg. The formation is not particularly well exposed at that locality, but the dearth of geographic names in the quadrangle made it impossible to find one more appropriate.

The general sequence in the Hasmark formation, as shown in Plate VIII, is, in ascending order, (1) magnesian limestone, mostly blue-gray, about 550 feet; (2) calcareous shale, 150 feet or less; (3) magnesian limestone, mostly white, about 350 feet.

LITHOLOGIC DETAILS.

LOWER MAGNESIAN LIMESTONE MEMBER.

The rock that constitutes the greater part of the lowest member of the Hasmark is a magnesian limestone, which forms beds of moderate thickness. It generally exhibits on weathered surfaces a characteristic light dirty bluish-gray tint and on fresh fracture a somewhat darker and purer tint of blue-gray. Its compact crystalline texture of moderately fine, and as a rule very uniform, grain is made manifest by the pearly reflections from the faces of crystals usually much less than a millimeter in diameter. The weathered surfaces are gritty, not, as might be supposed, from the projection of sand grains out of a more soluble cement, but from differential solution of the carbonate crystals. The rock is harder than true limestone, and the application of cold dilute acid produces no effervescence except on bruised edges and crevices where finely divided material is exposed to its action. The details of weathered surfaces exhibit less markedly the effects of solution by atmospheric waters and a less complete rounding of corners than pure limestone. These features indicate the magnesian character of the rock.

The following chemical determinations were made by W. T. Schaller on a typical specimen:

	Per cent.
Insoluble in hydrochloric acid	0.45
CaO soluble in hydrochloric acid	44.33
MgO soluble in hydrochloric acid	6.46

Although the lower limestone of the Hasmark formation yields no identifiable fossils, it has some lithologic features that are possibly of organic origin and that may serve, like fossils, as aids to correlation. (See Pl. VIII.) These features are stated below.

1. An obscure mottling in lighter and darker gray on weathered surfaces is very common. Its appearance is shown in Plate VIII, *C*. The darker patches, which stand in slight relief, are more coarsely crystalline than the lighter patches, and apparently look darker only because they are rougher. They seem relatively richer in dolomite.

2. Weathered surfaces locally show an alternation of the lighter and darker materials in obscure bands about 1 centimeter broad.

3. The blue-gray to black limestone commonly incloses white vermiform, twiglike, or pinlike bodies about 1 millimeter to 3 millimeters thick and 1 centimeter or more in length. These resemble somewhat the altered coral remains found in the Jefferson limestone, although they are much smaller and more sparsely distributed in the rock mass. (See Pl. VIII, *B*.)

4. A feature peculiar to the lower magnesian limestone of the Hasmark formation is the oolitic structure illustrated in Plate VIII, *A* and *D*. The ellipsoidal oolites are darker than their matrix, and are especially conspicuous on the weathered surface. They ordinarily occur in two generations of markedly different size; the diameter of the larger ones is about 1 centimeter, and that of the smaller ones, which are partly clustered into berry-like masses, is about 0.5 millimeter.

The form is that of flat lenses about five times as broad as they are thick, sections parallel to the flat sides being nearly circular. The larger bodies show concentric banding.

In thin sections from the purer limestone of the lower Hasmark the grains, which are in part irregular, commonly show a more or less idiomorphic outline. They are clouded to a greater or less extent with a fine dust, presumably carbonaceous. Aside from this material the rock is almost entirely composed of carbonate and contains only scattered particles of quartz and mica.

SHALE MEMBER.

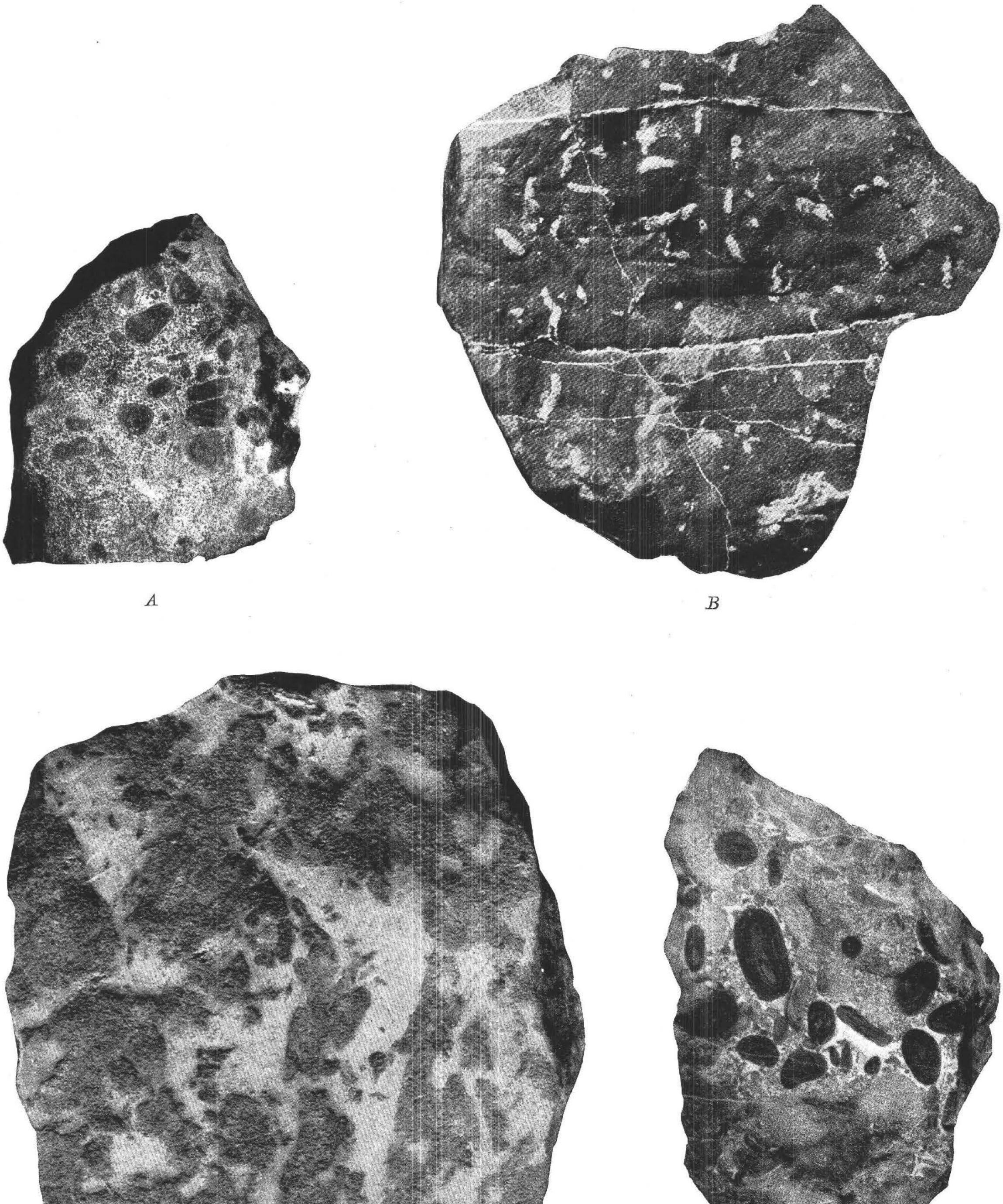
The most characteristic rocks of the shale member where it is thick are similar in type to those dominant in the uppermost division of the Silver Hill formation. They consist, broadly speaking, of more or less calcareous shales, but chocolate-brown material predominates notably over the greenish rocks, and the gray fine-grained limestone associated with the argillite tends to form nodules and lenses less than 1 inch thick rather than continuous layers. On weathered surfaces the limestone masses are sunken.

UPPER MAGNESIAN LIMESTONE MEMBER.

The dominant rock of the upper member is thick-bedded fine-grained magnesian limestone, cream-white on weathered surfaces but slightly grayish on fresh fractures.

The upper limestone resembles the lower except that it is paler and finer grained and does not show the peculiar markings described above.

Microscopic examination of this upper limestone reveals the same tendency, already observed in the lower member, to partial expression of crystal form in the outer boundaries of carbonate grains. Impurities consisting of small grains of quartz and particles of sericite are more common than in the earlier limestone and constitute a noteworthy proportion of the basal beds.



CHARACTERISTIC FEATURES OF THE LOWER LIMESTONE OF THE HASMARK FORMATION.

A and *D*, Oolitic structure; *B* and *C*, Mottling due to projection of larger crystals (of dolomite?), *B* showing also white twiglike, possibly organic bodies.

TYPICAL SECTIONS.

Typical sections of the Hasmark formation follow:

Partial section of Hasmark formation on Warm Spring Creek 3 miles southeast of Cable.

Shale, coal-black, fine grained, brittle and homogeneous (base of Red Lion formation).

Hasmark formation.

UPPER MAGNESIAN LIMESTONE MEMBER.

	Feet.
Magnesian limestone, white, weathering yellowish, with some irregular bunches of pale-green cherty material in which amphibole is developed by contact metamorphism	4
Magnesian limestone, white, weathering slightly yellow, without chert	15
Magnesian limestone, fine grained, slightly gritty on weathered surfaces, mostly cream-white, although the lowest exposed is pale bluish gray	250±
Unexposed; probably magnesian limestone for the most part	90

SHALE MEMBER.

Unexposed; float indicates rock like that below	25
Shale, banded in chocolate-brown and green, interlaminated with lenses and layers, averaging about 1 inch in thickness, of light-gray limestone, which forms about 40 per cent of the whole	20
Shale, banded in chocolate-brown and green, with ellipsoidal masses of limestone at the top	3
Shale, chocolate-brown, interlaminated with limestone in laminæ about one-half inch to 3 inches thick	1½
Shale, banded in chocolate-brown and green	3
Limestone, pale drab, sugary	1
Shale, mostly chocolate-brown with green laminæ	1
Unexposed; probably shale	12
Chocolate-brown and green shale interlaminated with limestone	3
Unexposed; probably shale	10
Shale, banded in chocolate-brown, with thin laminæ of harder light-green material and of limestone, mostly in layers, and lenses about one-half inch in average thickness, but which forms two layers about 1 foot thick	14
Magnesian limestone with thin siliceous partings, white to blue-gray on fresh fracture, but deeply stained with limonite on weathered surfaces	3

LOWER MAGNESIAN LIMESTONE MEMBER.

Magnesian limestone, somewhat softer than the typical dolomite, blue-gray, beds mostly 2 or 3 feet thick, but thinner above	20±
Magnesian limestone, white, drab, and blue-gray, stained with limonite	3
Shale, banded, mostly chocolate-brown, with lenses and discontinuous layers of limestone about one-half inch thick and about 1 inch apart	3
Magnesian limestone, pale brownish gray	1
Argillite, fine grained and calcareous, white, dark greenish gray, and brown, weathering rusty	3
Shale and flaggy limestone, brown, imperfectly exposed	6
Unexposed	6
Sandstone, fine grained, calcareous, pale greenish gray	4
Magnesian limestone, dark blue-gray and mottled	8
Calcareous sandstone and shale	2
Magnesian limestone like second layer above	4
Argillite, siliceous, pale greenish gray, weathering white to orange	4
Magnesian limestone, dark blue-gray, mottled and of medium grain, containing white vermicular bodies; probably belongs to the main mass of the lower dolomite	20+

Section of Hasmark formation and base of Red Lion formation on east slope of Silver Hill.

Red Lion formation.

	Feet.
Shale	5+

Hasmark formation.

UPPER MAGNESIAN LIMESTONE MEMBER.

Magnesian limestone, cream-white, fine grained	335

SHALE MEMBER.

	Feet.
Concealed, probably shale for the most part (some dolomite possibly cut out by faulting)	50

LOWER LIMESTONE MEMBER.

	Feet.	
Magnesian limestone, mostly blue-gray, partly concealed	250	
Magnesian limestone, blue-gray, medium to very fine grained, with sharp jointings, the edges of the joint blocks slightly rounded	50	
Magnesian limestone, nearly white	90	
Magnesian limestone, cream-white on fresh fracture, blue-gray on weathered surface	45	
Magnesian limestone, medium to fine grained, blue-gray and white	100	
Thickness of lower limestone member exposed		535
Unexposed, part Hasmark and part Silver Hill formation		90

HORIZONTAL VARIATIONS IN THE SHALE.

The foregoing sections in their main features are typical for the entire quadrangle so far as the dolomites are concerned; these do not show any considerable variations in thickness nor any important variations in lithologic character apart from the effects of metamorphism.

The shale, however, varies considerably in both composition and thickness. Imperfect exposures much affected by contact metamorphism indicate that in the southeastern part of the quadrangle it everywhere has much the same character as in the Warm Spring Creek section. Sections that show a different phase of the shale in unmetamorphosed condition, occur in the western part of the Anaconda Range near the Carp mine, where it is represented by a reddish-purple calcareous layer about 20 feet thick, and on the west slope of Cable Mountain, where it consists in greater part of drab, yellow-weathering shale, very fine grained and homogeneous. The thickness here is apparently less than to the southeast.

In the vicinity of Philipsburg and along Boulder Creek below Princeton the shale member is thinner and less conspicuous than at the localities mentioned. It is not exposed at Philipsburg, although a thin stratum of weak rocks is locally indicated there by a depression between the upper and lower limestone members. Near Boulder Creek about 25 feet of interbedded ferruginous limestone and shale, in part sun cracked, represent the shale member of the Hasmark formation.

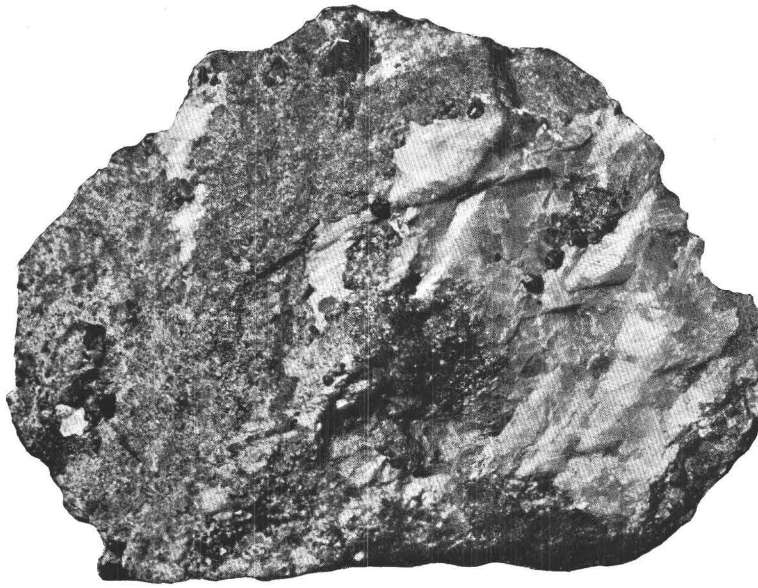
EFFECT OF CONTACT METAMORPHISM.

LIMESTONE.

Contact metamorphism has the same general effect on both magnesian limestones, and it also lightens the color of the lower limestone by expulsion of inclosed carbonaceous matter. It is therefore difficult to distinguish the two limestone members where both are metamorphosed.

The limestones of the Hasmark formation are not, as a rule, so much coarsened by metamorphism as the less magnesian limestones of the higher formations, such as the Mississippian. Even strong metamorphism will generally make the average diameter of the grains only about twice what it was before metamorphism and notably coarse textures are rarely produced. The metamorphic minerals characteristic of the Hasmark limestones are forsterite, diopside, humites, tremolite, phlogopite, spinel, and pale chlorites. Their development is most common in the southeast part of the quadrangle, especially in the contact zone of the porphyritic granite south of Thornton Creek, where the forsterite and chlorites form large crystals. The formation of magnetite deposits at certain granite contacts, notably at Cable, is perhaps to be considered a special case of metamorphism of the Hasmark limestones (Pls. IX, *B;* XV, *B*, p. 130). The magnetite deposits are discussed on pages 129, 186.

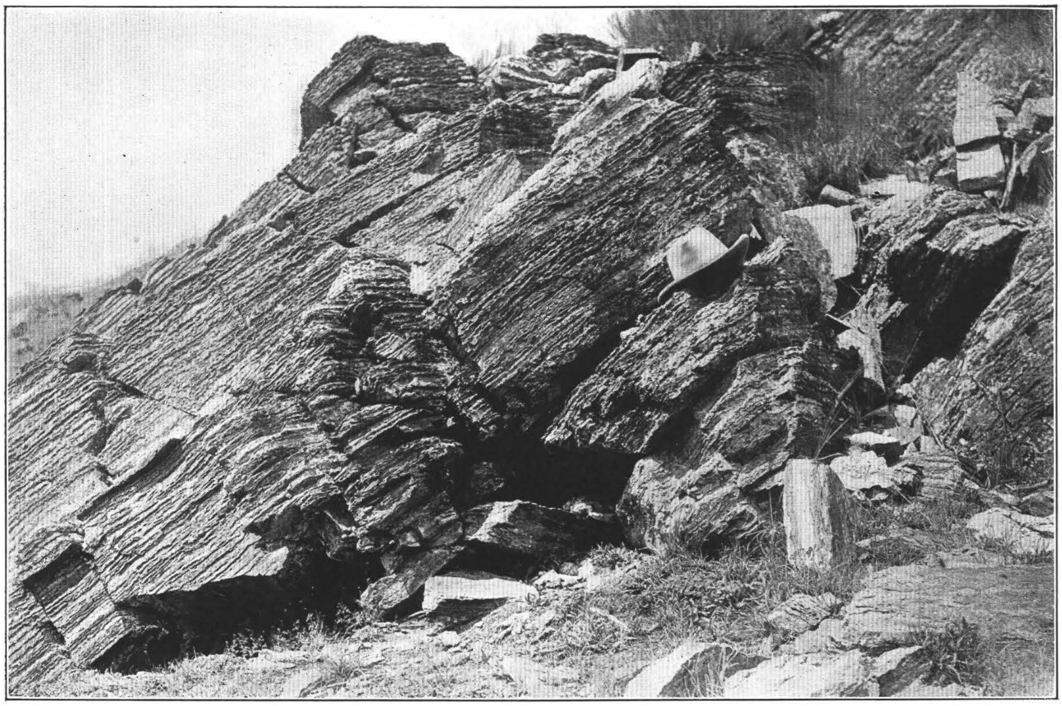
Diopside is always inconspicuous, and so is tremolite except where it forms spherulitic aggregates. Forsterite does not readily catch the eye when fresh, for it is almost colorless; but when partly decomposed to a yellowish serpentine, as it commonly is, it is more conspicuous. Its common form is that of relatively slender prisms a few millimeters long, and about 1 millimeter thick. Minerals of the humite group form small orange-colored grains that are easily



A. GARNET ROCK FORMED BY INTENSE METAMORPHISM OF THE LOWER PART OF THE RED LION FORMATION.

Shows garnet crystals, calcite, and magnetite (black granular mass near center), intimately associated with fine granular aggregate of metamorphic minerals, chiefly garnet, pyroxene, amphibole, and epidote.

B. MAGNETITE IN LIMESTONE; FROM AN INCLUSION IN GRANODIORITE NEAR CABLE.



A. SILICEOUS LAMINATED LIMESTONE OF RED LION FORMATION NEAR GOLD COIN.

B. CHERTY MADISON LIMESTONE NORTH OF STEWART GULCH.

recognized. Pale phlogopite and chlorite generally form minute spangles not easy to discriminate except by the aid of the microscope. At the locality south of Thornton Creek the chlorite, which is of the nearly colorless variety leuchtenbergite, forms well-developed, squat prisms about an inch in diameter. Deep-green spinel forms crystals generally of almost microscopic size, but so large in places that their octahedral form is apparent.

SHALES.

The most evident effect of slight metamorphism on the shales of the Hasmark is development of biotite, which colors them chocolate-brown. The effect of more intense metamorphism is much the same as on the rocks of the Silver Hill formation. Cordierite hornstones occurring in Olson Gulch are apparently the highly metamorphosed equivalents of the least calcareous phase of the Hasmark shales. The rocks with bands and nodules of limestone are altered to hornstones consisting essentially of quartz, calcite, biotite, diopside, and locally scapolite.

RED LION FORMATION.

PRINCIPAL FEATURES.

The Red Lion formation is named for a mine at the head of the North Fork of Flint Creek. The spur north of this mine is a hogback of the formation and affords a good exposure of its middle part.

The Red Lion formation comprises two members. The upper and thicker member consists of laminated limestone, a typical exposure of which is shown in Plate X. The lower member is chiefly calcareous shale, locally interbedded with flaggy magnesian limestone. The total thickness of the formation is about 300 feet.

LITHOLOGIC DETAILS.

LAMINATED LIMESTONE MEMBER.

The proportion of siliceous material to limestone is greater in the lower than in the higher beds of the limestone member. The highest layers ascribed to the formation are of white limestone, with thin, rather widely spaced siliceous laminæ that weather yellow or orange. In the main body of the formation the limestone is drab or blue-gray and predominates in volume over the siliceous material, which weathers dull yellow, brown, or red.

Near the base the proportion of siliceous matter increases, the limestone becomes subordinate and much of it is in isolated nodules or lenses. The siliceous layers are deep reddish-purple and the limestone a lighter shade of the same hue.

The limestone of the formation is evidently not very magnesian, for it effervesces freely on the application of weak acid and the microscope shows the carbonate grains to be anhedral. It is as a rule rather fine grained. The laminæ that stand out in relief on weathered surfaces are hardly siliceous enough to be called chert. Under the microscope they appear to consist of about equal parts of quartz in very minute grains and an aggregate of carbonate and sericite.

In the vicinity of Princeton the Red Lion formation contains beds made up of small subangular pieces of limestone embedded in somewhat argillaceous material. These beds appear to be intraformational conglomerates, the fragments being derived not as in ordinary conglomerates from an older terrane and transported a considerable distance, but more probably from the breaking up of slightly compacted calcareous ooze by wave or current action and the redeposition of the fragments within a short distance.

The effect of metamorphism on the laminated limestone is essentially the same as on the similar rocks of the Silver Hill formation. Near Twin Peaks the siliceous layers are altered to material rich in vesuvianite, and near Cable the laminated limestones are altered to banded hornstones very rich in magnetite, the other essential constituents being calcite, amphibole, and scapolite.

SHALY MEMBER.

The exposures of the shaly member in the vicinity of Cable and Warm Spring Creek show a predominance of fine-grained, almost coal-black shale, which is locally characteristic of the lower Red Lion, distinguishing it especially from the underlying brownish shales of the Hasmark formation. The formation comprises, however, some olive-green shale, thin beds of greenish-gray fine-grained indurated sandstone and flaggy limestone. The limestones of the lower Red Lion are of sugary texture, generally reddish purple or mottled in purple and cream-white or pale green. They become covered with ocher on weathered surfaces.

In a good exposure on the west side of Cable Mountain, the lower Red Lion consists of two beds of shale—the lower black to purple, calcareous, and weathering yellow; the upper olive-green and not notably calcareous—separated by a thin layer of ferruginous limestone. At the head of the East Fork of Meadow Creek this member consists of about 20 feet of red limestone grading into shale.

Contact metamorphism affects the lower Red Lion rocks in the same way that it does the similar rocks of the Hasmark and Silver Hill formations. Slight metamorphism changes them to fine-grained greenish or brownish hornstones whose characteristic minerals are quartz, calcite in varying amounts, diopside, and biotite. Intense metamorphism of the calcareous portion is exemplified at the contact with the granite near the forks of the gulch north of Gold Coin, where the sedimentary rock is changed to coarsely crystalline aggregates consisting chiefly of reddish-brown garnet, epidote, green pyroxene and amphibole, calcite, quartz, and magnetite. The garnets are especially conspicuous, some being crystals nearly 2 inches in diameter. A typical specimen from this locality is shown in Plate IX, *A*. Impure magnesian limestone of the lower Red Lion is locally altered to a greenish banded hornstone, containing abundant olivine (forsterite?) and diopside, both considerably altered to serpentine.

TYPICAL SECTION.

The best section measured is on the east side of Warm Spring Creek, where the shale member and the upper member of the Hasmark formation are exposed.

Section of Cambrian rocks on slope east of Warm Spring Creek above Cable Creek.

	Feet.
Maywood formation (lower part).	
Sandstone, fine grained, calcareous, green and white.	
Magnesian limestone, gray to green, impure	40
Red Lion formation.	
Limestone, white to light gray, with siliceous laminæ weathering yellow to red in small proportion	40±
Limestone, blue-gray, with siliceous laminæ averaging about one-eighth inch thick and about one-half inch apart, although some layers of pure limestone are 4 inches thick; siliceous material forms about one-fifth of the whole	12
Limestone, like bed above, imperfectly exposed	120
Limestone, blue-gray, with siliceous laminæ like those of second bed above forming one-fourth or more of the entire layer; siliceous material is more abundant near the top where the laminæ anastomose, so that much of the limestone lies in isolated lenses	30
Unexposed; presumably limestone like that above	40
Magnesian limestone, thin bedded, white, weathering yellow	6
Magnesian limestone, gray or reddish purple on fresh fracture, a little rusty on weathered surface; contains ellipsoidal masses of red impure limestone about one-half inch in diameter, also large irregular masses	7
Magnesian limestone, white, stained with yellow ocher on weathered surfaces	1
Shale, coal-black, brittle, checking irregularly without distinct lamination; rusty brown on weathered surfaces	5
Magnesian limestone with wavy partings, drab on fresh fracture, stained with limonite on weathered surfaces	3
Silica-carbonate rock, fine grained, brittle, flaggy, and banded in white, green, and drab	5
Rock similar to that of bed above, but obscurely banded and not flaggy	4
Shale, coal-black, fine grained, brittle, and homogeneous	3
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FOSSILS.

Fossils were collected from the upper part of the Red Lion formation by E. M. Kindle, of the United States Geological Survey, in 1907, and submitted to Secretary Walcott, of the Smithsonian Institution. In a collection from Rock Creek, in the western part of the Anaconda Range, he found *Billingsella coloradoensis* Shumard and Anomocare sp.; in a second lot from the vicinity of Princeton the same forms together with Cyrtolites sp. and Agraulos sp. All the specimens, according to Dr. Walcott,[1] are of Upper Cambrian age, and therefore correspond to the Yogo limestone, but appear to be of a younger facies than any that have been found in the Yogo limestone farther east.

CORRELATION OF CAMBRIAN ROCKS.

The assignment of the series above described as a whole to the Cambrian depends on the unconformity at the base of the lowest quartzitic member (pp. 50–52), which can reasonably be correlated only with the widespread unconformity at the base of the Flathead quartzite, the lowest Cambrian formation of the known Montana sections, and on the presence of Upper Cambrian fossils in the limestone of the Red Lion formation. The stratigraphic position of the base and that of the top of the series are therefore known beyond reasonable doubt.

The correlation of the intermediate divisions of the series, however, can not so readily be settled; the basis of such correlation as is now possible is wholly lithologic, and sufficiently detailed comparison of the Philipsburg section with those previously described has not been made. A tentative correlation may, however, be based on the following considerations. There is in the Philipsburg Cambrian and in that of the Little Belt Mountains and the Livingston region a basal sandstone or quartzite, overlain by alternating shales and limestones that constitute more or less definite and logical stratigraphic units. It is a reasonable supposition that, considering only relatively thick and homogeneous strata, the lowest shale in the Philipsburg section corresponds approximately to the lowest shale in the Livingston section, the lowest limestone in the one to the lowest limestone in the other, and so on. It will presently be apparent, however, that the application of this hypothesis has practical difficulties apart from the objection that the limestone beds of one region may pass horizontally into the shales of another.

In regard to the correlation of the Flathead little doubt exists. Lithologic similarity, unconformable relation to the Belt series, and subjacency to a shale are three points which serve to identify the stratum called Flathead quartzite in the Philipsburg quadrangle with the sandstone called Flathead in the type region.

The Silver Hill formation was at first thought to be the equivalent of the Wolsey shale. The possibility has suggested itself more and more insistently, however, that the three subdivisions of this formation (p. 53), notwithstanding the difficulty of distinguishing them except in restricted portions of the Philipsburg quadrangle, may be coordinate with three formations of the Little Belt Mountain section. The choice between these two hypotheses depends in part on the correlation of the Hasmark formation. This formation consists of two distinguishable magnesian limestones parted by a shale thick enough, over a large part of the quadrangle at least, to rank as a formation. The obvious inference first made was that the lower, overlying the supposed Wolsey shale, was the Meagher limestone, the shale the Park shale, and the upper the Pilgrim limestone. A different correlation is indicated, however, by the nonpersistence of the shale bed.

The original Pilgrim contains thin beds of shale not distinguished as formations. The medial shale of the Hasmark may be one which is not more important than these, but which is locally thickened. The upper and lower limestones present no differences that in themselves would strongly suggest subdivision of the Hasmark or its equivalence to more than one of the formations in the type sections for the Montana Cambrian. It seems, therefore, wholly plausible, though proof is lacking, that the Hasmark is essentially the equivalent of the Pilgrim limestone.

[1] Letter to F. C. Calkins, June 3, 1908.

Assuming this to be true, the Silver Hill formation of the Philipsburg quadrangle must be equivalent to the Park, Meagher, and Wolsey if these are all here developed, in which event the lowest dark shale division would correspond to the true Wolsey shale, the portion comprising the thick strata of laminated limestone to the Meagher limestone, and the overlying predominantly shaly part to the Park shale. Either scheme of correlation leaves the Red Lion to represent the Dry Creek shale and Yogo limestone.

It is perhaps after all more important to show the necessarily tentative character of any detailed correlation at this time than to decide what correlation is most probable. There is not a sufficiently close and detailed lithologic resemblance between the Philipsburg section and those farther east to make purely lithologic correlation safe. The Pilgrim limestone, for example, has not been described as magnesian, and had it been as obviously magnesian as the Hasmark the fact would hardly have escaped notice. The few specimens in the National Museum do not appear to be magnesian. The peculiar laminated limestone of the Red Lion formation, moreover, does not seem to resemble the Yogo. A real correlation between the Philipsburg and other sections is hardly possible until more Cambrian fossils have been found about Philipsburg or until strata have been actually traced from one region to another. When both these things have been accomplished there is reason to believe that formations equivalent in the usual senses may not be quite contemporaneous. The highest limestone in the Philipsburg quadrangle has a fauna of younger facies than that in the Little Belt Mountains, and the Flathead quartzite contains older fossils in eastern Montana than in the western part of the State. It may be that for several epochs of the Cambrian period, if not for all of them, the controlling conditions of deposition were initiated at the east and gradually invaded more and more westerly areas, or, in other words, that there were successive westward transgressions.

SILURIAN (?) SYSTEM.

MAYWOOD FORMATION.

PRINCIPAL FEATURES.

The Maywood formation is named for Maywood Ridge, west of Princeton, on whose northeast face, 2 miles above the mouth of South Boulder Creek, the best exposure occurs.

The Maywood is generally ill exposed, being less resistant to erosion than the limestone of the Red Lion formation below or the Jefferson limestone above. It consists of thin-bedded calcareous rocks, including reddish, gray, and whitish flaggy magnesian limestones, gray and olive-green calcareous shales, and near the base some light-colored calcareous sandstone.

There is some doubt as to its exact limits, notwithstanding that as a whole it is in marked lithologic contrast with the Red Lion formation and with the Jefferson limestone. Kindle[1] regards the lowest sandstone as basal. In the present paper, however, the formation is assumed to embrace about 40 feet of limestone similar to that in the main body of the formation, but lying below the sandstone. At the top the line between the Maywood and the Jefferson is also ill defined, for certain beds of nearly black flaggy limestone at this horizon might plausibly be assigned to either formation, and the section across the contact gives the impression of gradation from one to the other. Owing to the uncertainty of its boundaries, an exact measure of the thickness of the Maywood formation is impossible, but in round numbers it is about 200 or 300 feet thick.

The distribution of the Maywood formation corresponds in general to that of the Cambrian rocks described on page 49. The only continuously exposed section of the unaltered rocks, apart from that on Maywood Ridge, is on the East Fork of Rock Creek in the southwest part of the quadrangle, although considerable exposures of the limestones occur on the North Fork of Flint Creek and south of Silver Lake. Some of the best exposures of metamorphosed Maywood rocks are west of Franklin Hill and west of Tower, near Philipsburg, and on the spur east of Cable.

[1] Kindle, E. M., Fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, Cornell Univ., vol. 4, No. 20, 1908, p. 10.

LITHOLOGIC DETAILS.

The sandstone of the Maywood is the rock of which outcrops and float are most common, and its peculiarities make it easy to recognize. It is cream-white on fresh fracture, but exposures are invariably stained a tawny yellow by limonite. The weathered surfaces are rough, so that the sand grains stand out in strong relief, and the lamination, in places, is expressed by a fine fluting that locally shows a cross-bedded structure.

The shales and limestones of the formation, which grade into each other, are partly of kinds found in the lower part of the Red Lion formation. The fine exposure of the almost vertical beds south of Boulder Creek, as viewed from the Maywood farm, appears banded in grays and rather dull reds and yellows, the yellow hues being due to weathering of calcareous beds. The shales and limestones which on fresh fracture are gray to dull olive-green or reddish mostly weather to cream color, yellow, or orange. The weathered surfaces of the limestones are, as a rule, somewhat gritty, owing to siliceous impurities and to a partly magnesian character. Much of the limestone is mottled in red and gray, the gray portions weathering buff. For about 100 feet below the typical thick-bedded limestones of the Jefferson, beds of dark-gray limestone like the Jefferson are interbedded in subordinate proportion with fine-grained gray, buff-weathering thin-bedded limestones and calcareous shales.

Strong metamorphism of the Maywood rocks, by recombining the iron of oxides and carbonates into silicates, turns the red beds green and lessens the tendency to weather yellow. Metamorphism of the sandstone is exemplified on Silver Hill, where the calcareous cement has become abundantly charged with minute needles of tremolite. The calcareous shales alter to green hornstones characterized by diopside and other silicates of magnesia and lime. In the contact zone of the granodiorite exposed at Cable, some of the Maywood has been converted to distinctly crystalline rocks rich in poikilitic scapolite. An iron-poor olivine mineral, probably forsterite, occurs abundantly in some of the metamorphosed limestones near Philipsburg.

AGE.

The Maywood formation has been carefully searched for fossils without results and can not be correlated on lithologic grounds with any part of the Montana sections previously studied. No more is known of its age than that it lies between that of the Red Lion below, which is Upper Cambrian, and the Jefferson above, which is early Devonian. It seems probable, therefore, that the Maywood is either Ordovician or Silurian, though it may represent the uppermost Cambrian or the lowermost Devonian.

DEVONIAN SYSTEM.

The only rocks of known Devonian age in the Philipsburg quadrangle belong to the Jefferson limestone. This is immediately succeeded by the Madison limestone (Carboniferous) without the intervention of the Threeforks shale, which represents the uppermost Devonian farther east.

JEFFERSON LIMESTONE.

PRINCIPAL FEATURES.

The Jefferson formation consists essentially of rather thick bedded, somewhat magnesian limestone, and is about 1,000 feet thick in the Philipsburg quadrangle. Its correlation is well established by fossils. It is comparatively resistant and fairly well exposed wherever it occurs.

Some of the best exposures of the Jefferson occur at and below Princeton, along Boulder Creek. Smaller areas on Gird Creek are interesting because they show the formation in perhaps its least altered condition. Near Philipsburg the formation is extensively exposed. It forms the hill northeast of town, and is the principal country rock of the Hope mine. Good exposures occur in the hills between Georgetown and the Gold Coin mine, and in the canyon west of Silver Hill. Along Foster Creek and in the hills east of it are large areas of somewhat altered Jefferson limestone. A cliff exposure, shown in Plate XVI, *A* (p. 144), indicates the alternation of light and dark beds that is characteristic of the formation. In the basin of the East Fork of Rock Creek, the Jefferson, like the rest of the Paleozoic rocks, is well exposed.

LITHOLOGIC DETAILS.

The limestones of the Jefferson range in color from white through grays and browns to nearly black. In the Philipsburg quadrangle the light-colored beds predominate. The least altered material, such as that on Gird Creek, shows a somewhat brownish cast. Some beds exposed north of the Maywood ranch on Boulder Creek are almost sooty black; these contain locally a small white coral, which is the only conspicuous fossil in the formation. The textures vary from very fine to somewhat sugary, and weathered surfaces, like those of the magnesian limestones of the Hasmark formation, are more or less gritty. The appearance of the Jefferson limestone and its behavior toward acids indicate that it is magnesian, but less so than the limestones of the Hasmark formation. The formation contains a little chert in irregular nodules, but on the whole much less than the overlying Madison limestone.

In most places the Jefferson limestone has no brownish tinge, probably because metamorphic action, which in varying degrees is prevalent in most parts of the quadrangle, partly destroys the organic pigment, so that the lighter-tinted beds become white and the darker assume a bluish cast in measure as the texture becomes more perceptibly crystalline. The most common rock of the Jefferson, as it occurs in the quadrangle, is a rather fine grained cream-colored dull and opaque limestone, which commonly forms large rounded outcrops without marks of bedding.

By strong metamorphism crystallinity is accentuated, but like the magnesian limestones of the Hasmark formation, those of the Jefferson do not commonly attain a texture distinctly coarse. On Foster Creek and near Cable, for example, these limestones are of medium grain, with crystals averaging less than 1 millimeter in diameter at the very contact with granitoid rocks. The most characteristic metamorphic mineral developed in the Jefferson is tremolite in lustrous, splintery crystals, white or mottled with gray by inclusions of carbonaceous dust. Less common, and inconspicuous when present, are minute crystals of diopside, olivine, and a mineral doubtfully identified as colorless humite. Pale mica, probably phlogopite for the most part, is widely distributed but only locally abundant.

FOSSILS AND CORRELATION.

The lithology and stratigraphic position of the rocks assigned to the Jefferson in the Philipsburg quadrangle would suffice in themselves to make the correlation reasonably certain, and the paleontologic evidence establishes it beyond doubt. Although most of the fossils are so small and inconspicuous as to escape an untrained eye, a large number of them were found in 1907 by Mr. Kindle on the East Fork of Rock Creek and near Princeton. His report on them is as follows:

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

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

CARBONIFEROUS SYSTEM.

SEQUENCE.

The general succession of Carboniferous rocks in the Philipsburg quadrangle, in descending order, is as follows:

		Feet (approximate).
Pennsylvanian series:		
Quadrant formation	Quartzitic member	400
	Shaly member	50–600
Slight unconformity (?).		
Mississippian series:		
Madison limestone	Thick-bedded limestone	300–1,000
	Shaly limestone	300

MISSISSIPPIAN SERIES.

MADISON LIMESTONE.

PRINCIPAL FEATURES.

The Madison limestone in all the Montana sections has basal shaly beds overlain by more massive beds. Weed has recognized three lithologic subdivisions in the Little Belt Mountains, and two or three might be discriminated in the Philipsburg quadrangle, but these are not mapped separately. The lower part in this quadrangle consists mainly of flaggy limestones, black on fresh fracture, but weathering to a delicate blue-gray or drab tint, intercalated in most places with two thin beds of coal-black calcareous shale, one lying near the base and the other a little below the middle of the lower member. The upper member contains abundant chert. Its lower part is mostly dark blue-gray and in beds of moderate thickness; its upper part of more massive limestones, mostly white to pale gray. The formation is abundantly fossiliferous.

DISTRIBUTION AND EXPOSURES.

The upper part of the Madison tends to crop out boldly; the lower flaggy part does not ordinarily do so.

The formation occurs mainly in about half a dozen tracts, of which the most extensive is a virtually continuous area extending from a point near the northern edge of the quadrangle to the vicinity of Silver Hill. In this area, near Princeton, are some of the best and most accessible exposures. The southwest faces of Pierre Hill and of the two spurs next north are steep slopes or cliffs carved from nearly vertical beds, chiefly of the upper division, though the lower beds appear on the cliff nearest Princeton. The area extending from Boulder Creek to Red Hill, although it affords no complete section, gives bold outcrops visible from the railway. It is chiefly remarkable for an unusual development of chert in the middle part of the formation. Good exposures appear south of this area, in the immediate vicinity of Philipsburg. Almost the entire section is exposed north of Stewart Gulch, and the cliff of which a view is shown in Plate X, *B*, gives one of the best sections of the lower middle part.

Perhaps the best exposures occur in the U-shaped area south and southwest of Georgetown Lake, particularly along the East Fork of Rock Creek. Just west and north of the hill marked "7780" on the map (Pl. II, in pocket) are very steep cliffs carved from vertical beds of the middle and upper parts and south of the hill are fine exposures of more gently dipping beds, including a nearly complete cliff section of the flaggy basal beds.

THICKNESS.

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

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

LITHOLOGIC DETAILS.

The shale locally present near the base and best exposed in a shallow prospect pit a quarter of a mile southwest of Stewart Lake is dull black, fairly hard and compact, and breaks into small rectangular fragments. Acid tests and microscopic study determine it to be highly calcareous, and it grades into the flaggy limestone forming most of the lower Madison.

The limestone constituting most of the lower division is in beds whose thickness ranges from about an inch to a foot or more. The unaltered rock exhibits on fresh fracture a dark blue-gray to nearly black color and a dense compact texture. Weathered surfaces are of a much lighter blue-gray.

The limestone immediately above the flaggy beds is similar to it in most respects, but is thicker bedded and characterized by a large proportion of chert (Pl. X, *B*), whose occurrence is in contrast to the lamellar arrangement of the siliceous material in the Red Lion formation (Pl. X, *A*, p. 61). The chert of the Madison is in irregular masses which tend to segregate into layers. Its distribution through the limestone is well illustrated by the plate.

Thin beds of white limestone, absent from the lowermost part of this formation, become increasingly abundant upward and predominate in the upper half. The thick-bedded white and light-gray limestones of the upper Madison, although they do not present in general appearance any marked difference from those of the Jefferson, show distinct differences when closely examined. For one thing the upper Madison is characterized by abundant chert in larger masses and of less regular distribution than in the dark beds below. Other differences are due to the nonmagnesian character of the Madison as opposed to the more or less magnesian character of most of the lower limestone formations. The thick Madison strata weather with surfaces that may be wavy and uneven in the large, but are smooth in detail, not gritty like those of magnesian limestone. Light-gray or white pieces of limestone from this formation also have a luster and translucency suggesting that of paraffin, in contrast to the dullness and opacity of the typical Jefferson and the limestones of the Hasmark formation.

Fossils are so abundant and conspicuous in the Madison limestone as to aid even those unable to identify species in recognizing outcrops of the formation. The commonest organic remains are white cylindrical sections of crinoid stems 1 centimeter or less in diameter; probably second in abundance are cone-shaped coral fossils so divided by vertical partitions that a cross section of a specimen suggests a little wheel 4 centimeters or less across, with the hub off center. The fossils are more fully discussed on page 69.

Microscopic sections of Madison limestone present little that is worthy of especial remark. They show interlocking anhedral carbonate grains more or less clouded with carbonaceous dust. This dust is particularly abundant in the black flaggy limestones, which contain an appreciable, though very subordinate amount, of quartz, sericite, and other impurities.

A partial analysis by Schaller of a specimen of the black shaly part of the lower Madison limestone from a point near the county boundary just east of Warm Spring Creek follows.

Partial analysis of lower Madison limestone.

[By W. T. Schaller.]

	Per cent.
Insoluble in hydrochloric acid	7.18
CaO soluble in hydrochloric acid	50.48
MgO soluble in hydrochloric acid	.74

The chert masses, as shown by the microscope, consist chiefly of quartz in allotriomorphic grains, mixed with more or less carbonate. The texture varies from moderately fine to almost cryptocrystalline.

The foregoing statements on the vertical distribution of chert in the Madison are broadly general. It should be remarked further that the amount of chert in the beds of a given horizon varies from place to place. Chert is particularly abundant in the formation south of Philipsburg and along Flint Creek canyon. There is a prominent outcrop of chert just south of the mouth of Boulder Creek. Farther south the proportion of chert increases, and near the fault contact with the Algonkian is a great, almost continuous mass of dark chert nearly 100 feet thick, which evidently belongs to the Madison. In this vicinity the Newland also is somewhat silicified and cherty—a fact that hints at a possible cause for the limestones of local richness in chert. The zone in which the condition exists is one of faulting, and it appears probable that the chert is at least partly secondary and due to the action of siliceous waters arising in the fault fissures. Some confirmation of this surmise is given by the development of secondary chert in the limestone of the Hasmark formation north of Flint. Thin sections of this material show it to consist chiefly of quartz replacing carbonate, for dust lines in the quartz mark the position of the original cleavages of the calcite or dolomite. The chert of the Madison limestone is, to be sure, of finer grain and reveals no structure suggesting that of a replaced carbonate. These differences, however, are possibly due to readier solubility and more rapid replacement of the less magnesian limestone.

The limestones of the Madison, especially the purer beds of the upper portion, are more readily recrystallized by metamorphic agency than are the older magnesian limestones. The mineral most commonly produced in the Madison limestone by contact metamorphism is snow-white or gray tremolite, which is more abundant in this formation than in the Jefferson limestone. In certain beds it is distributed more or less uniformly, but more usually it tends to form bunches, especially in the chert masses or on their margins. Diopside is locally developed but never conspicuous in the Madison.

Scapolite locally occurs in the slightly altered basal flaggy limestones, where it forms relatively slender dull-black eight-sided prisms about 1 millimeter across. The black color is due to included carbon dust.

A more remarkable effect of metamorphism is a similar development of orthoclase crystals at two localities, one on the east slope of the knob 7,694 feet high west-northwest of the summit of Silver Hill, and the other about 1½ miles northwest of bench mark 5605 on Warm Spring Creek. (These points are marked by elevation figures on the topographic map.) They are black like the scapolites, which, with some tremolite, and titanite, occur in the same specimens. Every individual is completely bounded by sharp though not lustrous crystal faces. The form does not at once suggest the common habit of orthoclase, but in reality comprises the planes most commonly developed in that mineral with the exception of the clinopinacoid, usually the broadest. The faces present are *M* (110), *C* (001), and *X* (101), *X* being larger than *C*. Crystals of the same type are figured by Dana.[1]

FOSSILS AND CORRELATION.

George H. Girty, who has examined the abundant fossils collected from the Madison limestone in the Philipsburg quadrangle, considers them referable to the lower Mississippian fauna so widely distributed over the West. He has identified the following forms:

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

The lithologic character of the rocks corresponds to that of the Madison in other parts of Montana.

[1] Dana, E. S., System of mineralogy, 6th ed., p. 316, fig. 7.

PENNSYLVANIAN SERIES.

QUADRANT FORMATION.

PRINCIPAL FEATURES.

The Quadrant formation, as developed in the Philipsburg quadrangle, comprises two members that present strong lithologic contrast. The lower member consists of thin-bedded rocks, chiefly deep-maroon shale and red to white magnesian limestones, which are soft and not often well exposed. The upper member is mainly quartzitic, and is generally separable into three strata—the lowest of light-colored pure thick-bedded quartzite the middle of calcareous shale and impure cherty limestone; the uppermost of somewhat impure quartzite and quartzitic sandstone. The quartzite strata crop out boldly, while the calcareous beds between them are nowhere well exposed. Near the top thin beds of shale are intercalated with quartzitic sandstones assigned to the Quadrant.

Since the geologic survey of the Philipsburg quadrangle was completed, phosphate rock has been found in the calcareous beds between the quartzites of the upper member of the Quadrant formation.[1] Inasmuch as phosphate is a valuable fertilizer the areal distribution of the formation is a matter of considerable economic interest.

POSSIBLE UNCONFORMITY BETWEEN THE PENNSYLVANIAN AND THE MISSISSIPPIAN SERIES.

The considerably different ages of the faunas of the Madison and the Quadrant indicate the lapse of a considerable time interval between them. Physical evidence of unconformity is given by the sharp lithologic distinction between the uppermost beds of Madison limestone and the lowest part of the Quadrant formation. A further indication of an erosion interval between them is the dwindling of the upper Madison west of Foster Creek in the Flint Creek Range to about half its normal thickness. Angular unconformity has not been proved.

DISTRIBUTION.

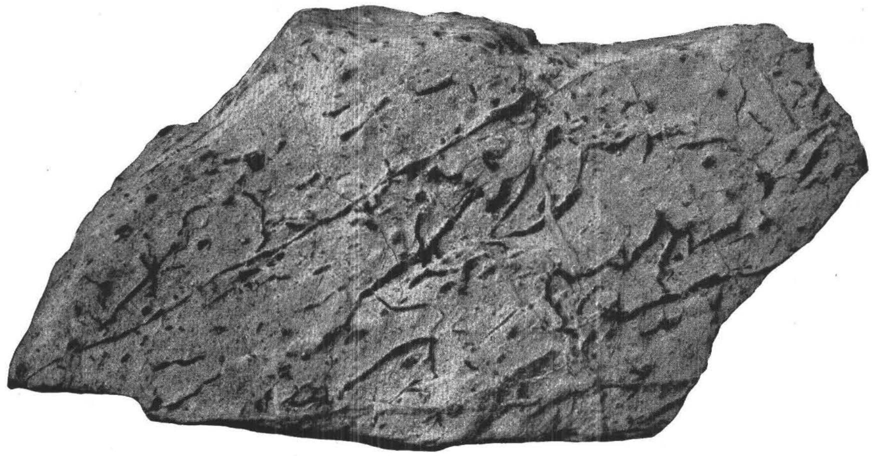
The most extensive exposures of the Quadrant are northeast of Boulder Creek, where nearly vertical beds of the quartzitic member form bold parallel reefs striking for miles across ridges and ravines. The lower red beds in this vicinity are generally concealed, but their position is marked in places by float. A good exposure of the limestone between the quartzites occurs on the hill 5,292 feet high, north of Douglas Creek. Good exposures of the lower member and of the calcareous beds between the quartzites occur southeast of Goat Mountain. Other extensive areas occur to the south on either side of Foster Creek, where strong metamorphism prevails, and still farther south near Warm Spring Creek, where the rocks are not greatly altered. The best exposure of these beds in the quadrangle is on the west slope of the hill 7,780 feet high near the East Fork of Rock Creek. A detailed description of this section is given on page 72.

Near Philipsburg the quartzite of the Quadrant is one of the most conspicuous terranes. It forms the knob west of the high school sometimes called Flagstaff Hill and a similar one 3 miles south. Fossils have been collected on Flagstaff Hill from the limy beds between the quartzites. The quartzite is the country rock of Red Hill, and its outcrop defines a pitching anticline and syncline to the northeast. It also forms part of the crest west of Wyman Gulch. The red beds of the lower member are concealed in most places near Philipsburg but are partly exposed on and north of Stewart Gulch.

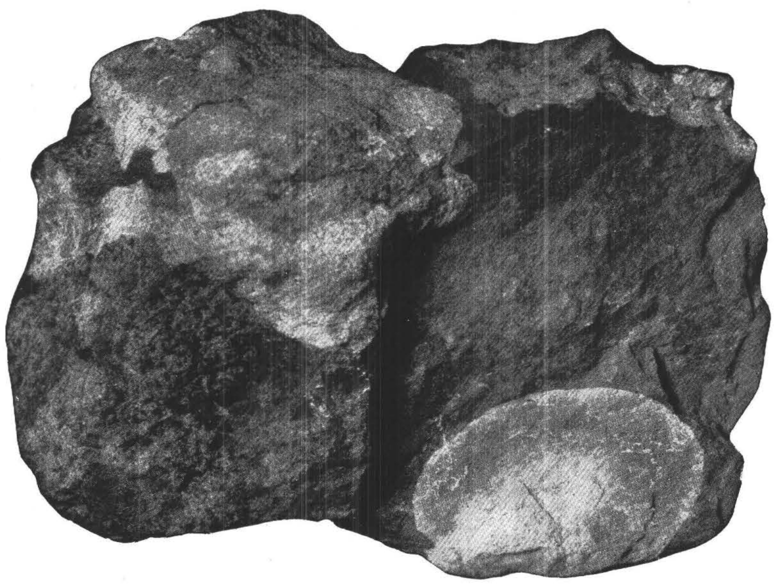
THICKNESS.

The greatest observed thickness of the lower Quadrant is on the East Fork of Rock Creek, where the shaly beds measure about 500 feet, unless some unobserved faulting occurs. The thickness north of Philipsburg is roughly estimated at 200 to 300 feet. The least apparent thickness, less than 100 feet, was observed west of Foster Creek, where the upper Madison is also of less than normal thickness.

[1] Gale, H. S., Phosphates in Montana: Bull. U. S. Geol. Survey No. 470-A, 1911.



A. LOWER LIMESTONE OF THE KOOTENAI FORMATION, SHOWING TWIGLIKE BODIES THAT ARE PROBABLY ORGANIC.



B. RED SHALE WITH GRAY NODULES IN THE LOWER PART OF THE QUADRANT FORMATION.

The best measure of the upper member was obtained on Flagstaff Hill, where it is 430 feet thick, and in general the thickness does not appear to vary much from this amount.

There is some doubt regarding the position of the upper limit of the Quadrant formation on the East Fork of Rock Creek, in the Anaconda Range. The well-exposed limestones and red shales of the lower member are here overlain by a single stratum of massive quartzite, about 350 feet thick, instead of by two quartzite strata separated by calcareous rocks, as in most sections. The quartzite is overlain in turn by calcareous shales and cherty limestones. A portion of these which resembles the calcareous division of the upper member as usually developed is mapped as Quadrant, and it is assumed that the uppermost quartzite stratum of the more typical sections is absent. A possible alternative, not definitely disproved, is that the calcareous bed of the upper member has tapered out.

LITHOLOGIC DETAILS.

LOWER MEMBER.

The most characteristic rock seen in the float of the lower Quadrant is a deep brick-red to maroon shale with round or oval greenish-white spots that give the rock the appearance of having been spattered with paint. The spots, however, are cross sections of nodules not notably different from their matrix except in color; though in places they are more distinct and weather out as spheroids or irregular lumps (Pl. XI, *B*). The phenomenon is essentially the same as that described for the Spokane formation (p. 46) but is here more prominently developed. Indeed, this red shale superficially resembles that of the Spokane, but is, on the whole, of finer, more homogeneous texture, and without distinctly sandy or quartzitic layers. The microscope shows that most of the shale contains carbonate, which, however, is not notably more abundant in the light-colored nodules than in their red matrix.

The other characteristic rock of the lower Quadrant, into which the red shale grades, is flaggy limestone with a gritty surface, ranging in color from dull red to white. The microscope shows that more or less quartz is present and that the carbonate is partly in rhombohedral crystals, conditions which, with its rather weak effervescence on application of acid, prove its magnesian character.

Red shale from the lower Quadrant, when slightly metamorphosed, is darker and more purplish than the unaltered rock, and shows the characteristic spots less distinctly. The microscope reveals green biotite as the only mineral developed in appreciable amount by the metamorphism. Stronger metamorphism would presumably produce cordieritic rocks like those produced from the similar beds in the Spokane formation, but no such rocks were observed.

The more limy beds alter to greenish banded rocks, composed chiefly of diopside, quartz, and amphibole with more or less feldspar, epidote, and titanite. They are fine grained and compact and resemble the diopsidic hornstones derived from the Newland formation (p. 43).

QUARTZITES.

The quartzite forming the lowermost part of the upper member is pure and thick bedded and does not differ essentially from the typical Flathead quartzite. It is nearly white on fresh fractures. The upper quartzite does not differ conspicuously from the lower in the general aspect of its outcrops. Weathered rocks of both, especially the upper, are characterized by a rusty surface from which appearance Red Hill, near Philipsburg, where the Quadrant is well exposed, derives its name. Close examination shows the upper quartzite to be less pure than the lower and somewhat calcareous near the top. Its weathered surfaces are rougher and more porous, and it becomes more deeply impregnated with limonite. Where it can be observed in fresh condition, as where there is metamorphism, it commonly shows a gray color and somewhat cherty texture. It is essentially, however, a clastic rock.

The shales interbedded with the uppermost beds of quartzite are not exposed except in the vicinity of Goat Mountain, where they are interbedded with drab-weathering sandstones. Here they are blue-black, and they are rusty on the weathered surface. Similar shale occurs at the base of the upper quartzites.

BEDS BETWEEN THE QUARTZITES.

The comparatively soft beds between the boldly cropping quartzitic beds of the Quadrant are nowhere exposed with even approximate completeness, except in the northeastern part of the quadrangle, where they are indicated by metamorphism. The most characteristic rock in this vicinity is a mottled mixture of gray and white chert and limestone, with carbonate predominant in some parts and silica in others, although a little black rusty shale occurs at the top, and a bed of white calcareous sandstone is conspicuous near the middle. The small weathered outcrops near Philipsburg are chiefly of a yellow, iron-stained cherty rock. A thin phosphate bed has been found at this locality by Mr. Pardee.[1] The phosphate rock is dull dark gray and has an oolitic structure, being composed of closely packed spherules about 1 millimeter in diameter. Its specific gravity is notably high.

TYPICAL SECTIONS.

Typical sections of the Quadrant formation are given below:

Section including quartzite member of Quadrant formation, from hill west of schoolhouse, Philipsburg.

	Feet.
Ellis formation.	
Calcareous shale, yellow, weathered (float).	
Quadrant formation.	
Quartzite, fairly pure and thick bedded	20
Sandstones, grading into fairly pure quartzites, the latter forming three projecting reefs; all stained with brown ocher. Beds 2 to 3 feet thick. Little lenses of calcareous material weathering into hollows near base	100
Cherty limestones, impure, weathering buff; poorly exposed, fossiliferous	90
Quartzite, thick bedded, fairly pure, but less so near the top. Whitish on fresh fracture; outcrops stained with reddish-brown ocher. Much jointed and fractured	150
Imperfect exposure, country rock apparently as above	70
	430

Section of Quadrant formation, west slope of hill 7,780 feet high, near the East Fork of Rock Creek.

	Feet.
Quartzite member.	
Quartzite, massive, fine grained, white to pale drab on weathered surface, superficially stained with yellowish-brown ocher	350±
Shaly member.	
Calcareous quartzite, fine grained, grading into shale	20
Limestone, light gray, nonmagnesian	2
Limestone, impure, laminated, mottled yellow and gray	12
Shale, maroon, with light greenish-gray ellipsoidal nodules, 2 inches or less in diameter	8
Shale, like that of bed above, crowded with more irregular gray nodules 4 inches to 1 inch in diameter	8
Shale, with ellipsoidal concretions	9
Limestone, with irregular fragments of red shale	2
Limestone, fine grained, light gray, hard, magnesian	5
Limestone, pinkish, magnesian	4
Argillaceous limestone, deep red, with lenses and layers of pink and gray magnesian limestone	3
Magnesian limestone, light gray, cream colored on fresh fracture	3
Shale, deep red, with light-gray ellipsoidal concretions	3
Limestone, mottled, cream-white to reddish purple, with irregular laminæ of maroon argillaceous material whose amount increases downward, so that near the base limestone forms nodules in the argillite	5
Magnesian limestone, nearly white, weathering pinkish	8
Magnesian limestone, reddish, gray, and white, interbedded with red shale	25

Below this magnesian limestone the formation is mostly covered by talus. Float and occasional outcrops, however, indicate that underlying rocks are similar in general to those above. The lowest outcrop of Quadrant shows about 10 feet of shaly magnesian limestone, deep red to cream white, in beds 1 to 2 inches thick, approximately 300 feet stratigraphically below the rocks last described. About 175 feet stratigraphically lower is the highest outcrop of Madison limestone, black, rough weathering, and with shaly partings.

Thickness of shaly member of Quadrant, between 420 and 600 feet.

[1] Oral communication.

FOSSILS AND CORRELATION.

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

The following forms were collected from the red shales below the quartzite 2 miles south of Georgetown Lake, and were identified by Mr. Girty:

Archæocidaris sp.
Fenestella sp.
Rhombopora sp.
Derbya crassa.
Productus cora.
Spirifer rockymontanus.
Euomphalus catilloides.

Mr. Girty considers these fossils probably though not positively referable to the Pennsylvanian.

Fossils have also been found in the calcareous beds between the quartzites on Flagstaff Hill, at Philipsburg. A collection made at this place by Mr. Pardee was reported by Weed in 1900[1] and referred by Mr. Girty to the following forms:

Camarotœchia sappho.
Camarotœchia near Camarotœchia congregata.
Glyptodesma rectum?
Aviculopecten sp.
Cyathophyllum sp.

These fossils, in Mr. Girty's opinion, had a Devonian aspect.

In 1906 D. F. MacDonald gathered at the same place a small collection, even less satisfactory than Weed's. This was submitted to E. M. Kindle, who, though unaware of Mr. Girty's report, likewise referred the horizon with some hesitation to the Devonian.

In the light of later evidence Mr. Girty has further discussed this fauna as follows:[2]

> The fauna of lot 1 is with little question the same which Mr. Weed obtained from nearly the same locality and which I reported on in 1900.
>
> Although when I first encountered this fauna I referred it to the Devonian, I now believe that it is Pennsylvanian. The two most significant types are the Camarotœchias and the *Glyptodesma rectum?* Large Rhynchonellas are rare in the typical Pennsylvanian, and none are known having the structure of Camarotœchia, as is the case with these. An exception must be made of Rhynchopora, but that genus has also a punctate shell. It was largely on this account, since Camarotœchia appeared to be restricted to the Devonian and Mississippian, that I was previously led to determine the horizon as Devonian. The force of this evidence holds good to-day, more or less. On the other hand, the *Glyptodesma rectum?*, represented only by one external mold, is probably a Myalina related to *M. deltoidea* Gabb. In view of the fact that there has recently come to hand a large species of Camarotœchia (distinct, however, from the Philipsburg forms) from Utah high in the Pennsylvanian, and that the stratigraphic position of lot 1 is above that of lot 12, it now seems probable that the age of the former is, as already stated, really Pennsylvanian. In this event, the fauna is unusual and interesting.

Since the Quadrant formation is not fossiliferous at its type locality—Quadrant Mountain, in the Yellowstone National Park—the correlation of the rocks described under that name in the present report must depend chiefly on stratigraphic position and lithology. In respect to stratigraphy there is a general correspondence, for in both the Philipsburg quadrangle and the Yellowstone Park the rocks in question are underlain by Madison limestone and overlain by the Jurassic Ellis formation, and in both regions they comprise quartzite and saccharoidal limestone. The lithologic resemblance, however, is not detailed, and those who have studied the Quadrant formation in regions east of the Philipsburg quadrangle have not described it as composed of two sharply distinct members.

The assignment of Carboniferous and probably Pennsylvanian age seems less certain for the upper quartzite stratum, in which no fossils have been found, than for the beds below. The upper quartzite was included in the formation primarily because of its resemblance to the lower. Support is lent even to this part of the correlation, however, by the opinion of H. S. Gale, who in 1910 examined a section near Melrose, Mont., essentially similar to that of the

[1] Geology of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 288.

[2] Personal communication. See also Kindle, E. M., Fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Bull. Am. Paleontology, Cornell Univ., No. 20, 1908, p. 19, footnote.

Philipsburg quadrangle. Gale considers the lower and purer quartzite essentially equivalent to the Weber quartzite [1] of Utah, and the high beds here included in the Quadrant as equivalent to the Park City formation of Utah.[2] One reason for this correlation is lithologic resemblance, but a stronger one is the occurrence of a phosphate bed in the Melrose section corresponding to one found in the Utah and southern Idaho sections.[3] Gale suggests that the lower shaly member may have its equivalent in the Morgan formation of Utah [4] or in similar rocks locally interstratified with the base of the Weber quartzite in Utah.

[1] King, Clarence, U. S. Geol. Expl. 40th Par., vol. 1, 1878, p. 161.
[2] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 20, 1907, pp. 434-458.
[3] Gale, H. S., Phosphates in Montana: Bull. U. S. Geol. Survey No. 470-A, 1911.
[4] Blackwelder, Eliot, Bull. Geol. Soc. America, vol. 21, 1910, pp. 519, 529-530.

CHAPTER V.

MESOZOIC ROCKS.

JURASSIC SYSTEM.

ELLIS FORMATION.

GENERAL CHARACTER AND STRATIGRAPHIC RELATIONS.

The Triassic is apparently absent from the Philipsburg section, as from most of the sections in western Montana hitherto described. The Quadrant formation is succeeded in most exposures of the quadrangle by calcareous shales and buff-weathering impure limestone, which contain characteristic marine Jurassic fossils. No angular unconformity between the Carboniferous and Jurassic has been observed here, but the Ellis comprises a conglomerate with pebbles of chert and quartzite that are Carboniferous or older, a fact which, with the absence of the Triassic, proves an erosion interval. The thickness is about 400 feet in the best exposed section, but apparently less in places in the central and southern parts of the quadrangle. Near Twin Peaks it seems locally to be absent, but the appearance may be deceptive, and due to faulting rather than overlap.

Nothing suggests the presence of Triassic in the sections where Ellis fossils are found, but there is some possibility of its presence in a section in the basin of the East Fork of Rock Creek, where no fossils have been discovered and where the beds immediately above the Quadrant formation comprise some white and gray limestones like those in the Jefferson limestone.

DISTRIBUTION AND EXPOSURE.

The Ellis is weak and poorly exposed compared with the upper Quadrant, and is even less resistant than the overlying Kootenai formation; its position, therefore, is usually marked by a depression, and good exposures are few. Its distribution is virtually that of the Quadrant, described on page 70. The best section is on Gird Creek, 1½ miles west-northwest of the top of Mount Princeton; another fairly good one is the easternmost, on Douglas Creek. The Ellis is exposed in a metamorphosed condition about Racetrack Peak and southward to Olson Gulch, and some comparatively good exposures occur on the hill south of the quarries on Warm Spring Creek. Near Philipsburg there are fragmentary exposures at the base of Flagstaff Hill, on Red Hill, and on Stewart Gulch. In the basin of the East Fork of Rock Creek, just across the deep canyon north of the peak marked "7780" on the topographic map, is a section presenting peculiar features. The formation is well exposed along Threemile Creek, east of Drummond, about 30 miles north of the Philipsburg quadrangle.

The position of the base of the Ellis formation near the East Fork of Rock Creek is not accurately known. No fossils have been found at this locality, and if the foregoing assumptions regarding the content of the Quadrant formation are correct, there is no abrupt change in lithology at the horizon where the Jurassic succeeds the Carboniferous. The rocks mapped as Jurassic in this part of the quadrangle consist partly of yellow-weathering shale and sandstone such as predominate in the Gird Creek section, but they comprise also some black to pale gray magnesian limestone, remarkably similar to the Jefferson limestone.

LITHOLOGY.

The general character of the Ellis formation appears in the following section:

Section including the Ellis formation, exposed on north side of Gird Creek, $1\frac{1}{2}$ miles northwest of Mount Princeton.

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

The rocks of the typical Ellis are of familiar kinds and need no extended description. Their most obvious characteristic is a tendency to weather in buff or ocher-yellow hues resembling those of the Newland formation. On fresh fracture most of the rocks vary from pale olive-green or gray to very dark gray. The shale at the base is rarely seen except in weathered condition, when it is of dull-yellowish color, but, as is shown at a point on Gird Creek where it forms the dump of a shaft, its color when fresh is dull coal-black. The limestone nodules that occur in much of the shale are rather irregularly distributed. The cross-bedded structure of some of the sandstone is accentuated by weathering.

The pebbly bed as exposed south of Warm Spring Creek and near Drummond, north of the quadrangle, is a sandy conglomerate rather than a pebbly sandstone. It contains some pebbles of quartzite, but predominance of chert pebbles is a constant and distinctive feature. The conglomerate has not been observed except about Mount Princeton and near lower Warm Spring Creek.

Contact metamorphism has the same effect on the typical Ellis rocks as on the Newland rocks (p. 43), which they somewhat resemble. The metamorphosed Ellis is not characterized by buff tints on the weathered surface. It consists of compact green, white, and chocolate-brown rocks, of which quartz, feldspar, diopside and biotite are the commonest minerals. The commonest type about Princeton is a biotitic hornstone, chocolate-brown on fresh fracture and drab on the weathered surface, with calcareous nodules in which relatively large grains of epidote and hornblende are likely to be conspicuous.

FOSSILS.

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

Ostrea stringulecula White.
Camptonectes pertenuistriatus Hall and Whitfield.
Eumicrotus curta Hall.
Trigonia sp.
Pleuromya subcompressa Meek.

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

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

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

CRETACEOUS SYSTEM.

GENERAL SEQUENCE.

The Cretaceous is represented in the Philipsburg quadrangle by the Kootenai and Colorado formations and perhaps by some later beds. Although the sequence is to all appearance structurally conformable, the Dakota, which naturally should intervene between the Kootenai and Colorado, seems to be wanting as in other known Montana sections.

LOWER CRETACEOUS SERIES.

KOOTENAI FORMATION.

PRINCIPAL FEATURES.

The Kootenai formation, as developed in the northeast quarter of the quadrangle, has a total thickness of about 1,500 feet. The general sequence is locally well exposed in this part of the quadrangle and about Drummond, where the formation is as follows:

The base consists of a ledge of tough red and green pebbly sandstone or sandy conglomerate, rarely more than 20 feet thick, which is generally prominent. This is succeeded by softer red and green shaly rocks, and these again in places by a peculiar very fine-grained buff-weathering limestone, which near Drummond forms a prominent stratum about 200 feet thick some 300 feet from the base of the formation. About Mount Princeton, however, it is thinner and apparently absent in places. Above this limestone lies the main mass of red and green shales and flaggy sandstones, with which a few thin and inconspicuous beds of limestone are intercalated. Rather well up in this part of the formation is a bed of a peculiar limestone conglomerate, with subangular pebbles of rock much like the lower limestone. The main body of the colored rocks is succeeded by the "gastropod limestones," pure gray limestones rich in fossils, chiefly fresh-water snails. These form several beds, which are separated by shales and almost invariably crop out as reefs. They are especially conspicuous in the neighborhood of Drummond, where the limestones are the prevailing rocks through a vertical range of about 200 feet; but, like the lower limestone, they are thinner in the Philipsburg quadrangle, where their total thickness is measurable in tens of feet. They do not seem to be lacking, however, from any complete section of the Kootenai. Nearly all the fossils found in the formation come from the gastropod limestones. Above these beds is usually a little red shale and some olive-green to nearly black calcareous shale and sandstone.

The highly metamorphosed Kootenai rocks show little or no red color.

DISTRIBUTION AND EXPOSURES.

The most extensive areas occupied by Kootenai rocks are in the northeast part of the quadrangle and the best exposures of the formation as a whole are about Mount Princeton. There are good exposures of the sandstones, shales, and gastropod limestones in the basin of Douglas Creek, especially near the margin of the quadrangle and at the head of the stream. The only considerable outcrop of the lower limestone is about 2 miles east-southeast of the mouth of Gird Creek canyon. Slight metamorphism, due to the action of post-Cretaceous granites, is apparent in the Kootenai rocks not far south of Mount Princeton, and they are intensely metamorphosed about Racetrack Peak and in the narrow zone adjacent to the great fault between Foster and Warm Spring creeks.

In the area near the quarries on Warm Spring Creek the basal pebbly sandstone is prominent and forms the crest of the hill northeast of the "silica quarry." The hill south of Warm Spring Creek affords good exposures, particularly of the lower buff-weathering limestone at its west end and in the ravine opposite the mouth of Olson Gulch.

LITHOLOGIC DETAILS.

Basal conglomerate and pebbly sandstone.—Inasmuch as the conglomerate of the Ellis formation and the pebbly bed of the Kootenai formation are close enough together to be in some danger of confusion, it is important to emphasize their lithologic differences, which are sufficiently characteristic to distinguish them. The leading features of the conglomerate in the Ellis are the prominence of black chert pebbles and the highly calcareous nature of the cement, which causes the weathered rocks to be deeply impregnated with limonite. In the base of the Kootenai, on the contrary, the pebbles are chiefly of light-colored quartzite like the lower Quadrant, and the cementing sandstone substance, while apt to be stained a dark rusty brown on the surface, gives no evidence of being distinctly calcareous. The average size of the pebbles in the Kootenai is larger than in the Ellis rock; the pebbles of the conglomerate in the Kootenai near Warm Spring Creek, where the most distinctly conglomeratic phase of the basal Kootenai is exposed, have a maximum diameter of about 6 inches. They are invariably well washed and commonly of oval form. This matrix is a firm, somewhat quartzitic sandstone, and the pebbles are broken out of it with difficulty. Its colors are the same as those of the higher sandstone beds.

Red and green sandstones and shale.—The sandstones and shales that form the greatest part of the Kootenai bear some resemblance to those of the Spokane formation. Their colors, however, are less rich, the reds being darker, duller, and more purplish and the greens more inclined to gray, and the rocks disintegrate somewhat more readily than those of the Spokane. They have not been observed to contain the sun cracks and ripple marks that so strongly characterize the Algonkian red rocks, but some beds have a mud-breccia structure that may indicate an origin in shallow water.

A highly characteristic feature of the colored shales is a coarse mottling in red and green, which, though locally observed in the Spokane, is far less common in that formation. Rounded calcareous gray nodules about an inch in maximum diameter occur in the shales of the Kootenai precisely as they do in the Ellis.

Lower limestone and calcareous shale.—The lower calcareous bed as exposed near Gird Creek is apparently a fairly pure limestone. It has a delicate grayish-drab tint on fresh fracture and is for the most part extremely fine grained and homogeneous. It is shot through, however, with little twiglike bodies of crystalline calcite about 1 millimeter in diameter and 2 or 3 centimeters in maximum length, invariably crooked and sometimes branching. On the weathered surface the rock has a thin film of buff and the twiglike bodies show more prominently, being dark and standing in slight relief. (See Pl. XI, *A*, p. 70.) They suggest some organic origin but have not been identified as fossils. They are so characteristic, however, that they may aid in identifying the bed in other districts. The rock effervesces briskly on application of weak acid and appears under the microscope to consist essentially of almost cryptocrystalline cloudy calcite.

This bed is more flaggy near Warm Spring Creek, possibly owing to deeper weathering, but it seems less purely calcareous and strikingly resembles the Newland. It shows the characteristic twiglike bodies.

Gastropod limestone.—The gastropod limestone is strikingly different from the lower limestone and resembles rather the dark beds of the Madison limestone. On fresh fracture it is of rather dark-gray color; on weathered surfaces, pale bluish gray. The texture is coarser and less compact than that of the lower limestone. Remains of spiral fresh-water snail shells, with which it is crowded, are especially conspicuous on the weathered surface and characterize the rock so strongly that it can instantly be recognized.

Upper calcareous shales.—The calcareous shales interbedded with the gastropod limestones and overlying them are partly of an olive-green ocherous-weathering type common in older formations; and these grade into sandstones. The uppermost beds mapped as Kootenai on the east slope of Mount Princeton are more or less calcareous shales, gray to nearly black on fresh fracture but weathering to a blue-gray or brownish color, which virtually grade into limestone.

SECTION.

The subjoined section shows details of the upper part of the formation:

Generalized section of upper part of Kootenai formation from east slope of Mount Princeton.

Colorado formation.	
Black shale.	
Kootenai formation.	Feet.
Dark-gray to black limy shales and flaggy impure limestones, weathering in lighter tints of gray and grayish brown. Bone fragments in limestone 65 feet from base, and a 5-foot bed of rusty-weathering calcareous sandstone 20 feet from base	275
Gray pure fine-grained limestone, dark on fresh fracture; contains gastropods	25
Gray shale, calcareous	10
Gray limestone	3
Gray shale	15
Gray limestone, with Unio and gastropods but fewer of the latter than in the upper bed	20
Gray shale	30
Gray limestone; irregular streaks of siliceous material in the lower part	10
Green argillite with calcareous nodules about 1 inch in diameter, underlain by purple argillite mottled with green, also containing calcareous nodules	10+

EFFECTS OF CONTACT METAMORPHISM.

The Kootenai is much metamorphosed in places, the transformations being especially complete in the calcareous beds. The metamorphic rocks to which the Kootenai gives rise are so various that any detailed description of them is impossible here, but some of the more characteristic types may be mentioned.

The sandstones alter, like those of the Spokane, to quartz-mica schists of green or gray color. Advanced recrystallization of these rocks was not observed in the Philipsburg district.

The shales alter in places to green phyllitic schists, some of which are knotted with andalusite. The red rocks commonly alter to dense chocolate-brown or nearly black, finely dappled cordieritic hornstones, similar to those derived from the Spokane though not attaining such coarse textures. The mottled appearance presented by some unaltered beds persists in places under fairly strong metamorphism, which may recrystallize the rock to a considerable degree without converting the ferric oxide into silicates.

The calcareous nodules tend to become more radically altered than their matrix, and to develop recognizable crystals of epidote, hornblende, garnet, and other metamorphic minerals.

The gastropod limestones are so pure that strong metamorphism may have no other effect than to recrystallize them and partly to obliterate fossils whose presence is indicated only by ill-defined white spots. Some of the impure limestones and calcareous shales, however, especially on the ridge east of Twin Peaks, change to rocks rich in garnet, vesuvianite, and wollastonite.

FOSSILS AND CORRELATION.

The nonmarine beds occupying, in the Philipsburg quadrangle, the interval between the marine Jurassic and the marine Upper Cretaceous, have been referred to the Kootenai formation chiefly for stratigraphic and lithologic reasons. In its type area a short distance north of the international boundary the coal-bearing Kootenai formation, with a thickness of several thousand feet, occupies the same interval and includes rocks of the same lithologic character. It has there yielded a considerable flora.

The formation has been identified in the Great Falls and Lewistown coal fields by its stratigraphic position, lithology, and fossil flora. In those two areas Fisher and Calvert have recognized the Morrison formation beneath the Kootenai, from which it does not differ greatly in lithologic character. The Morrison formation is nonmarine and has a wide distribution southward in Wyoming, Colorado, and adjoining States.

On Yellowstone River between Yellowstone National Park and Livingston, according to unpublished work of Calvert, the Kootenai is recognized on lithologic and stratigraphic grounds and includes the rocks which in the Yellowstone National Park folio are mapped as Dakota. A characteristic feature of the formation in Yellowstone Park is a "gastropod" limestone like those in the Kootenai of the Philipsburg quadrangle and containing some of the same species. The Kootenai flora has not been found in Yellowstone Park nor in the Philipsburg region.

The invertebrates from the Kootenai formation in the Philipsburg region have been examined by T. W. Stanton, who states that those from one of the lower limestones near Drummond are "poorly preserved smooth gastropods, possibly belonging to Goniobasis, although more than one genus may be represented." The upper "gastropod" limestones and overlying shale have yielded two or more undescribed species of Unio, one related to *U. douglassi* Stanton, and the gastropods *Goniobasis* (?) *increbescens* Stanton and Viviparus (?) sp. These forms occur also in the so-called Dakota of Yellowstone Park, now believed to be Kootenai.

It is possible that the rocks referred to the Kootenai formation in the Philipsburg quadrangle may include the equivalent of the Morrison formation, and the upper limit also is somewhat uncertain, but at present there is no basis for a division into more than one formation.

UPPER CRETACEOUS SERIES.

COLORADO FORMATION.

PRINCIPAL FEATURES.

The rocks mapped as Colorado in the Philipsburg quadrangle consist of a black shale whose thickness as measured on the east slope of Mount Princeton is about 500 feet, overlain by beds consisting chiefly of gray sandstone but comprising a subordinate amount of shales. These sandy beds are developed within the quadrangle to a thickness of more than 1,000 feet.

The shaly and sandy members are conformable, the one passing to the other by a rapid gradation. Some very thin seams of coal have been found near Drummond in the upper part of the shale, but the formation has not been prospected for coal in the Philipsburg quadrangle.

DISTRIBUTION.

The Colorado in the Philipsburg quadrangle occupies only three considerable areas, two being in the northeast corner of the quadrangle and the third in Wyman Gulch. In addition to these is a very small area south of the quarries on Warm Spring Creek. The best readily accessible exposure of the unaltered shale is on the northeast side of Mount Princeton and the best exposures of the upper sandy beds north of Gold Creek. The shale, changed by metamorphism to an andalusite schist, forms a cliff 1¼ miles north of Rose Mountain.

The soft lower member, though naturally forming few prominent outcrops, gives rise to characteristic smooth slopes, usually without much vegetation, covered with lustrous flakes of shale. The sandstones are moderately resistant, and the lowest part tends to form hogbacks above the shale slopes.

LITHOLOGIC DETAILS.

The material constituting the lower member of the Colorado formation is readily distinguishable from other rocks in the district. It is a remarkably homogeneous fine-grained clay shale, blue black on fresh fracture, and, unlike the shale of the Ellis formation, is not discolored on the weathered surface except for slight bleaching. It is extremely fissile and disintegrates into paper-thin flakes.

The few shale beds in the upper part of the formation are at most only a few score feet in thickness. None are quite so black, fissile, and fine grained as the shale of the lower member. As a rule they are perceptibly sandy, and range from dark blue-gray to olive-green in color.

The commonest rocks of the upper part, which make most of the prominent outcrops, are sandstones, prevailingly gray to olive. The sandstone forming the top of Mount Princeton is typical; it is flaggy, dark gray on fresh fracture, and dull olive-drab to brown on the weathered surface, which is porous because some of the calcareous cement has been leached out. The rock effervesces briskly on applications of acid. The grains of the sandstones are ill rounded and comprise much feldspar, chert, etc. Other beds are more distinctly greenish, and some weather to a reddish brown. When fresh, none show the red color characterizing much of the sandstone of the Kootenai formation. Certain beds are pebbly and a bed near the top of the section in the Gold Creek area contains small pebbles of black shale, which may indicate an unconformity.

No beds of gray limestone were noted in the upper part of the formation in the quadrangle, although they appear at places north of it.

Contact metamorphism alters the black shale of the lower member to an andalusite schist. The andalusite forms fairly regular prisms averaging about 1 millimeter thick and somewhat less than 1 centimeter long, embedded in a fine-grained blue-black matrix consisting chiefly of quartz, biotite, and a large quantity of carbonaceous dust.

The effect of strong metamorphism on the sandstone of the upper part has not been observed. An intrusive sill in the Gold Creek area has indurated some of the sandstone and shale and given them a compact flinty texture. The color of these slightly altered rocks is usually green; some of the shale is altered, however, to a chocolate-brown, flinty-looking biotitic hornstone, which weathers pale buff.

TRANSITION FROM LOWER TO UPPER MEMBER.

The passage from the shale to the prevailingly sandy beds is illustrated by the following section:

Section of lower part of Colorado formation on east slope of Mount Princeton.

	Feet.
Sandstone, with Mactra, gray, flaggy, forming top of Mount Princeton	10
Dark bluish-gray clay shale, interbedded with lighter sandy shale and flaggy gray sandstone	60
Gray sandy shale, passing downward into dark shale with some lighter slightly sandy layers	75
Blue-black, fissile clay shale	500

FOSSILS AND CORRELATION.

T. W. Stanton, who examined the Cretaceous rocks near Drummond and Mount Princeton and collected fossils from them, makes the following report [1] on the correlation of the rocks here described as the Colorado formation:

The body of black shale which overlies the Kootenai in the Philipsburg and Drummond areas is lithologically like the Colorado shale and has the same stratigraphic position. Unfortunately, we did not find any fossils in it, and its assignment to the Colorado must be on lithologic and stratigraphic relations only.

In the sandstones above the principal mass of black shale, we obtained two small lots of fossils. These are doubtfully referred to Mactra and Callista. Unfortunately they are considerably distorted and otherwise not well preserved, so that I am unable to make positive generic determinations, but I believe them to be marine forms, probably belonging to the fauna of the Colorado group. The thin beds of coal that occur near this horizon, above one of which we found a few Unios (lot 5470), may also belong to the Colorado, though of course the evidence is insufficient for positive opinion.

In the still higher beds, near Drummond, no fossils were found except a few plants which, according to Mr. Knowlton, are not sufficient for determining the horizon. His report on them is appended.

No. 1300. 1½ miles southeast of Drummond, Mont.

There are three things in this little collection: A Marchantia which is probably new, a conifer which is probably a Glyptostrobus, and a fern that is pretty close to if not identical with *Aspidium oerstedi* Heer. The latter is from Pateet, which=Senonian=Fox Hills. I can not place this material definitely, but should be inclined to regard it as possibly Upper Cretaceous.

No. 1303. Top of Mount Princeton, Mont.

A single narrow leaf without nervation except midrib. No age determination possible.

[1] Personal letter.

In 1910 Mr. Pardee collected better fossils from a limestone outcrop in Coberly Gulch about 6 miles south-southeast of Drummond and 10 miles north-northwest of the northeast corner of the quadrangle. The exact position of the horizon is not known; the limestone bed, however, is underlain by about 400 feet of sandstone and shale similar to those above the black shale. A sill of dioritic rock occurs almost immediately above the limestone, and this may be the same that occurs in Gold Creek basin. If so, it is not improbable that it remains through a distance of some 10 miles approximately at the same horizon. It is virtually certain at all events that the fossils occur in what has here been mapped as Colorado, and at least 400 feet stratigraphically above the main body of black shale.

The list of forms identified by T. W. Stanton, with his report on them, follows:

6552. Specimen 10-P 4. NE. ¼ NW. ¼ sec. 34 and SW. ¼ sec. 27, T. 10 N., R. 12 W. Granite County, Mont.
Modiola sp.
Cyrena securis White.
Corbula sp.
Glauconia coalvillensis Meek.
Admetopsis subfusiformis Meek.

The horizon is in the Colorado group. The same association of forms occurs in the Oyster Ridge sandstone member of the Frontier formation of southwestern Wyoming.

It is evident that lithologic and paleontologic evidence correlate the black shale beds and several hundred feet of the overlying sandy beds with the Colorado beyond reasonable doubt. It is still possible, however, that Montana strata occur in the syncline cut by Gold Creek. The sandstone with pebbles of black shale (p. 81) may indicate an erosional unconformity at the base of a formation later than Colorado. It occurs several hundred feet above the intrusive sill, which may mark the horizon of the fossils found by Mr. Pardee. The evidence, however, hardly justifies the mapping of a distinct formation.

CHAPTER VI.

INTRUSIVE ROCKS.

GENERAL FEATURES.

Intrusive igneous rocks occupy about half the area of the Anaconda and Flint Creek ranges, but form only a few small areas west of Philipsburg Valley. They occur chiefly in large irregular or domelike masses, and to a less extent in dikes and sheets injected parallel to the bedding of sedimentary rocks. For the most part they occupy the high parts of the mountains, because both the igneous rocks and the sediments metamorphosed by them are resistant compared with the unmetamorphosed sedimentary rocks. The granular masses of igneous rock are almost wholly bounded by irruptive contacts.

AGE.

The irregular or batholithic masses are probably all of Tertiary or, at the earliest, of very late Cretaceous age. The youngest sediments known to be metamorphosed by any of them belong to the Colorado formation, the lower, shaly member of which, in the northeast part of the quadrangle, is altered to andalusite schist by a biotite granite. But this granite, after being strongly sheared along the east front of the Flint Creek Range, was intruded by a porphyritic granite which has not been sheared. The later of these granites is shown by these facts alone to be much younger than the Colorado formation and can hardly be considered pre-Tertiary. This porphyritic granite is probably the latest of the batholithic intrusions, and several others cut only Cambrian and Algonkian sediments. There are strong considerations, however, against ascribing a pre-Cretaceous age to the masses whose relation to Cretaceous rocks can not be proven by direct evidence. Almost every mass has invaded strata of Cambrian or later age by cutting across their bedding or engulfing fragments of them. Now, it is well established that extensive irregular igneous intrusions are generally accompanied—whatever the relation of cause and effect—by deformation of the invaded strata. As the stratigraphic series from Cambrian to Cretaceous is unbroken by any distinct angular unconformity, there were probably no great batholithic intrusions during that period. The intrusive masses, furthermore, have not been affected by the great faults that cut the Cretaceous and earlier sediments. On the other hand they are older than the little-disturbed beds of volcanic ash in the valleys, which are probably Miocene. It is probable, therefore, that they are, generally speaking, about contemporaneous with or posterior to the first great deformation of the sedimentary rocks, which occurred either at the close of the Cretaceous or in early Eocene time.

Only two of the large irregular intrusions are not absolutely proven to be post-Cambrian. Both have been greatly sheared and are known from this fact and their relation to other batholiths to be among the earlier intrusions. These intrusions are the diorite near the center of the eastern boundary of the quadrangle and the even-grained biotite granite near the southeast corner of the quadrangle. There is not, however, the slightest positive evidence that these are pre-Cambrian.

The argument above urged against the pre-Tertiary age of some of the domelike intrusions does not apply to relatively thin layers of igneous rock intruded between the strata when they were horizontal. The extensive diabase sill in the upper part of the Spokane formation has been complexly folded and faulted, so that it must be earlier than most of the granites. It is probably not pre-Cambrian, for the basal conglomerate of the Cambrian, lying not far above it, contains no diabase pebbles. On the other hand, its intrusion must have taken place without seriously disturbing the horizontality of the strata, else it could not have kept the same horizon over so great a distance. It is altogether possible, even probable, then, that it is pre-Tertiary.

COMPOSITION.

The large intrusions of the quadrangle range in composition from diabase to a siliceous granitoid rock with muscovite and biotite. They include, apart from local marginal facies, no ultrabasic rocks; for example, there is no olivine-bearing igneous rock in the quadrangle, and there are few rocks that contain no quartz. There is also an absence of highly alkaline rocks. The only large mass that can be characterized as alkaline is a granite on Lost Creek, which consists essentially of albite, microcline, abundant quartz, and a little mica. The common rocks of the district are quartz-bearing diorites, rocks of the granodiorite type, and rocks that would be classified in the field as more or less typical granites; all these are connected by gradations, so that the number of readily distinguishable varieties is large.

Not enough chemical analyses have been made fully to define the characteristic chemical features of the Philipsburg rocks. The results of a few analyses and the study of many slides can be generalized, however, to this extent. The rocks of the province, chemically, are in striking contrast with those in central Montana, which are characteristically alkaline. There is, on the other hand, a general resemblance between the Philipsburg rocks and those of the districts in Montana west of the line drawn by Harker[1] between the alkaline and subalkaline regions. Even from these, however, there is a slight but characteristic difference; for the rocks in the Philipsburg district that most resemble the prevailing rocks of the Boulder batholith are a little poorer in alkalies and show a slightly smaller ratio of potash to soda than the Boulder rocks. On the other hand, they are more alkaline and relatively richer in potash than the granodiorites of the Sierra Nevada and the Cascade Mountains, which they also resemble.

The most acidic rocks of the large intrusions have the megascopic features of typical granites, but microscopic and chemical study shows them not to fulfill the definition of granite which makes it essential that alkali feldspar shall predominate markedly over soda-lime feldspar. At most, the potash feldspar barely exceeds the soda-lime feldspar, which is usually oligoclase, so that these rocks, according to the widely accepted definition of Brögger, would be quartz monzonites. The present writer, however, is loath to decide the name of a rock by one characteristic alone[2] and to call a rock monzonite which in containing abundant and conspicuous alkali feldspar and quartz and no ferromagnesian mineral but biotite resembles orthodox granite in all features except those that require quantitative laboratory study for their determination.

CLASSIFICATION AND METHOD OF DESCRIPTION.

The names of the granular rocks are used in the following senses in this report:

Diabase: A rock composed chiefly of plagioclase and augite, with ophitic texture.

Diorite: Granular rocks whose dominant phase contains hornblende as a prominent constituent and in which quartz is inconspicuous and potash feldspar scarce. Local modifications contain much biotite but no hornblende, and one small intrusion with much orthoclase is included to avoid making an additional class.

Granodiorites: Granular rocks with considerable potash feldspar but with distinctly more soda-lime feldspar, containing generally hornblende and biotite, though the former mineral is lacking in parts of certain masses described under this head.

Granites: Rocks with abundant quartz and alkali feldspar, the latter in some cases considerably less abundant than the plagioclase, containing biotite, with or without muscovite, but with no other ferromagnesian mineral.

Most rocks forming dikes and other very small intrusions, including aplites, pegmatites, lamprophyres, and porphyries genetically related to the granites, are as a rule omitted from the map and are described very briefly or not at all, though exception is made of certain rocks of marked interest or importance.

In general, the rocks are described in order of decreasing basicity.

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[1] Harker, Alfred, Natural history of igneous rocks, 1910, p. 95, fig. 21; p. 97, fig. 22.

[2] Cf. Rosenbusch, H., Mikroskopische Physiographie, 4th ed., vol. 2, 1907, pl. 1, p. 166.

NOMENCLATURE OF THE SODA-LIME FELDSPARS.

The soda-lime feldspars have been determined in the important rocks with considerable care by the use of diagrams constructed from the most accurate optical data furnished in recent years, chiefly by Prof. Becke, of Vienna.

The composition of the plagioclase, when determined with sufficient accuracy, has been stated after the fashion now prevalent among German petrographers, in terms of molecular percentage of anorthite: An_{25}, for example, means $Ab_{75}An_{25}$, or Ab_3An_1. It is believed that this notation gives, with the least trouble to the eye and mind, the means of comparing one feldspar with another.

As there is no general agreement regarding the meaning of species names like albite and labradorite, it is necessary to indicate the meanings they will have when employed without qualification. They will be employed in accordance with the following scheme: Albite, Ab to An_{10}; oligoclase, An_{10} to An_{30}; andesine, An_{30} to An_{50}; labradorite, An_{50} to An_{70}; bytownite, An_{70} to An_{90}; anorthite, An_{90} to An.

DIABASE.

OCCURRENCE.

The upper part of the Spokane formation south of Princeton, on Twin Peaks, and in the vicinity of Lost Creek contains sheets of diabase remarkable for their great extent—about 15 miles—and for the constancy with which they keep at nearly the same horizon. The rock also forms irregular dikes in the Newland formation on the lower part of Lost Creek, just outside the quadrangle.

The sheets are best exposed on the north side of Lost Creek canyon, where at least two have been intruded in the flaggy beds below the sandstone. To avoid complication only one sheet has been mapped. These sheets have participated in all the complex folding and faulting of the sedimentary rocks on Lost Creek and to the south. On the northwest face of Twin Peaks there is a single sheet about 300 feet thick intercalated with the overturned sandstones of the Spokane formation, stratigraphically not far below the Flathead quartzite.

PETROGRAPHY.

The diabase has the usual megascopic features, being heavy, compact, and nearly black, tending to become somewhat rusty on the weathered surface where lath-shaped feldspars can be distinguished from the mass of dark minerals that fills the interstices between them. The texture ranges from that of ordinary granite to very fine.

The constituents appearing in a thin section from the least altered specimen are plagioclase, augite more or less altered to uralite, some hornblende that may be original, ilmenite or magnetite, biotite, quartz, apatite, and zircon; no olivine is present, nor do any secondary minerals suggest its former presence. The texture is ophitic. The plagioclase is but faintly zoned, cores of sodic labradorite with a composition near An_{55} shade into margins of andesine near An_{40}. The biotite is greenish brown and forms finely felted aggregates mostly on the borders of the iron-ore grains, although some is intergrown with hornblende.

The last portion of the rock to solidify is represented by micropegmatitic intergrowths of quartz and feldspar whose appearance is shown in Plate XII, *A*. The feldspar might be taken at first glance for orthoclase, but careful examination discloses fine albite striations, and comparison of the refractive indices with those of quartz show the feldspar to be an oligoclase with a composition near An_{20}.

In most specimens the augite is completely altered to amphibole, a change probably due in some of them to the action of later intrusives. In the vicinity of Lost Creek the diabase has suffered the same strong contact metamorphism that has affected the associated sedimentary rocks. (See Pl. XII, *A*.) The texture is essentially that of the unaltered rock, but the micropegmatitic growths of quartz and oligoclase are larger than in the fresher diabase. The augite has completely given way to green hornblende, which does not have the character of typical uralite, but is wholly similar to the ordinary primary hornblende of rocks like granodiorite. This forms large ragged individuals intergrown with quartz, and also small grains and prisms inclosed partly in the plagioclase laths but mostly in the micropegmatite.

DIORITE (EPIDIORITE?) NEAR MOUNT HOWE.

OCCURRENCE.

A small area of diorite is shown on the map about a mile southeast of Mount Howe. The rock forms a sill in the Prichard formation, and is intruded by granite. Float of the same rock has been found on the divide between Mounts Howe and Evans. The petrographic character of the rock, together with its occurrence as a sill, suggests that it is a diabase affected by the same intense metamorphism that has changed the sediments to schists and gneisses.

PETROGRAPHY.

The rock is gray, of about the same shade as the diabase, and superficially similar to it in texture. Some of the white areas that project into the dark areas have lath-shaped outlines, suggesting an ophitic texture. The areas of light and dark constituents, however, are evidently not single crystals but crystalline aggregates.

In thin section the dark parts prove to consist chiefly of hornblende and biotite, the former predominant. Imbedded in these aggregates are numerous large irregular grains of black iron ore, with rims of finely granular titanite. The white parts are mosaics of labradorite and quartz grains. The feldspar is remarkably fresh and free from zoning but contains inclusions of hornblende and biotite.

DIORITE SOUTHWEST OF GEORGETOWN LAKE.

OCCURRENCE.

Two small areas of diorite lie between Georgetown Lake and the East Fork of Rock Creek. The rock is clearly intrusive in the surrounding calcareous shales, which it has indurated and partly altered to diopsidic hornstones. The outcrops are not prominent.

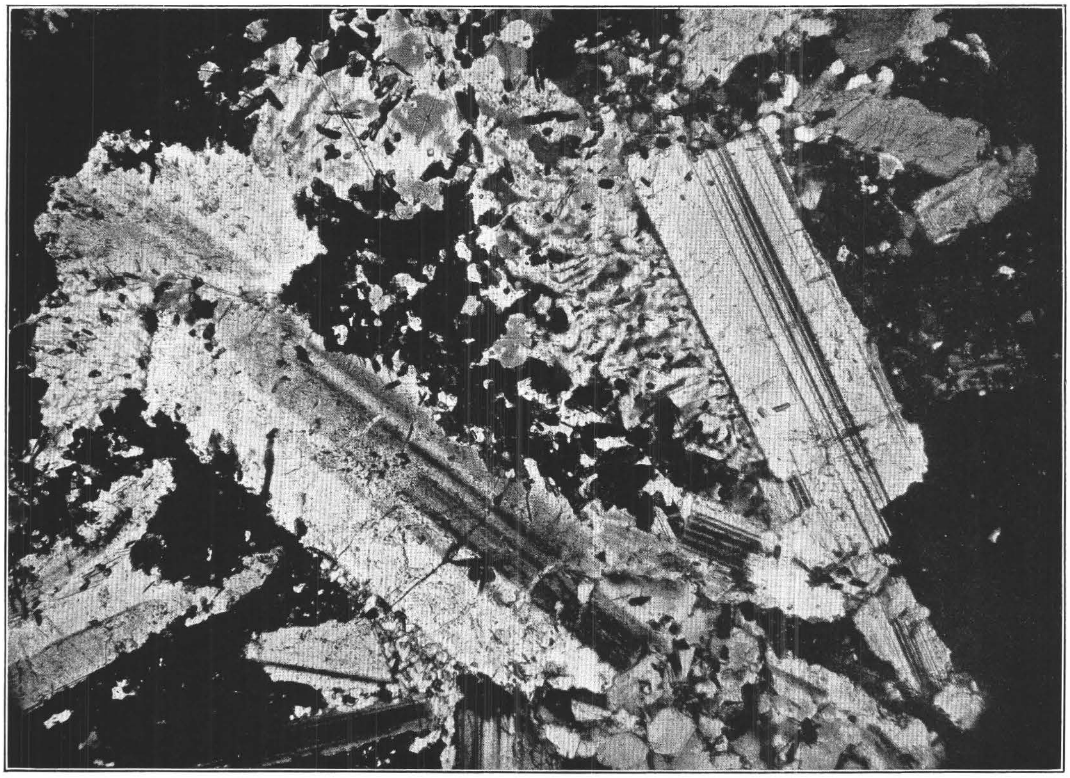
PETROGRAPHY.

A specimen from the northern area is strikingly characterized by abundant, rather slender, prisms of black hornblende averaging about 1 centimeter long. These are embedded in a white, finely crystalline feldspathic groundmass, whose bulk is slightly greater than that of the hornblende.

The microscope shows hornblende to be the most abundant mineral; orthoclase and plagioclase, about equal in quantity, come next; and quartz and augite are somewhat less abundant. Hypersthene seems to have been present in small quantity but has been altered to serpentine. Titanite and apatite are prominent accessories; zircon and magnetite are scarce. The hornblende, as in the rock of Olson Gulch, is deep greenish brown to pale green, the green tints being marginal. The crystals are penetrated by embayments of groundmass. Augite forms a few phenocrysts, clearly older than those of hornblende, and incloses the pseudomorphs after hypersthene. Plagioclase forms well-zoned crystals with clouded centers, mostly less than 1 millimeter in diameter, with the average composition of a labradorite. Orthoclase is in larger anhedral grains, partly intergrown with quartz. The titanite is clearly later than plagioclase.

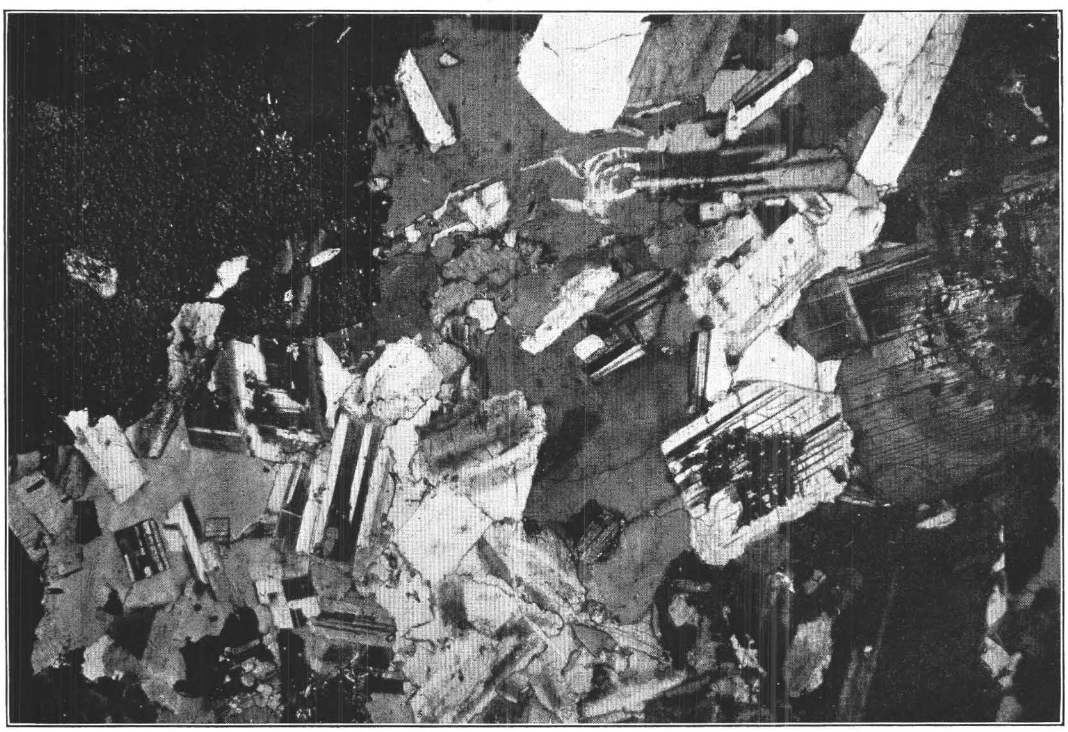
SILL IN SILVER HILL FORMATION.

The sill (unmapped) in the Silver Hill formation (p. 53) is a very dark green rock of fine texture. Megascopically, it seems to consist in the main of a feltlike mass of ill-defined amphibole individuals 1 or 2 millimeters long, with a dull silky luster, among which biotite flakes, mostly less than 1 millimeter in diameter, are rather thinly sprinkled.



A. THIN SECTION OF METAMORPHOSED DIABASE FROM SILL IN ALGONKIAN ROCKS NORTH OF LOST CREEK.

Shows micropegmatitic intergrowth of oligoclase and quartz oriented on large crystal of labradorite. Black is chiefly hornblende, intergrown with quartz. Slender needles of apatite conspicuous near top. Crossed nicols. Enlarged 60 diameters.



B. THIN SECTION OF GRANODIORITE EXPOSED NEAR CABLE.

Shows poikilitic habit of quartz, orthoclase, and biotite, micropegmatitic intergrowth of quartz and orthoclase, and myrmekite fringe of plagioclase. Enlarged 50 diameters.

The microscope shows the rock to be porphyritic, with ferromagnesian phenocrysts in a microgranular groundmass whose volume is rather less than that of the phenocrysts. Alteration has been extensive and is possibly due in part to the same concealed intrusive that has slightly metamorphosed the inclosing sediments.

Except for a few relatively large flakes of greenish-brown biotite, the phenocrysts are extremely ragged prisms of bluish-green hornblende inclosing a great deal of biotite, partly in parallel intergrowth and partly as irregularly oriented flakes. These phenocrysts also inclose quartz, yellow and brown epidotes, feldspar, titanite, and calcite. The groundmass is composed mainly of lath-shaped zoned plagioclase (An_{60-25}), subordinate quartz and potash feldspar, and very numerous irregular particles of hornblende and biotite, besides a good deal of secondary muscovite and calcite. Apatite is conspicuous in stout prisms, some of which are larger than most of the plagioclase laths of the groundmass.

The rock somewhat resembles the upper part of a sill at the same stratigraphic horizon in the Threeforks district, which Merrill[1] describes as having phenocrysts of uralitic hornblende and pseudomorphs probably after some other ferromagnesian mineral.

BASIC INTRUSIVES IN THE CRETACEOUS ON GOLD CREEK.

Rocks that may roughly be classified as diorite porphyry and fine-grained diorite form sills, and perhaps dikes as well, in the Cretaceous rocks of Gold Creek basin, near the northeast corner of the quadrangle. Their character is illustrated by two specimens from the easternmost area, different in texture but similar in composition and probably belonging to a single intrusion.

One specimen is porphyritic and shows lustrous bladed crystals of olive-green amphibole or pyroxene mostly about 1 or 2 millimeters across in a finely crystalline groundmass of the same color.

The microscope shows most of the phenocrysts to consist of intergrown augite and amphibole, both nearly colorless in thin section. The augite forms irregular nuclear masses, and that these are residual and the amphibole secondary is indicated by the fact that a crystal consisting chiefly of amphibole has the typical octagonal cross section of augite. Less numerous phenocrysts of some other mineral, possibly hypersthene, are represented by pseudomorphs of serpentine penetrated by splinters of actinolite. The groundmass contains a second generation of these altered minerals, together with much lath-shaped feldspar (andesine and labradorite), and a little quartz. The rock is badly decomposed, and contains much finely divided acicular amphibole with biotite, calcite, and other secondary minerals. There is considerable apatite in slender prisms, and a titaniferous iron ore almost completely altered to leucoxene.

The second specimen is a dark-gray rock of medium-fine granular texture. Megascopically it seems to consist mainly of almost equal parts of greenish-black hornblende and dull-white feldspar in individuals about 1 or 2 millimeters in diameter; with considerable biotite in smaller foils.

Under the microscope the hornblende shows a slightly porphyritic texture, yet it is allotriomorphic against plagioclase and incloses some small crystals of it. It therefore shows no crystal form to indicate whether or not it is secondary, and it contains no inclusions of augite. Its allotriomorphic character and its pale tint suggest, however, that it is uralitic like that of the specimen just described. It is crowded with small flakes of biotite, possibly secondary, but biotite clearly primary also occurs in flakes of about 1 millimeter in diameter. The feldspar is chiefly a strongly zoned plagioclase, in prisms elongated parallel to *a* and slightly flattened on 010; the cores are labradorite near An_{65}, and the narrow rims into which the cores shade rather abruptly are oligoclase and oligoclase-albite, partly as sodic as An_{10}. In interstitial relation is a rather small amount of alkali feldspar and quartz, partly forming micropegmatic intergrowths. The alkali feldspar seems to be anorthoclase with the character of that in some of the pyroxene aplites (p. 122). The rock is altered and contains considerable calcite, sericite, and plainly secondary actinolite, which penetrates the feldspar.

[1] Merrill, G. P., Notes on petrography, from report by A. C. Peale, Paleozoic section in the vicinity of Three Forks, Mont.: Bull. U. S. Geol. Survey No. 110, 1893, pp. 47-54.

This rock, if the hornblende is uralitic, shows some affinity to the diabase intrusive in the Algonkian, but differs from it in the less distinctly lath-shaped form and more basic composition of the plagioclase, the somewhat porphyritic development of the amphibole or pyroxene, and the presence of conspicuous flakes of biotite. It seems a little less basic than the porphyry just described.

DIORITE OF FOSTER CREEK AND OLSON GULCH.

CHARACTER.

In Olson Gulch and Foster Creek basin are several areas of intrusive rock somewhat similar to the diabase in its dark-gray color, but distinguished from it by the prismatic form of the chief dark mineral—hornblende—and by the presence of considerable biotite. These basic diorites are, on the other hand, darker, finer, and less feldspathic than the diorites of Mount Haggin and Racetrack Creek. There is considerable range of composition in the rocks described under this heading, but as specimens taken close together show considerable difference it is probable that all belong to one rather variable intrusion.

OCCURRENCE.

A prospect tunnel has been driven in the diorite near the forks of Olson Gulch proper, and from the dump near this tunnel the best specimens of the rock are obtained. The natural outcrops are deeply weathered.

Although the contacts of the diorite are not well exposed in Olson Gulch, its intricate boundaries, the form of its area, and the numerous limestone inclusions, the larger of which are mapped, indicate that it is a stocklike intrusion in the Paleozoic rocks. There is no evidence that it has been affected by the complex faulting that has displaced the limestone; it seems to be either later than the faulting or contemporaneous with it, and hence distinctly later than the diabase sills in the Spokane formation.

The diorite of Olson Gulch is not known to be cut by later intrusives. Along its northern and higher border have been found decomposed fragments of a biotite granite whose relations to it are not clear, but which possibly represent a marginal differentiate from the diorite.

The diorite occurs on Foster Creek about 3 to 5 miles from its mouth. It intrudes the Jefferson and Madison limestones and is cut in turn by a granite described on page 112.

PETROGRAPHY.

The most basic phase of these diorites is illustrated by a specimen taken from the dump of the prospect on Olson Gulch.

The rock is fairly coarse grained and dark gray, with dark and light constituents about equal in amount. The most abundant dark mineral is hornblende in crystals some of which are 1 centimeter long; their form, shown on weathered surfaces, is that of stumpy imperfect prisms. On freshly broken surfaces the cleavage faces show bright reflections somewhat mottled by inclusions. The chief light constituent is feldspar in dull-white masses smaller than the hornblende crystals, and lacking the definite lath shape exhibited by the feldspar of the diabase above described. The only other constituents visible to the naked eye are a little biotite and numerous grains of pyrite.

The microscope shows that the original constituents are hornblende $\gtrless$ plagioclase > augite $\gtrless$ biotite $\gtrless$ quartz > hypersthene > magnetite $\gtrless$ apatite. Secondary bastite, chlorite, sericite, and calcite are present. It is doubtful, in view of the somewhat decomposed condition of the rock, whether the pyrite is original or secondary. The hornblende, which carries many small inclusions of the other minerals, ranges in color from deep greenish brown to pale green. The plagioclase forms stoutish prisms elongated parallel to $\breve{a}$. The crystals consist in greater part of anorthite near An_{92}. The individuals, except where they are in contact with ferromagnesian minerals, have a narrow rim of sodic labradorite (An_{50-55}), surrounding a sharply defined anorthite core; the core and rim are each nearly homogeneous. Where the feldspar is in contact with hornblende or biotite the rim is wanting. The augite is always surrounded by hornblende that seems to be original. The biotite forms irregular poikilitic foils, partly inclosed in hornblende. Hypersthene forms a few small pleochroic grains inclosed in hornblende, and is altered in part to a fibrous substance like bastite. Quartz, which is more abundant than megascopic examination would lead one to expect, forms a poikilitic cement for small grains of the other constituents. The order of crystallization in the rock has been, roughly, apatite and iron ores, pyroxene and cores of plagioclase, biotite, hornblende, rims of plagioclase, quartz.

A more acidic facies common on Foster Creek is a dark-gray rock of rather fine granular texture with a slightly porphyritic development of biotite and plagioclase. Its most conspicuous though not most abundant mineral is biotite, which forms irregular foils mostly from 1 to 5 millimeters across. Dull-white grains of feldspar about 2 millimeters in average diameter also stand out from a groundmass chiefly of feldspar and splintery hornblende. In certain specimens the presence of a highly poikilitic unstriated feldspar can be recognized by reflections flashed from cleavage faces as much as 1 centimeter across.

The original constituents identified microscopically are plagioclase, hornblende, biotite, quartz, microcline, titanite, magnetite, and apatite; the secondary ones are calcite, chlorite, epidote, kaolin, sericite, and a zeolite.

The plagioclases are strikingly zoned, with sharply defined cores near An_{90}, as in the rock of Olson Gulch, but with rather broader borders, in which the composition ranges from about An_{60} to about An_{40}. The hornblende and biotite are of the ordinary colors and both inclose plagioclase, the larger individuals of biotite being especially rich in inclusions. Quartz, fairly abundant considering the generally basic aspect of the rock, forms relatively large poikilitic individuals. Microcline, where it is abundant, occurs in the same way but where it is scarce forms small interstitial areas. Its amount varies remarkably. In some specimens it is little less abundant than plagioclase but commonly is very subordinate; it is rarely or never absent. The accessories, titanite, magnetite, and apatite, are relatively abundant.

In another phase the most prominent constituent is hornblende in rather slender prisms less than 0.5 centimeter in average length. In a specimen of this type from the northernmost area on Foster Creek, near the contact with limestone, the microscope reveals a few spongiform grains of apparently original scapolite.

DIORITE OF TWIN LAKES AND MOUNT HAGGIN.

GENERAL CHARACTER AND OCCURRENCE.

The largest area of diorite in the quadrangle is that extending from Storm Lake Creek to the head of Mill Creek. Another area, which includes the top of Mount Haggin, is of similar rock and probably belongs to the same intrusion. The dominant type of rock in these areas is a diorite coarser grained and less basic than those above described, in which the chief constituents are plagioclase, quartz, hornblende, and biotite. The dark minerals are plainly inferior in amount to the quartz and feldspar and do not form well-developed crystals, and the aspect of the rock is that of a typical quartz-mica diorite or tonalite. Near the margins there is more or less variation, the outer parts being on the whole more basic than the main mass.

The diorites are well exposed in both the Twin Lakes and the Mount Haggin areas. They are distinctly darker than the other igneous rocks associated with them, and are somewhat rusty when weathered.

In the area to the west, the intrusive relation to the Cambrian and Algonkian rocks is clear. The diorite has engulfed great masses of magnesian limestone resembling that of the Hasmark formation but intensely metamorphosed. Some of these are mapped, and Plate VI, *A* (p. 46), shows small inclusions with hornblendic reaction rims. On the walls of Fourmile Basin, the diorite may be seen to cut across the bedding of the Algonkian rocks. In the Mount Haggin area the contact with the sediments is much obscured by talus, though the intrusive relation to Cambrian beds is clear in one place where the diorite, normal 4 feet from the contact, becomes streaky, finer grained, and more siliceous as the contact is approached, and the limestone for a few inches from the contact is changed to a rock rich in garnet and epidote.

The diorite, so far as observed, is older than the more acidic intrusives with which it is in contact. It is cut by the granodiorite near Storm Lake and is penetrated in the Mount Haggin area by innumerable strikingly conspicuous light-colored dikes of aplite and pegmatite, as well as by some granite dikes that seem to be apophyses from the muscovite-biotite granite that surrounds Haggin Lake. About the divide between Mill Creek and Twin Lake Creek the diorite is strongly sheared.

PETROGRAPHY.

The prevailing type of diorite east of Storm Lake is a gray, medium coarse grained rock, at least two-thirds of which consists of feldspar with subordinate and inconspicuous quartz, the remainder being made up chiefly of hornblende and biotite in about equal quantity. All these constituents form individuals without well-developed crystal form, of which the maximum diameter is about 5 millimeters and the average much less. The dark minerals show some tendency to cluster in ill-defined aggregates.

The microscope shows plagioclase to be the most abundant constituent, with hornblende, biotite, and quartz, in amounts not far from equal, next in order of abundance. Augite, titanite, apatite, magnetite, zircon, and rutile are accessory. The ordinary effects of weathering are shown, but not to a marked degree.

The plagioclase, slightly zoned but conspicuously mottled, averages about 50 per cent anorthite.

Hornblende and biotite are of their ordinary colors and present no noteworthy features, except that a little augite is intergrown with the hornblende. The quartz is interstitial rather than poikilitic. No potash feldspar is present. Numerous hairlike inclusions like rutile in the quartz and plagioclase are somewhat characteristic of the rock.

The percentages of silica and alkalies in a sample of this rock were as follows:

Partial analysis of diorite from ridge east of Storm Lake.

[Analyst, W. T. Schaller.]

SiO_2	57.00
K_2O	1.55
Na_2O	2.65

In the American quantitative classification the rock would probably be a tonalose. The percentages are similar to those in a pyroxene-mica diorite from the Yellowstone National Park.[1]

The variations from the normal type can be indicated only briefly.

A specimen from Mount Haggin, very similar in appearance to that just described, has much more biotite than hornblende. Marginal basification of a familar type is well shown at the end of the spur southeast of Twin Lakes, where the diorite is generally finer grained and richer in dark minerals than usual, although it is streaky and variable in composition and texture. In some phases the plagioclase tends to form phenocrysts in a comparatively fine grained, dark groundmass. The thin sections of these rocks show essentially the same minerals as the normal diorite. A very little interstitial microcline appears in some specimens.

A more interesting rock occurs near the contact east of Storm Lake. It is darker and coarser than the normal diorite. The most conspicuous mineral is hornblende, which forms imperfect crystals nearly as broad as they are long, with a maximum diameter of 2½ centimeters (1 inch) or more and lustrous cleavage faces mottled with inclusions. Between the large crystals are smaller ones mingled with white feldspar.

The microscope shows plagioclase and hornblende to be about equally abundant. Augite, hypersthene, quartz, and biotite all occur in subordinate quantity, the two last being very much less abundant than in the normal diorite. The hornblende, as in the more basic diorites previously described, varies from greenish brown through green to nearly colorless. The hypersthene, which like the augite is inclosed in hornblende, is mostly altered to talc and magnetite. The plagioclase crystals consist chiefly of sodic labradorite but have irregular cores of anorthite.

[1] Bull. U. S. Geol. Survey No. 228, 1904, p. 103, analysis A.

The secondary constituents of these diorites are the ordinary ones, and none deserve particular notice but epidote, which is one of the most abundant. In some specimens this mineral, by its association with chlorite and sericite, appears to be a product of familiar processes of decomposition. In certain slightly gneissoid phases of the diorite, however, where the feldspar is almost unclouded and the biotite hardly touched by chloritization, abundant epidote in large grains is associated with the fresh minerals. Most of the epidote belongs to the variety pistacite, but some grains have cores of allanite. A strong case for primary origin of this epidote might be made out if the rock were known to be unaltered, but it has been subjected both to dynamic and to thermal metamorphism, and it is probable that these agencies, acting at a great depth, formed the epidote without causing the decompositions that usually attend the formation of that mineral under a lighter cover.

DIORITE OF RACETRACK CREEK.

GENERAL CHARACTER AND OCCURRENCE.

The diorite along Racetrack Creek in the northeast quarter of the quadrangle is strikingly similar in general aspect to that near Mount Haggin and Twin Lakes. It is well exposed on the slopes of the hill between Racetrack and Thornton creeks, locally known as Sugarloaf Mountain, and on the glaciated sides and bottoms of the canyons.

It is in contact with overturned Cambrian rocks south of Thornton Creek and is almost certainly later than the sediments, but no clearly irruptive contact with them has been found. Diorite observed within a short distance of the limestone at this locality had a south-dipping schistosity suggesting that it has been affected by the strong thrusting that has deformed the sediments.

The diorite is cut by porphyritic biotite granite and muscovite-biotite granite and penetrated by immense numbers of related aplite dikes, whose whiteness is in striking contrast to the dark tone of the diorite.

A shearing has affected this rock like that of Mount Haggin, and it everywhere has a schistosity that is readily visible on large outcrops though not always conspicuous in hand specimens.

PETROGRAPHY.

The diorite of Racetrack Creek resembles the normal phase of the Twin Lakes mass in tone and in the nature of its chief minerals, and its grain is about as coarse. Typical specimens from the two masses show, however, some differences that seem to be consistent. The most obvious is one of texture. In the diorite of Racetrack Creek the plagioclase is partly in large crystals as much as 12 millimeters long, distinguishable from a coarse-grained matrix, and these give the rock a rudely porphyritic appearance. In composition the diorite of Racetrack Creek appears to be a little less basic than that of Twin Lakes, for it contains a somewhat smaller proportion of ferromagnesian constituents, and the thin sections all show an appreciable amount of microcline.

Except for the differences indicated, the rock resembles that previously described, even in microscopic features. The microcline, which is the least abundant of the essential constituents, forms small interstitial anhedra, in contact with which the plagioclase has the micropegmatitic borders called myrmekite by German petrographers.

BASIC GRANODIORITE OF STORM LAKE.

GENERAL CHARACTER, DISTRIBUTION, AND GEOLOGIC RELATIONS.

The intrusive east of Storm Lake is a rock composed essentially of plagioclase, hornblende, biotite, potash feldspar, and quartz. It is characterized by a peculiar development of the biotite, which forms large conspicuous ragged foils crowded with inclusions of the other minerals. The rock occurs mostly in a single area of about 2 square miles, extending northwest and southeast of Storm Lake. A few small knobs projecting through the moraine north of the main area are perhaps connected with it underground.

The necessity for qualifying the last statement is due to the fact that the rock shows considerable variation. These areas isolated from the main mass resemble it more than they do the diorite of Mount Haggin, the only other large intrusion with which they might plausibly be connected. The variation evidently depends for the most part on proximity to contacts. The rocks near contacts are characterized by intricate mingling of more acidic and more basic portions, the acidic penetrating the fissures of the sedimentary rocks more deeply than the basic, and the same sort of variation is notable in large apophyses from the main mass on the ridge west of Storm Lake. The Storm Lake intrusion is also characterized by abundant inclusions of sedimentary rocks. Many of the large ones have been shown on the map, and the abundance of smaller ones near the contact west of Storm Lake is well illustrated in Plate XIII, *B*. Many of these inclusions are partially absorbed and surrounded by hornblendic reaction rims, as shown in Plate VI, *A*, page 46.

The evidence regarding the age relation of the granite of Storm Lake to the sediments is of the clearest character. Plate XIII, *B*, shows the phenomena of intrusion in such a manner as to prove this relation at the west end of Storm Lake dam more cogently than any argument could do. The contact of the main mass with sediments has not been observed, but the rock east of Storm Lake Creek is intrusive in the diorite of Mount Haggin, which is itself intrusive in the sediments. The priority of the diorite, suggested by the areal relations, is proved by the fact that the granodiorite is a little finer than usual near its contact.

PETROGRAPHY.

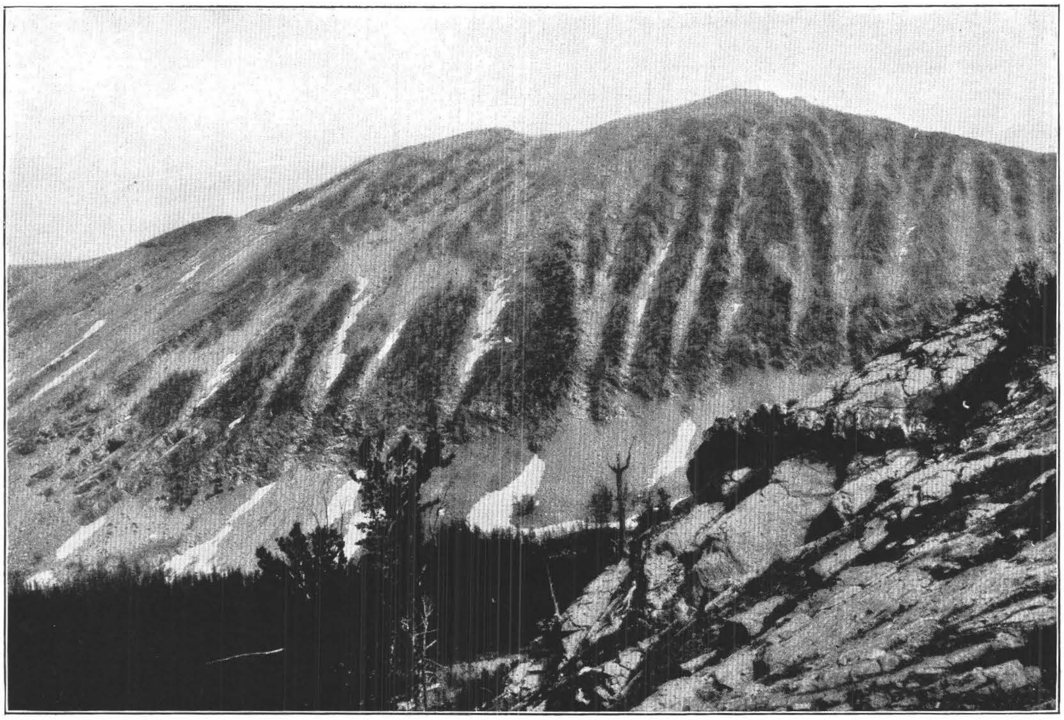
DOMINANT TYPE.

The most typical rock of the Storm Lake batholith is rather dark gray and of medium-fine grain. The fresh glassy feldspar is not readily distinguishable from quartz, except that some irregular poikilitic grains of unstriated potash feldspar can be recognized by the flashes from their basal cleavage planes. The hornblende is in the usual grains or in imperfect prisms less than 3 millimeters in maximum diameter. The biotite is far more conspicuous; it forms ragged foils as much as $\frac{3}{4}$ centimeter in diameter, and apparently separate pieces flash together over areas 2 or 3 centimeters across. The reflections from its cleavage faces are much broken by inclusions.

The thin section shows the complete list of original minerals and their relative abundance to be as follows: Plagioclase $>$ quartz $\gtrless$ biotite $>$ microcline $\gtrless$ hornblende $>$ augite $>$ magnetite $\gtrless$ apatite $>$ zircon $>$ rutile (?).

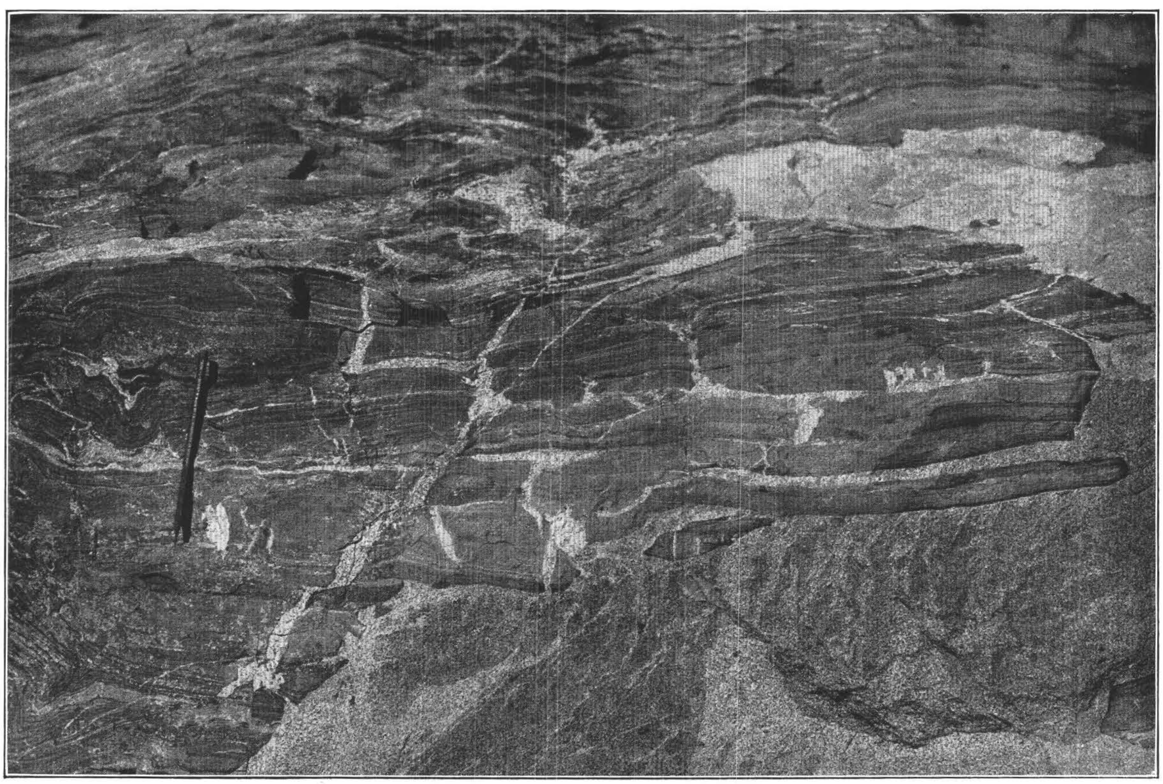
The plagioclase is in subhedral crystals, considerably zoned and mottled; the most basic portions are of basic labradorite (An_{65-70}), and the most abundant combination is a sodic andesine of average composition, approximately An_{40}. The slightly perthitic microcline is subordinate. The hornblende and biotite are of the ordinary varieties, and the irregular cores in most of the hornblende grains are formed by augite of pale-green tint. Magnetite is rather abundant.

The relations of the minerals indicate an unusual order of crystallization. All the chief constituents, except plagioclase, are in very ragged individuals. Those of quartz, microcline, and biotite are extremely poikilitic and commonly interpenetrate one another. The hornblende and augite grains are smaller and less poikilitic, but they occasionally interpenetrate with quartz and biotite and inclose plagioclase. Plagioclase, on the other hand, incloses small particles of hornblende, augite, and biotite. The main bulk of the essential constituents appears to have crystallized in the following order: Plagioclase, augite and hornblende, biotite, quartz and microcline. There has been, however, much overlapping, and the ferromagnesian constituents began to crystallize at least as early as the plagioclase.



A. IRRUPTIVE CONTACT OF GRANODIORITE WITH NEWLAND FORMATION AT THE HEAD OF THE EAST FORK OF ROCK CREEK.

The contact, which is parallel to the bedding, runs from the top of the peak toward the lower left-hand corner of the view. Looking south.



B. DETAIL OF CONTACT BETWEEN GRANODIORITE AND ALGONKIAN ROCKS AT STORM LAKE.

Shows stoping, apophyses, and variation in igneous rock.

CHARACTER OF VARIATIONS.

The variations in the rocks mapped with that just described are so multiform that only their general character can be indicated.

Of secondary interest are the variations, chiefly textural, observed particularly in the eastern area near contacts with the diorite. The poikilitic habit of the biotite, though usual and characteristic, does not everywhere obtain. A specimen from a frozen contact with the diorite east of Storm Lake shows the latter to be normal except for some development of pyrite, while the granodiorite is about twice as fine in texture as usual and contains less than its usual amount of ferromagnesian minerals. The microscope shows it to be without hornblende.

Another textural modification is a granodiorite porphyry collected from float on the slope east of Storm Lake, and probably belonging to an apophysis extending from the granodiorite into the diorite. At first glance the porphyritic nature of the rock is hard to recognize, for the most abundant phenocrysts—those of fresh glassy plagioclase—show no color contrast with the gray and perceptibly crystalline groundmass, and the ferromagnesian constituents, which are biotite and a dull-black mineral identified microscopically as pyroxene, do not form well-developed crystals.

The microscope shows numerous phenocrysts of plagioclase, pyroxene, and biotite with sporadic phenocrysts of microcline. The groundmass, which constitutes about half the rock, is microgranular, and consists chiefly of quartz and microcline with subordinate plagioclase. The zoned plagioclase phenocrysts consist chiefly of andesine with some sodic labradorite. The pyroxene phenocrysts are of intergrown augite and hypersthene, and some are partly bordered with hornblende. The biotite, like that of the granular rock, is extremely poikilitic.

The "streakiness" of the granodiorite near contacts with the sediments is illustrated in Plate XIII, *B*, but is in places much more marked than is there shown. The highly variable marginal zone consists in part of rock nearly normal in character. Specimens from the locality where the photograph was taken show angular to subangular fragments of green hornfels, rich in diopside and hornblende, embedded in granodiorite whose biotite is not conspicuously poikilitic, and which is somewhat finer and darker than the normal rock, though not markedly different in composition. Elsewhere an impoverishment in ferromagnesian constituents is visible for a few millimeters from the contact.

The inclusions, though mainly of rock produced by the alteration of calcareous sediments and similar to those shown in Plate VI, *A*, comprise some of dioritic character, probably produced by differentiation from the granodiorite magma. Certain phases of the marginal rocks near Storm Lake are quartz-mica diorites without alkali feldspar.

The rocks differing most markedly from the normal granodiorite have the variable textures of pegmatites and aplites. The coarser rocks are in general the more basic. They are characterized by large and conspicuous crystals—in some specimens attaining a length of 1 or 2 inches—of pyroxene, or of hornblende intergrown in places with biotite. More or less feldspar, and, usually some quartz, are present. The feldspar is for the most part basic plagioclase, some of which is sharply zoned, with cores of anorthite, but microcline is also present locally. The most abundant accessory is titanite. These rocks are generally much decomposed.

The finer grained rocks are of rather alkaline composition. Their character is illustrated by a specimen consisting partly of quartz-mica diorite and partly of rocks with somewhat aplitic features, obtained at the west end of Storm Lake dam. One part consists chiefly of sugary feldspar and quartz, with a small or moderate amount of hornblende in slender prisms about 1 centimeter long. Thin sections show the feldspar to be chiefly microcline, but there is a subordinate quantity of plagioclase. A little pale-green pyroxene of diopsidic facies is present, and titanite, apatite, and zircon are abundant accessories. This rock adjoins, on a rather ill defined contact, a light-gray aplite with a few crystals of hornblende. The microscope shows it to resemble the adjacent rock except that it contains abundant pyroxene and more sodic plagioclase.

GRANODIORITE AT CABLE.

GENERAL CHARACTER, DISTRIBUTION, AND GEOLOGIC RELATIONS.

The granite forming the principal country rock of the Cable mine is composed of the same minerals as the granodiorite of Storm Lake, but does not show the poikilitic development of biotite. It forms a mass, roughly circular in plan, bounded mainly by irruptive contacts with sedimentary rocks ranging from Algonkian to late Carboniferous. It has greatly metamorphosed these rocks and is thought to be the source of the mineralization which formed the auriferous deposits of the Cable, Southern Cross, Gold Coin, and other mines, as well as of many magnetite bodies developed along its contact.

The great part of the mass is of fairly constant composition, but locally the rock is very basic near contacts, and to a slight extent assimilates the calcareous rocks cut by it. It is characterized, as all rocks of similar composition seem to be, by lamprophyric inclusions. It is associated with aplites and pegmatites rich in albite, and near the margin with rocks of the "pyroxene aplite" type.

Being in an unglaciated area and rather susceptible to weathering, the granodiorite at Cable is not very well exposed. On the little plateau between the Cable and Southern Cross mines, where it forms a base-leveled surface that has long been immune from vigorous erosion, and has been covered with a mantle of quartzite waste from Cable Mountain, it is decayed to an incoherent sand, which is excavated with pick and shovel to a depth of 10 feet or more and carted away for use in making mortar. The most extensive and prominent outcrop of the prevailing rock forms the summit of the hill a mile southwest of Cable, and the freshest specimens are to be obtained in the quarry on the west side of this knob. The best exposure of the contact with adjacent sediments is on the spur east of Cable, where the metamorphism and the variation in the magma are both very striking. Remarkable metamorphism is also exemplified in the gulch north of Gold Coin, where the calcareous shale of the Red Lion formation is changed to coarsely crystalline aggregates whose chief constituents are garnet, calcite, quartz, epidote, and pyroxene. Characteristic features of the contact zone are local development of scapolite and abundant formation of magnetite in limestones and dolomites. (See Pls. IX, *B*, p. 60; XV, *B*, p. 130.)

The granite has cut across the preexisting structures in making its way upward, and the adjacent sediments more frequently dip toward it than away from it. Its boundaries are irregular in detail, and it partly or wholly surrounds several small sedimentary masses, most of which do not appear to be much removed from the situation that they had before the intrusion, and may be "roof pendants"[1] isolated by erosion.

Of particular interest among these is the dolomite mass, largely replaced by magnetite, in which the ore of the Cable mine has been formed. Its plan on the surface is shown roughly by the geologic map (Pl. I, in pocket), and its boundaries beneath the surface have been explored to a large extent in the workings of the Cable mine (figs. 42 and 43). Although these workings have not been extended to the northern limit of the mass, the dolomite appears from surface observations to abut there against a fault contact with the quartzites and shales of the Spokane formation. The boundary of the granite is partly in line with this fault, and movement on the contact between granite and quartzite is shown in the Queen tunnel, but inasmuch as no extensive movement is apparent in line with the fault to the west, it is probable that the subsidence of the dolomite was chiefly contemporaneous with the intrusion and that the postgranitic movement was of slight amount.

[1] Daly, R. A., The Okanogan composite batholith of the Cascade Mountain system: Bull. Geol. Soc. America, vol. 17, 1906, pp. 329-376, p. 336.

PETROGRAPHY.

NORMAL FACIES.

A specimen from the quarry half a mile southwest of Cable has been subjected to careful petrographic study and chemical analysis. It is a dark bluish gray, evenly granular rock, somewhat finer in texture than most granites, in which the dark minerals occupy roughly about one-fourth of the bulk of the light-colored ones. It contains lustrous irregular biotite flakes with a maximum diameter of about 4 millimeters, although most of them are about 1 millimeter in diameter. The duller and less conspicuous hornblende, which occurs in grains of similar dimensions, is not quite so abundant. By turning the specimen about to catch reflections from cleavage faces the little subhedral plagioclase crystals can be distinguished from the larger, highly poikilitic individuals of potash feldspar, although they show no marked difference of color. A thin section is shown in Plate XII, *B*, page 86.

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

The plagioclase is zoned, and the cores are conspicuously mottled by an intergrown lacework of basic feldspar, showing in most specimens a distinctly higher birefringence than the matrix and of noticeably higher refractive index. A large part of each crystal is basic andesine—An_{44} in the best-determined crystal and An_{37-45}, with an average of An_{42}, in five determinations—the most acidic combination being oligoclase approximately An_{20}. The composition of the most basic part varies in different crystals from An_{75} to An_{80}. The average composition of the crystals is estimated to be that of a basic andesine, between An_{40} and An_{50}.

The potash feldspar is highly poikilitic orthoclase. The inclusions of a given individual have on the average an aggregate volume somewhat less than half that of the orthoclase itself. Almost no definite perthitic veinlets of albite are present, and the crosshatching of microline has not been developed.

The quartz has the same poikilitic relation to the other minerals as the orthoclase, but the maximum diameter of the individuals is less than for the feldspar. Locally graphic intergrowth of quartz and potash feldspar coarser than the fringes of myrmekite is developed on the borders of the plagioclase crystals at the contact with orthoclase. Of the accessories, apatite in small prisms is notably abundant; magnetite is present in moderate quantity; zircon and primary titanite are scarce. One or two individuals of titanite are intergrown with hornblende.

The hornblende and biotite present no features of striking interest. The former is fully 50 per cent more abundant than the latter. The hornblende is slightly altered to calcite, and the biotite more extensively replaced by chlorite, in which there are streaks of a cloudy leucoxene that resembles titanite when examined under high powers. The two ferromagnesian constituents are partly in parallel intergrowth, but some unoriented individuals of hornblende are inclosed in biotite, which is therefore mostly younger.

The general sequence of crystallization is as follows: Zircon (?), apatite, magnetite, plagioclase, titanite, hornblende, biotite, quartz, orthoclase. The biotite abundantly incloses plagioclase, although the latter locally incloses small grains of the ferromagnesian minerals.

A specimen representing the dominant phase of the granodiorite above described has been analyzed with the following result:

Analysis of granodiorite from quarry southwest of Cable.

[By George Steiger.]

	Per cent.	Molecular proportions.		Per cent.	Molecular proportions.
SiO_2	60.19	1.003	ZrO_2	0.04	
Al_2O_3	17.39	.171	CO_2	.21	0.005
Fe_2O_3	2.04	.013	P_2O_5	.30	.002
FeO	4.28	.060	MnO	.11	.001
MgO	2.10	.053	S	None.	
CaO	5.69	.102	SO_3	None.	
Na_2O	3.30	.053	BaO	.08	
K_2O	2.67	.029	SrO	.02	
H_2O-	.31				
H_2O+	.89			100.47	
TiO_2	.85	.01			

To determine the position of the rock in the quantitative classification the norm was calculated with the following result:

Quartz	14.8					Salic, 83.4.
Orthoclase	16.1			Feldspar	68.6	
Albite	27.8	Plagioclase (An_{46})	52.5			
Anorthite	24.7					
$CaSiO_3$	0.7	Diopside	1.4	Femic, 16.3.		
$MgSiO_3$	0.4					
$FeSiO_3$	0.3					
$MgSiO_3$	4.9	Hypersthene	9.5			
$FeSiO_3$	9.5					
Magnetite	3.0					
Ilmenite	1.7					
Apatite	0.7					

$\frac{\text{sal}}{\text{fem}}=\frac{83.4}{16.3}\quad\frac{7}{1}>\frac{5}{3}$ persalane.

$\frac{Q}{F}=\frac{14.8}{83.4}>\frac{1}{7}<\frac{3}{5}$ quardofelic.

$\frac{K_2O'+Na_2O'}{CaO'}=\frac{83}{89}>\frac{3}{5}<\frac{5}{3}$ alkalicalcic.

$\frac{K_2O'}{Na_2O'}=\frac{29}{53}>\frac{1}{7}<\frac{3}{5}$ dosodic, near sodipotassic.

The rock is tonalose, near harzose. The rock in Washington's tables having the most nearly similar norm is a quartz porphyrite from Grass Valley, Cal.,[1] but the rock at Cable has less quartz, more orthoclase, and less diopside, and it differs similarly from most granodiorites. It differs from the harzoses of Butte[2] in being poorer in both quartz and orthoclase. The ratio of MgO to FeO is unusually low.

LAMPROPHYRIC INCLUSIONS.

The lamprophyric inclusions, which have well-defined boundaries and subangular outlines, are also well shown in the quarry. A typical specimen shows the rock to be much richer in ferromagnesian minerals and darker than the normal granite, with a granular texture about half as coarse.

The thin section shows the constituents to be the same as in the dominant rock, but with the ferromagnesian constituents more abundant and the orthoclase less so. The plagioclase does not differ materially in average composition from that of the normal rock. The ferromagnesian minerals are xenomorphic against plagioclase, and titanite, which is fairly abundant, although inclosed in hornblende, also incloses plagioclase. Alteration of the ferromagnesian constituents and basic plagioclase to epidote, chlorite, and calcite is common. The latter mineral shows in places an interesting development that simulates the poikilitic fabric; individuals crystallographically continuous over diameters of 4 or 5 millimeters inclose and locally interpenetrate the original constituents in a manner very similar to that shown by scapolite in the rocks described on pages 120–126.

[1] Washington, H. S., Chemical analyses of igneous rocks: Prof. Paper U. S. Geol. Survey No. 14, 1903, pp. 236–237, No. 57.
[2] Idem, p. 229, No. 5.

APLITIC AND PEGMATITIC ROCKS.

A block lying near the office of the Cable mine consists of rock very similar superficially to the analyzed specimen, except that its color is lighter. It contains little hornblende and quartz, however, and many small and evenly disseminated grains of pyrite.

The microscope shows that its composition is very different from that of normal granodiorite. The essential constituents are nearly pure albite and biotite; the accessories are zircon, rutile, and apatite. It contains neither quartz nor potash feldspar. Secondary sericite, calcite, pyrite, and kaolin are abundant, and chlorite is present in small amount. The biotite crystals, which are xenomorphic against plagioclase, are formed by the intergrowth of two varieties, one dark and the other pale. The darker variety is usually in a central, the lighter in a marginal, position, but the boundaries between the two, although sharp, are very irregular. It seems likely that the paler mica has been produced by a leaching of the darker, but the common alteration to chlorite is not observed. Rutile is abundant and forms clusters of nearly opaque prisms of submetallic luster.

A small exposure of pegmatite occurs at the end of the flume on the spur east of Cable. It is essentially an aggregate of snow-white albite crystals, with maximum diameters of several centimeters, small polygonal interstices between which are filled with green chlorite. Quartz and potash feldspar are absent. The accessories are zircon and rutile, the latter showing the same mode of occurrence as in the rock last described, which, indeed, this pegmatite so strongly resembles in composition as to suggest a close genetic relationship.

A rock similar to these in composition but of fine-grained porphyritic texture appears on the dump of the Cable mine.

MARGINAL FACIES.

The bold outcrops at the contact of the granodiorite of Cable with the sediments on the spur to the east show a complex mingling of light greenish gray granular rock with dark rock rich in hornblende, this mineral being locally the only one visible megascopically. The dark rock is shown by microscopic examination to contain vestiges of basic plagioclase altered to aggregates of epidote, sericite, albite, and other minerals. Allanite is very abundant and occurs partly in parallel intergrowth with pistacite, which always surrounds it. Probably it is primary and has furnished nuclei for the crystallization of secondary pistacite.

The lighter colored rock resembles to some extent the pyroxene aplites, fully described on pages 120–126. It consists chiefly of a very basic soda-lime feldspar (bytownite or anorthite) and a diopsidic pyroxene, with some poikilitic scapolite which appears to be original. There is abundant titanite and considerable apatite, allanite, and zircon.

GRANODIORITE OF THE PHILIPSBURG BATHOLITH.

GENERAL CHARACTER AND OCCURRENCE.

The wall rock of the Granite-Bimetallic lode is a granular intrusive, whose essential constituents are plagioclase, orthoclase, quartz, hornblende, and biotite. It resembles the well-known granodiorites of California but is richer in potash feldspar. It also resembles the Butte quartz monzonite, but is poorer in potash feldspar and more siliceous than this rock.

It forms a large mass of roughly elliptical ground plan in the mountains east of and overlooking the Philipsburg batholith. There is a small outlier on the southeast edge of the town, and other small masses, described on page 102, may also have a genetic relation to this mass.

The granodiorite is in contact with the Algonkian Newland formation and the overlying strata up to the Carboniferous Madison limestone. The irruptive nature of the contact is made evident by strong contact metamorphism in the sediments about the entire periphery, by the projection of apophyses into these, and by marginal variations in the granodiorite. Apophyses in the Cambrian rocks are shown on the map southwest of Twin Peaks. The evidence of intrusion is perhaps nowhere more striking than in the immediate vicinity of

Philipsburg, especially on Frost Gulch, north of Franklin Hill, where the Silver Hill formation is altered to coarsely crystalline rocks, which are penetrated by dikelets of porphyry similar in composition to the rock of the batholith. Special features of the metamorphism produced by the granodiorite of the Philipsburg batholith are the formation of iron ores (some containing the rare boron mineral ludwigite) at the contacts with calcareous sediments near Philipsburg, and the abundance of scapolite in the calcareous metamorphic rocks at Philipsburg and northeast of Rumsey Mountain.

The upper surface of the mass, as is evident from the course of the boundaries, is rudely domelike. It is noteworthy that the contact nearly follows in many places the bedding of the adjacent sediments—this being conspicuously the condition near Twin Peaks. Through fully half its circumference, however, it cuts across the bedding, and the mass is not in any strict sense a laccolith.

It is cut by some fault fissures near Philipsburg but apparently not by any of the major faults in the adjacent sediments.

Although the main part of the mass is fairly uniform, it tends to become more or less basic near contacts. At the south, near Rumsey Mountain, the normal granodiorite apparently grades into a basic diorite. Aplite of ordinary character forms numerous small dikes but is not so abundant as in the more acidic granitoid rocks. Pyroxene aplite of more interesting character is associated with the granodiorite. (See pp. 120–126.)

The granodiorite of the Philipsburg batholith in fresh condition is well exposed on the high glaciated plateau about Fred Burr Lake in the heads of the canyons that drain from this plateau. The little weathered outcrops, which show considerable jointing, have a pure light-gray tone. About Granite, beyond the limits of glaciation, the granite is deeply weathered, and its uneven surface is strewn with great subangular bowlders of disintegration. On lower slopes the granite areas are generally covered with deep soil and show few outcrops.

PETROGRAPHY.

NORMAL PHASE.

The character of the prevailing rock is well illustrated by typical specimens from the gulch east of Copper Creek near Princeton, a mile or more from the contact.

The rock is brownish gray and of granular texture, without distinctly porphyritic development of any of the constituents. Few grains are more than 3 millimeters in diameter, and most are much smaller. More than half the rock consists of feldspar of two easily distinguishable varieties. One variety is of a pale flesh tint, and its glistening cleavage faces are not striated; the other forms smaller grayish-white, partly transparent grains, which not uncommonly show striations on the better (basal) cleavage. Both feldspars have rude crystal form. Glassy grayish quartz grains with irregular fractures are abundant. The glistening black crystals of biotite, which, though numerous, form a relatively small part of the bulk of the rock, are more or less irregular, but many show the characteristic form of a six-sided tablet. Less abundant are small grains or rude prisms of dull greenish black hornblende. A few grains of brownish-yellow titanite are visible.

The complete list of original constituents visible under the microscope, with a rough indication of their relative abundance, is as follows: Plagioclase $\gtrless$ quartz $>$ potash feldspar $>$ biotite $>$ hornblende $\gg$ magnetite $\geqq$ apatite $>$ zircon $\gtrless$ allanite. The secondary minerals are chlorite, epidote, calcite, kaolin, and sericite. The diameters of the grains constituting most of the rock range from 0.5 millimeter to 3 millimeters, the average being about 1.5 millimeters.

The plagioclase is in subhedral grains somewhat elongated parallel to *a*. Zonal structure and mottling are rather conspicuous. The composition in the greater part of the crystal fluctuates between An_{35} and An_{55}, but sodic oligoclase occurs in very narrow and irregular peripheral zones and in myrmekite fringes at the contacts with potash feldspar. The average anorthite percentage is probably near 40. The plagioclase is altered in rather sharply defined patches to calcite, sericite, kaolin, and epidote.

The potash feldspar is a slightly perthitic orthoclase. The individuals contain abundant inclusions of all the other constituents, and their outlines are irregular in detail, but they are partly bounded by surfaces approximating to crystal planes, especially at the contact with certain large grains of quartz. The orthoclase is slightly kaolinized.

The quartz has the usual anhedral habit and forms individuals about as large as those of feldspar.

The biotite is of the common variety, pleochroic in brownish yellow and pure deep brown and partly chloritized. Some of it occurs poikilitically inclosed in or in parallel intergrowth with the hornblende, which is of the ordinary green kind.

The common accessories are present in moderate quantity and have no especially noteworthy features. Deep brown allanite occurs sporadically in small stout prisms.

The general order of crystallization, so far as determined, is zircon (?), apatite, magnetite, titanite, most of the plagioclase, biotite, hornblende, orthoclase, rims of plagioclase in part, quartz. The plagioclase, biotite, and hornblende are probably of about the same age, for, although small crystals of plagioclase are abundantly inclosed in the ferromagnesian constituents, the relation is not uncommonly reversed, and intergrowths between biotite and hornblende prove their partly simultaneous crystallization. Quartz distinctly later than any of these appears to have overlapped with the orthoclase, from which it is often separated by irregular boundaries and in which it is sometimes inclosed. Only local subhedral development of the orthoclase at contacts with quartz indicates a slight degree of priority for the orthoclase.

The following chemical determinations made on this rock, together with its mineral composition, serve to indicate its approximate classificatory position.

Chemical determinations on granodiorite from the Philipsburg batholith.

[Analyst, W. T. Schaller.]

	Per cent.	Molecular proportions.
SiO_2	68.21	1.137
Na_2O	3.22	.052
K_2O	3.56	.038

Analogous percentages of silica and alkalies occur in the subrang amiatose of the quantitative system of classification; the high ratio of soda to potash, however, brings the rock near to yellowstonose. The qualitative mineral composition is identical with that of typical granodiorites, and the amounts of silica and alkalies are very near the amounts present in granodiorite (amiatose) from Silver Lake House, Eldorado County, Cal., described by Lindgren[1] (SiO_2, 67.45; Na_2O, 3.47; K_2O, 3.66). Compared with average granodiorite, however, the rock of Silver Lake is high in silica and alkalies, and the percentage of K_2O is the highest observed in the granodiorite group as defined by Lindgren.[2] It therefore approaches the quartz monzonites. The ratio of Na_2O to K_2O, in weight percentages, is 0.91 for the rock from California and 0.95 for the rock of the Philipsburg batholith, indicating a slightly greater proportion of orthoclase for the latter. The batholithic intrusions of the Butte and Elkhorn districts, on the other hand, which are similar in qualitative mineral composition, are less siliceous than the rock of the Philipsburg batholith, richer in potash, and poorer in soda.

VARIATIONS.

The main mass of the Philipsburg batholith is very uniform, but it varies somewhat in texture, and near contacts it varies rather widely in composition.

The principal variations in texture that occur independently of conspicuous variation in composition are a poikilitic development of the orthoclase and an obscurely porphyritic development of plagioclase or of both orthoclase and plagioclase.

[1] Am. Jour. Sci., 4th ser., vol. 3, 1897, p. 306; also Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 183.

[2] Am. Jour. Sci., 4th ser., vol. 3, 1897, pp. 30–31.

The composition is in general more basic near contacts than away from them, but the rule is not without exceptions, for some specimens taken from the immediate contact are especially rich in orthoclase. More commonly, however, the normal granodiorite passes into a quartz diorite with hornblende in larger and more perfect crystals, with a somewhat more calcic feldspar, and with less orthoclase, this feldspar being almost wholly absent from some specimens.

This marginal basification is illustrated by the rock on the divide between Fred Burr Creek and Summer Gulch, about one-eighth of a mile from the contact. It is notably richer than the normal in dark minerals, and some of the biotite is conspicuous by its development in wavy ragged foils about 1 centimeter in diameter. Considerable quartz is visible, but it is difficult to detect any orthoclase with the unaided eye.

The microscope shows as original constituents plagioclase $>$ hornblende $\gtrless$ biotite $\gtrless$ quartz $>$ orthoclase $\gtrless$ magnetite $>$ titanite $\gtrless$ apatite $>$ allanite $\gtrless$ zircon.

The rock is apparently transitional to a more basic diorite developed in the basin of Summer Gulch, but the exposures are poor at the northern limit of the basic diorite and the transition can not be considered absolutely proved. It is not inherently improbable, in view of the observed variations in the Philipsburg batholith. The best evidence of transition is the fact that the rock just described is intermediate in location between the normal granodiorite and the basic diorite of Summer Gulch and also intermediate in character.

DIORITE OF SUMMER GULCH.

The basic diorite occupies the baylike extension on the south side of the Philipsburg batholith. The dominant rock of this little area is very dark gray. Plagioclase, hornblende, and biotite are the only constituents identifiable, and the form of the grains is unrecognizable. The texture is notably finer than in the more acid rocks, and a tendency for the small grains of ferromagnesian minerals to cluster produces an obscurely dappled appearance.

The microscope shows the mineral constitution to be plagioclase $>$ quartz $\gtrless$ hornblende $\leqq$ biotite $>$ orthoclase $>$ magnetite $\gtrless$ apatite $\gtrless$ titanite $>$ zircon $\gtrless$ allanite. There is some decomposition giving rise to epidote, chlorite, calcite, and sericite.

The plagioclase, in polarized light, appears strongly zoned and mottled, with ragged cores that generally show much higher double refraction than the outer zones. These cores are of calcic bytownite near An_{85}. In one section nearly normal to M and P, the extinctions are, in the core, 41° (corresponding to An_{84}); in the next zone, 32° (An_{60}); in the next, 27° (An_{48}); on the extreme edge, 11° (An_{28}). Like the feldspar of the rock described above, it incloses indeterminate dust particles, which are especially abundant in the more basic parts. The general order of crystallization is the same as in most rocks of the Philipsburg batholith, the plagioclase being very commonly inclosed in ferromagnesian minerals.

A still more basic phase, represented by specimens taken near the eastern margin of the mass, near the bottom of the ravine, is characterized by a porphyritic development of part of the hornblende in crystals that attain a length of about 1 centimeter and have good crystal form. The biotite is megascopically inconspicuous.

The most noteworthy features revealed by the microscope are the character of the plagioclase and the presence of scapolite. The plagioclase individuals, markedly flattened on 010, have boundaries approximating to crystal planes, but irregular in detail; each, however, has a sharply defined, nearly homogeneous euhedral core of notably high refringence and birefringence. Numerous determinations of its anorthite percentage give figures ranging from 89 to 96, with an average of 94. In the rim, the anorthite percentage diminishes somewhat gradually from about 50 next the core to about 30 on the extreme edge. The cores form a little more than half the bulk of the crystals, so that the average composition of these is near An_{70}.

The scapolite occurs in very small quantity and appears in thin section as a delicate lacework interpenetrating with the feldspar. It has uniform orientation over areas as much as 1 centimeter in diameter, and the feldspar crystals with which it is intergrown have all possible orientations. The scapolite, although intergrown with plagioclase of widely differing composition, shows no evidence of similar variation. Inasmuch as the feldspars are considerably altered to epidote, sericite, and calcite, it would be plausible to suppose the scapolite secondary, but the occurrence elsewhere in the quadrangle of primary scapolite, similar in many respects to this, suggests primary origin at this locality.

The general order in which the minerals began to crystallize is zircon and apatite; plagioclase and scapolite; magnetite; titanite; biotite; augite and hornblende; quartz and orthoclase partly intergrown. There has, however, been much overlapping.

LAMPROPHYRIC INCLUSIONS.

Dark inclusions characterize the granodiorite of the Philipsburg batholith, especially in the neighborhood of contacts, which consist of the same minerals as the parent rock, but which contain the ferromagnesian minerals in greater abundance and have a finer texture. The average diameter of the grains is about half that in the normal granite, and there is commonly an obscure porphyritic development of plagioclase and ferromagnesian minerals.

A thin section of a specimen taken near the contact at Philipsburg shows rock essentially normal in sharp contact with that of a basic inclusion. In the basic inclusion, hornblende, biotite, titanite, magnetite, and apatite are more abundant, orthoclase and quartz less so, than in the granodiorite. The strongly zoned and mottled crystals of plagioclase, like those of the granodiorite, have rims of oligoclase and intermediate portions consisting largely of basic andesine, but their centers contain bytownite near An_{80}. The apatite is conspicuously developed in long needles. The general order of crystallization is that of the normal rock, but the titanite is partly xenomorphic against both plagioclase and hornblende.

GRANODIORITE PORPHYRY.

The small sills and dikes that cut the Silver Hill formation north of Frost Gulch are of a brownish-gray porphyry with rather sparsely scattered phenocrysts, about 2 millimeters in maximum diameter, of hornblende, biotite, and plagioclase.

The microscopic section of one specimen shows the original minerals to be plagioclase $>$ quartz $\gtrless$ orthoclase $>$ hornblende $>$ biotite $>$ magnetite $>$ titanite $>$ apatite $\gtrless$ zircon $\gtrless$ rutile $\gtrless$ tourmaline.

Three generations of crystals appear, but they are not very distinct. The first consists of the phenocrysts recognizable megascopically; the second, forming the bulk of the rock, consists of subhedral crystals, 1 millimeter or less in diameter, of plagioclase, orthoclase, quartz, and ferromagnesian minerals; and the last of an interstitial mosaic of subequant grains, chiefly of quartz and orthoclase, about 0.1 millimeter in average diameter. The plagioclase is zoned, but that of the first generation offered no determinable sections. That of the second generation has irregularly bounded cores of labradorite-bytownite (An_{70}), broad intermediate zones of basic andesine (An_{47}), and rather narrow rims of oligoclase (An_{30-12}). The more basic parts include innumerable minute needles, probably rutile. The orthoclase forms Carlsbad twins flattened on 010. The quartz has imperfectly developed dihexahedral or rudely spherical forms and contains few inclusions, being free from rutile needles. Green hornblende predominates over the brown biotite, which is much chloritized. Although subhedral, both locally enwrap large grains of quartz and of the feldspars. Titanite is notably abundant, and zircon somewhat more so than usual. Tourmaline, intensely pleochroic in blue-black and pale purplish brown, appears in sporadic grains.

APLITES.

Aplites and pegmatites are less abundant in the Philipsburg batholith than in most of the more acidic extrusives. Unfortunately they are not well represented in the collection. They consist in part of the pyroxene aplites that occur in several parts of the quadrangle, and these, because of their special interest, are described separately (p. 120). In addition to this rock, the granite is cut by aplite of more normal character containing mica as the sole ferromagnesian constituent.

A specimen of this latter type collected near the contact in the vicinity of Red Lion Mountain is chiefly interesting for its alterations. It consists mainly of flesh-colored feldspar and a little dull-white feldspar and silvery mica, through which are evenly disseminated abundant irregular grains of rusty-weathered iron-bearing carbonate, pyrite, and iridescent bornite.

Under the microscope the feldspar is seen to be chiefly microcline and orthoclase; the plagioclase is albite, forming rather coarse perthitic intergrowths with the potash feldspar. Quartz is subordinate and interstitial. The muscovite is partly in masses—possibly original, though their structure rather suggests derivation from biotite—about 1 millimeter in diameter, composed of rudely parallel, overlapping scales. Colorless mica is also abundantly developed as a secondary mineral in feldspar. Calcite also replaces feldspar and has filled miarolitic cavities into which feldspar crystals project. The sulphides occur in analogous relations, as does the ferruginous carbonate; but unlike the calcite, which is anhedral, these minerals are partly bounded by crystal faces.

Apatite and zircon are rather abundant accessories, and rutile, in groups of prisms possibly derived from the decomposition of titanite, is common.

SMALL INTRUSIONS OF BASIC GRANODIORITE.

GENERAL CHARACTER AND DISTRIBUTION.

Small areas of rock more or less allied in character to the rocks of Cable and of the Philipsburg batholith occur on Boulder Creek above Princeton, on Henderson Gulch, on Willow Creek near the west border of the quadrangle, on Sluice Gulch farther south, and southeast of Rumsey Mountain. Although these rocks are composed of essentially the same minerals as the granodiorite of the Philipsburg batholith, they differ in texture and composition so that they can hardly be described in general terms.

Two small stocks of porphyry east of Red Hill, as well as several dikes between Willow Creek and Henderson Mountain, have been mapped in a color that indicates their probable relationship with the rocks above mentioned. They are so much decomposed that their composition could not satisfactorily be determined. Those near Philipsburg have a contact zone of garnet rock. The dikes in the northwest part of the quadrangle are small, and many similar dikes were left unmapped in areas where other igneous rocks are abundant.

INTRUSION ON BOULDER CREEK.

The mass on Boulder Creek, probably a mere outlier of the Philipsburg batholith, is intrusive in Devonian and Carboniferous limestones and is cut by a large dike of pyroxene aplite.

It is a dark-gray rock, granular but finer grained than the granodiorite of the Philipsburg batholith. It contains the same minerals as that rock, but has relatively more hornblende, magnetite, and titanite.

INTRUSIONS ON WILLOW CREEK.

The small mass on Willow Creek, intrusive in the Algonkian, is of a rock resembling the granodiorite of Cable, but somewhat darker, partly because it is richer in ferromagnesian constituents and partly because the very fresh glassy plagioclase is of grayish tone. No poikilitic alkali feldspar can be recognized megascopically. The biotite locally shows a poikilitic habit like that of the granodiorite of Storm Lake but not so pronounced.

The microscope shows the essential constituents to be plagioclase, biotite, quartz, hornblende, orthoclase, augite; the accessories are magnetite, titanite, apatite, zircon, and rutile (?). The plagioclase is much zoned and mottled, with a range from basic labradorite to andesine. Quartz and orthoclase are less abundant than in most granodiorites. Augite forms nuclei to most of the hornblende crystals. A striking feature is the habit of the biotite, which is in extremely ragged individuals locally intergrown with quartz. Not only biotite but hornblende incloses plagioclase.

INTRUSION SOUTHEAST OF RUMSEY MOUNTAIN.

The very small area surrounded by the Newland formation southeast of Rumsey Mountain may represent part of a considerable mass; for, as strong metamorphism obtains continuously northward to the Philipsburg batholith, this little area is probably an outlier of that great intrusion.

It is a rather dark-gray rock, suggesting a finer grained phase of the granodiorite of the Philipsburg batholith, with about the same proportion of light and dark minerals; but close examination reveals only sporadic grains of hornblende.

The microscope shows quartz of strikingly poikilitic habit to be about as abundant as in the granodiorite of Philipsburg, but orthoclase is relatively scarce. The plagioclase is strongly zoned, with a range of An_{60} to An_{20}, and apparently a trifle more basic on the average than that of the granodiorite of the Philipsburg batholith.

INTRUSIONS ON SLUICE GULCH.

On Sluice Gulch, near its mouth, two very small masses of an intrusive cut the Newland formation and alter it to hard diopsidic hornstone.

The rock of these intrusions is light gray and somewhat resembles the granodiorite of the Philipsburg batholith, but obviously contains less hornblende. The microscope shows no conspicuous difference from the rock described on page 98 beyond a slightly porphyritic development of plagioclase. The orthoclase is partly interstitial and anhedral, but the larger grains are subhedral.

INTRUSION ON HENDERSON GULCH.

The igneous rock in Henderson Gulch is poorly exposed near its periphery, but strong metamorphism developed near its contact clearly shows it to be intrusive in the Newland formation. The contact zone is particularly characterized by rocks rich in garnet and epidote, as well as by the usual diopsidic hornstones. The metamorphism extends over a remarkably wide area; Henderson and Sunrise mountains, indeed, owe their existence to the induration through metamorphism of the rocks composing them, and this shell of metamorphic rock has probably protected from denudation an intrusive mass of far greater extent than the surface exposure.

Much of the rock shows a distinctly porphyritic habit, but the coarsest presents at first glance the aspect of a granular rock resembling the most acidic granodiorite of the Philipsburg batholith. A porphyritic texture can be made out on close examination, but the groundmass is relatively coarse and light colored, so that the phenocrysts are not conspicuous. The largest phenocrysts are of flesh-colored potash feldspar, some of which are as much as 1.5 centimeters long. Most of the numerous phenocrysts are far smaller; they are chiefly of whitish plagioclase, quartz, and biotite, but a few small phenocrysts of potash feldspar are also present.

The microscope shows the plagioclase phenocrysts to have cores of andesine and rims of oligoclase. The quartz is bipyramidal and corroded. The groundmass, which is of less bulk than the phenocrysts, consists chiefly of quartz and orthoclase, with a little plagioclase and biotite. The accessories are magnetite, titanite, apatite, and zircon.

GRANODIORITE OF OLSON GULCH.

GENERAL CHARACTER AND OCCURRENCE.

Adjacent to the lower part of Olson Gulch is an area of about 1½ square miles of granitoid rock bearing some resemblance to that of the Philipsburg batholith but containing very little hornblende. It is poorly exposed, and its relation to the adjacent sediments therefore is not clearly evident. Although no definite contact zone can be traced, this is partly because a considerable degree of metamorphism is general in this vicinity. There is a deposit of iron ore in the limestone near the western border of the area, which was doubtless formed by this granodiorite in the same way as those of the contact zone at Cable. There is no reasonable doubt that the contacts of the granodiorite with the Carboniferous rocks are chiefly irruptive. The form of the boundary at the east end of the area strongly indicates such a relation.

PETROGRAPHY.

This granodiorite is very uniform. A typical specimen shows a light, brownish-gray tint and a granitic texture somewhat finer than the average. The visible constituents are feldspar, biotite, quartz, and hornblende. The greater part of the feldspar is a dull greenish white plagioclase in grains mostly less than 1 millimeter in diameter, contrasting with a flesh-colored potash feldspar in poikilitic grains up to ½ centimeter in diameter. Quartz is not conspicuous. Biotite is evenly and rather plentifully disseminated in flakes about 1 millimeter in average diameter, and a few particles of hornblende can be detected.

The relative abundance of the minerals as shown by the microscope is roughly indicated by the expression plagioclase $>$ quartz $\gtrless$ orthoclase $\gtrless$ biotite $\gg$ hornblende $\gtrless$ magnetite $>$ apatite $>$ titanite, zircon, tourmaline, rutile. The texture is of the same type as in the granodiorite of Cable, and is characterized by more or less perfect crystals of plagioclase and ferromagnesian constituents, thickly sown in comparatively large allotriomorphic grains of quartz and orthoclase.

ACIDIC GRANODIORITE OF ANACONDA RANGE.

GENERAL CHARACTER AND DISTRIBUTION.

Distributed along almost the entire length of the Anaconda Range are several areas of a granitoid rock composed chiefly of plagioclase, quartz, orthoclase, and biotite, with locally a little hornblende. The quartz is abundant, but orthoclase is inconspicuous and very subordinate to the plagioclase.

Unlike the other granular rocks of this district, which do not send out long and thick apophyses, this granodiorite fingers out into many large dikes closely related to the parent mass in composition, but differing from it in having a finer porphyritic texture. In the dike mapped east of Carp Lake gradation can be traced from a rock at the south end, hardly differing from the granular rock described, to a drab felsitic rock at the contact with the sediments half a mile farther north.

The areas of this granodiorite fall within a relatively narrow zone extending east-northeast from a point near the southwest corner of the quadrangle to a point near the head of Clear Creek. The principal groups of areas from west to east are those about Carp Lake, about Mounts Howe and Evans, and between Tenmile and Mill creeks. In this last-mentioned tract, which is the largest, the rock is greatly sheared.

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

Shearing in the easternmost area has developed much chlorite, and makes the rock darker and more greenish than it is where unaltered. On the precipitous walls of Mill Creek canyon it can readily be distinguished at a distance from the lighter, more tawny granites on either side. Another effect of the stresses the rock has undergone has been the formation of shear zones along which erosion is relatively rapid, and to this cause is due the serrate character of part of the divide between Mill and Tenmile creeks. (See Pl. IV, *B*, p. 21.)

The apophysal dikes of granodiorite porphyry are most abundant and conspicuous about Mounts Howe and Evans. They are light enough in color to contrast markedly with the dark rusty rocks of the Prichard formation, and they can be readily traced on the steepest slopes, though they are concealed in places by talus or rock waste. On the other hand, the porphyry intrusions at the head of Barker Creek and those east of Mount Haggin are conspicuously dark by comparison with the rocks they penetrate, partly because these rocks are very pale tinted, partly because the granodiorite has been sheared and darkened like the granular rock to the south.

GEOLOGIC RELATIONS.

The intrusive relation of this granodiorite to the adjacent sediments is exceptionally clear, because it sends many porphyritic apophyses into the Cambrian and Algonkian beds with which it is in contact. The contact with the Newland formation near the peak marked "9814" on the topographic map is almost exactly parallel to the bedding for about 2 miles. (See Pl. XIII, *A*, p. 92.) The Newland formation here shows a metamorphism clearly related to this particular intrusion.

The acidic granodiorite of the Anaconda Range is apparently younger than any of the granular intrusives with which it is in contact except the porphyritic biotite granite, the evidence of whose later age is discussed on page 116. Apophyses of the granodiorite penetrate the nonporphyritic granites east of Mount Haggin and the diorite north of Mount Howe. It is not positively known that the acidic granodiorite cuts the basic granodiorite of the Storm Lake intrusion in this vicinity, for the relations are obscured by talus.

The relative age of the acidic granodiorite and the coarsely porphyritic muscovite-biotite granite is in some doubt. Clear proof was obtained that near Racetrack Creek, on the north, porphyritic two-mica granite like that on Tenmile Creek was later than porphyritic biotite granite, like that cutting the granodiorite in the Anaconda Range. If close petrographic similarity in the case of these porphyritic granites may be taken as evidence of identical age, the granodiorite is older than either of the porphyritic granites.

PETROGRAPHY.

NORMAL TYPE OF GRANULAR ROCK.

A specimen from a point about 1 mile south-southeast of peak 9814 in the west part of the Anaconda Range, which may be taken as representative of this group of intrusions, has been subjected to detailed study and chemical analysis. Its general shade is a light pure gray, its texture typically granitic and inclining to fine rather than to coarse. The constituents recognizable with the naked eye are feldspar, quartz, biotite, hornblende, titanite, and pyrite, the last occurring only in scattered small rusty grains along some obscure joint fissures. The dark minerals are present in relatively small quantity.

All the feldspar is nearly white, but two varieties can be distinguished. The more abundant variety, plagioclase, is somewhat the less transparent, and forms grains some of which are 4 millimeters long, but most of which are much smaller, 1 or 2 millimeters being about the average diameter. Some of the bright basal planes show a rudely oblong outline. The other variety, orthoclase, is more glassy and is best recognized by catching the bright reflections from the basal cleavage planes, which are mottled by abundant inclusions of plagioclase and the dark minerals. The average diameter of the orthoclase individuals is somewhat greater than that of the plagioclase crystals, and their outlines are mostly irregular though in part determined by crystal planes. Quartz is obviously abundant. On the surface of the rock, it mostly appears in irregular sugary patches some 2 or 3 millimeters in diameter, which are slightly grayish by comparison with the feldspar.

Hornblende and biotite appear mostly as evenly sprinkled, black, ragged particles, mostly less than 1 millimeter in diameter. A considerable part of these constituents, however, is segregated into more or less compact clusters about 0.5 centimeter in average diameter, about half a dozen of which appear on the face of an ordinary hand specimen. They are so characteristic of the rock that it was referred to in field notes as "spotted granite." Titanite forms a few inconspicuous yellowish-brown grains.

The relative abundance of the essential constituents as determined microscopically may be indicated by the expression plagioclase > quartz > orthoclase > biotite > hornblende. Accessory constituents are titanite, apatite, zircon, allanite, and magnetite, the last two being scarce. The rock is in general fairly fresh, but the feldspar is a trifle clouded and a very little of the biotite is chloritized.

The plagioclase occurs in subhedral crystals and is rather strongly zoned and mottled; the range of composition is approximately from An_{40} to An_{10}, and the average is estimated optically as about An_{30}. The crystals have myrmekite fringes at the contact with orthoclase. The quartz is mostly in aggregates of anhedral grains and the orthoclase, which is also anhedral, is very slightly perthitic. The biotite and hornblende are of ordinary aspect, and the accessories have no noteworthy peculiarities. The general sequence of crystallization as indicated by the relations of the minerals is as follows: Accessories; biotite and hornblende; plagioclase; quartz and orthoclase. It has been noted that in most of the basic rocks the plagioclase is earlier on the whole than the ferromagnesian constituents.

Analysis of the rock gives the following result:

Analysis of acidic granodiorite 1 mile south-southeast of peak 9814.

[By George Steiger.]

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

No SO_3, S, or CO_2 was found.

The norm calculated to fix the place of the rock in the American quantitative classification is as follows:

	Per cent by weight.			
Quartz	26.64			Salic, 92.80 per cent.
Orthoclase	19.46		Feldspar, 65.75 per cent.	
Albite	34.06	Plagioclase (An_{25}), 46.29 per cent.		
Anorthite	12.23			
Corundum	.41			
$FeSiO_3$	1.19	Hypersthene, 3.79 per cent		Femic, 5.82 per cent.
$MgSiO_3$	2.60			
Ilmenite	.76			
Magnetite	.93			
Apatite	.34			
	98.62			

The rock is lassenose (I.4.4.4.), near toscanose, which is more potassic.

VARIATIONS.

Some of the rock mapped with that described is perceptibly more basic and much is somewhat less so.

A specimen obtained about half a mile west of the 9,814-foot peak is slightly richer in ferromagnesian constituents and shows a slight tendency to porphyritic development of the plagioclase, differences from the analyzed rock possibly due to closer proximity of the contact with sedimentary rock.

Specimens from the Mount Howe area and farther east contain little or no hornblende and have a slightly more sodic plagioclase. The potash feldspar in these rocks is microcline, possibly because they have undergone more pressure than the masses farther west. It is somewhat more abundant than the orthoclase of the analyzed rock.

The differences between the rocks in Rock Creek basin and those east of it might be considered sufficient to justify a distinction in the mapping, but in fact they can be appreciated only by careful comparison of specimens, aided by microscopic study. The resemblances in tone, in the habit of the feldspars, and in the characteristic distribution of the ferromagnesian constituents are, especially in the field, more striking than the differences. The relationship to the contiguous rocks, so far as observed, indicate that all of the several masses are contemporaneous. Some of the porphyritic apophyses from the granular masses consisting chiefly of rocks free from hornblende contain small amounts of that mineral and strikingly resemble the analyzed specimen in mineral composition.

In the area south of Mount Tiny the granodiorite was observed in actual contact with the Newland formation. Within a yard of the sedimentary rock the intrusive is normal, except for being a little more basic than the average. For about 1½ feet from the contact it consists of irregular streaks and lenses of pegmatitic material alternating with material notably rich in biotite. The intrusive is intercalated, through a zone about a foot wide, with lenses of the flaggy diopsidic hornstone, and in immediate proximity to these it is almost free from ferromagnesian minerals.

LAMPROPHYRIC INCLUSIONS.

In addition to the little black knots of ferromagnesian minerals, the granodiorite is characterized by dark blotches whose presence is one of the obvious distinctions between this rock and the contiguous granites. These blotches, which attain a maximum diameter of about 6 inches and are usually of roundish or oval form, are of the same nature as those in the granodiorite of the Philipsburg batholith, and differ from the parent rock by having finer texture and greater richness in ferromagnesian constituents. One from a hornblende-bearing phase, examined microscopically, proves to contain almost as much hornblende as biotite, and zoned plagioclase whose most basic parts are near An_{50}. A specimen from a hornblende-free phase is very rich in biotite, but itself contains no hornblende.

GRANODIORITE PORPHYRY OF THE APOPHYSAL DIKES.

A very typical specimen of the granodiorite porphyry forming the dike phase of this granodiorite was obtained on the west slope of Mount Howe. The rock, except for a slightly darker gray shade, appears at first glance very similar to the granular rock described on pages 105–106. In particular, the ferromagnesian constituents show the characteristic tendency to form clusters. On closer scrutiny the porphyritic texture appears. The most abundant phenocrysts are of plagioclase, mostly from 2 to 5 millimeters long, but there are many somewhat smaller ones of slightly smoky quartz, with irregularly rounded outlines. Biotite and hornblende are visible as still smaller particles, few being more than 1 or 2 millimeters in diameter. All these are embedded in a gray microcrystalline groundmass not much different in tone from the feldspar phenocrysts.

Under the microscope the porphyritic texture is plain enough. The phenocrysts have about the same volume as the groundmass, which is microgranular and panallotriomorphic. The essential minerals of the first generation are plagioclase, biotite, and a subordinate amount of hornblende; those in the groundmass are abundant quartz, microcline, and orthoclase, subordinate plagioclase, and a little biotite. Magnetite, apatite, and zircon are accessory. The plagioclase is closely similar to that of the granular rock, being zoned and mottled, and ranging in composition from An_{40} to An_{10}. The hornblende and biotite are also of the ordinary types. The porphyritic quartz forms isolated grains or groups of grains with roundish outlines.

Besides varying in texture the dikes vary appreciably in composition. In some, hornblende is absent, and in a few of these phenocrysts of orthoclase are present. Hornblende with cores of green augite occurs in one dike on Mount Evans. The selvage of the dike east of Carp Lake is a drab felsitic rock with a few small and inconspicuous phenocrysts of quartz and some of feldspar, which the microscope shows to be orthoclase. The groundmass is almost cryptocrystalline and seems to consist chiefly of granophyric intergrowths of quartz and feldspar. The rock is obviously more acidic than the average porphyry.

BIOTITE GRANITE OF THE ROYAL BATHOLITH.

GENERAL CHARACTER AND OCCURRENCE.

The country rock of the Royal mine is a granitoid rock chiefly composed of quartz, plagioclase, potash feldspar, and biotite, and containing a little muscovite. Plagioclase is relatively more abundant and more basic than in the biotite granites of the Anaconda Range. The rock of the Royal mine perhaps resembles that of Carp Lake more than any that has been described, but it nowhere contains hornblende.

The rock forms a large intrusive mass of oval plan, lying mostly within the northeast part of the quadrangle but overlapping its east boundary, which may appropriately be called the Royal batholith. About most of its periphery this mass is in irruptive contact with sedimentary rocks. The most striking evidence of the irruptive relation is the contact metamorphism produced in the sediments, and although the youngest beds in actual contact with the granite are early Cretaceous the metamorphism strongly affects the Upper Cretaceous shales north of Rose Mountain, nearly a mile from any outcrop of the granite. Direct proof is thus given that the intrusion is not older than late Cretaceous.

The upper surface of the intrusion, like that of the Philipsburg batholith, slopes away from the center. More markedly than in any other large intrusion in the quadrangle the contact tends to follow the bedding of the adjacent sediments. This is strikingly apparent from the map, which shows the granite in contact with the comparatively thin Quadrant formation through the greater part of its circumference.

In Rock Creek basin this granite is apparently cut by the two-mica porphyritic granite. Perfectly clear direct evidence of this was not obtained, but although the porphyritic rock has not been observed in gneissoid condition that of the Royal batholith is powerfully sheared beyond the east edge of the quadrangle.

The general appearance of the rock of the Royal batholith in the field is similar to that of the granite of the Philipsburg batholith, but it is of lighter tone. On the other hand it is darker than the adjacent porphyritic granite. Unlike the biotite granite of the Anaconda Range it is nowhere tawny. The mass is on the whole very uniform, but marginally it tends to become more basic, and it generally shows a slight schistosity parallel to the contact.

Some of the Royal type of granite occurs at the head of Boulder Creek adjacent to the Philipsburg batholith. The area must be small, and because no opportunity to trace its limits occurred after the determination of the rock it is not mapped. It is very possible that the age relation of the Philipsburg and Royal intrusions could be determined on the glaciated slopes in this vicinity.

PETROGRAPHY.

DOMINANT PHASE.

The petrographic character of the prevailing phase of the granite of the Royal batholith is well illustrated by material gathered from the dump of the Royal mine. In general this rock is a very light gray. It consists mainly of feldspar, the material next most abundant being quartz and the third essential constituent black mica in foils about 0.2 millimeter across. A few little scales of white mica and some light-brown particles of titanite are visible but not conspicuous. The feldspar is of two kinds, distinct in habit. One kind forms many individuals rarely more than 2 or 3 millimeters in length, some of which when turned in a bright light exhibit striations and are therefore plagioclase. The other kind, which is shown by the absence of striations to be potash feldspar, forms much larger individuals, some of which are about a centimeter in length and exhibit rude crystal form. Their edges are poikilitic, but their centers do not carry many inclusions. The larger ones, which are more irregular in form, are so thickly crowded with grains of all the other constituents that the crystalline continuity of the poikilitic feldspar is shown only by the continuous reflections that flash from the cleavage planes when the specimen is turned into the right positions with respect to incident light. The largest crystal observed was a Carlsbad twin about 5 centimeters (2 inches) long.

Under the microscope the original minerals visible are plagioclase > quartz $\geq$ potash feldspar $\gg$ biotite > muscovite > apatite $\gtrless$ magnetite > zircon $\gtrless$ titanite $\gtrless$ allanite. The texture is hypidiomorphic granular, and the order of crystallization is roughly zircon, magnetite, apatite, magnetite, muscovite, plagioclase, biotite, microcline, quartz. Few grains are more than 4 millimeters in diameter, the average diameter being about 1 or 2 millimeters.

The plagioclase forms conspicuously zoned subhedral grains with a maximum diameter of 4 millimeters. These contain some material as basic as andesine-labradorite and have rims of oligoclase, but they consist mainly of andesine. Their average composition is estimated optically as An_{40}. Oligoclase intergrown with quartz (myrmekite) forms a partial ragged border to some of the crystals, always at the contact with orthoclase.

The potash feldspar locally shows microcline twinning, particularly near inclusions, and is perthitically intergrown with a little albite. In the thin section it appears partly as interstitial anhedra, but one fairly well developed crystal 5 millimeters long was observed. Inclusions are abundant near the margin, which is somewhat irregular, but approximates crystal planes at contacts with quartz, and inasmuch as inclusions of quartz in the potash feldspar are uncommon the quartz is probably the later.

The deep-brown biotite forms tablets with ragged edges. It partly enwraps some plagioclase crystals but locally penetrates their margins. It is considerably altered, the chief product being chlorite, with which is mingled some epidote, needles of rutile, and a turbid, strongly birefringent substance resembling titanite.

The original muscovite is mostly associated with biotite, in which it is commonly inclosed. A number of large inclusions in plagioclase appear to be primary.

Magnetite, titanite, and zircon are comparatively scarce. Apatite in moderate quantity is mostly inclosed in the biotite. A single ragged individual of deep-brown, strongly pleochroic allanite inclosed in microcline was observed.

Chemical analysis of this rock yielded the following results:

Analysis of granite from the Royal batholith.

[By George Steiger.]

	Per cent.	Molecular proportions.		Per cent.	Molecular proportions.
SiO_2	68.40	1.140	H_2O+	0.55	....
Al_2O_3	16.34	.160	TiO_2	.29	0.004
Fe_2O_3	.17	.001	P_2O_5	.22	.002
FeO	1.56	.022	MnO	.07	.001
MgO	.64	.016	BaO	.15	.001
CaO	3.77	.067	SrO	.05	....
Na_2O	3.39	.055			
K_2O	3.91	.041		99.80	....
H_2O-	.29	....			

No ZrO_2, CO_2, S, or SO_3 was found.

To classify the rock in the quantitative system, the norm was calculated and found to be:

Quartz	24.7			Salic, 93.0
Orthoclase	22.8		Feldspar, 68.3	
Albite	28.8	Plagioclase, 45.5		
Anorthite	16.7			
Corundum	0.1			Femic, 7.1
$MgSiO_3$	1.6	Hypersthene, 3.8		
$FeSiO_3$	2.2			
Ilmenite	0.6			
Magnetite	0.2			
Apatite	2.4			
	100.1			

$\frac{\text{sal}}{\text{fem}}=\frac{93.0}{7.1}>\frac{7}{1}$ (persalane) $\frac{\text{quartz}}{\text{feldspar}}=\frac{24.7}{68.3}>\frac{1}{7}<\frac{3}{5}$ (quardofelic).

$\frac{K_2O+Na_2O}{CaO}=\frac{96}{60}<\frac{5}{3}>\frac{3}{5}$ (alkalicalcic, near domalkalic).

$\frac{K_2O}{Na_2O}=\frac{41}{55}>\frac{5}{3}<\frac{3}{5}$ (sodipotassic).

The rock is amiatose, near toscanose, which is more alkalic.

The magnesia of the normative hypersthene and the alumina of the normative corundum belong to the micas, the titanium chiefly to titanite, biotite, and rutile rather than ilmenite. Part of the potash belonging to orthoclase in the norm actually goes to the formation of micas, but, on the other hand, the alkali feldspar contains some soda, so that the actual amount of alkali feldspar must be near that of orthoclase in the norm. The normative plagioclase is found from the molecular ratio to be $Ab_{55}\,An_{33}$, or An_{37}.[1]

The optical estimate—An_{40} for the crystals—did not take account of the albite intergrown with or dissolved in the orthoclase nor of the small grains of sodic micropegmatite. When these are allowed for, the agreement between the results—in this case independent—of optical examination and of computation from the analysis is very satisfactory.

Of the amiatoses in Washington's tables, the two most resembling the granite of the Royal batholith are a granodiorite from Silver Lake House, Eldorado County, Cal.,[2] which differs chiefly in that its norm has more pyroxene (represented by hornblende in the mode), and a "biotite granite" from the North Fork of Tuolumne River, Cal.,[3] which is richer in quartz and correspondingly poorer in feldspars and femic minerals. The two amiatoses from Butte[4] are much more femic, being indeed near the line between persalane and dosalane, although well within the alkalicalcic range. Among the toscanoses the nearest analogue is another California biotite granite[5] from El Capitan, in the Yosemite National Park.

In the old classification the rock would probably be called a quartz monzonite by those who apply the term monzonite broadly to plagioclase-orthoclase rocks. In the norm orthoclase is almost exactly half as abundant as plagioclase, so that the rock is just on the border of the monzonite family as defined by Lindgren.[6] It has nearly the maximum amount of silica (69 per cent) and a trifle more than the maximum amount of potash (3.75 per cent) allowable in granodiorite according to that author.

MARGINAL VARIATION.

The marginal parts of the batholith for several rods from the contact are more or less distinctly gneissoid and somewhat richer in biotite than the rock in the main body of the batholith. None has been observed to contain hornblende. Locally there is an obscure porphyritic texture, better perceived under the microscope than megascopically. Microscopic examination shows no striking difference in composition from the normal rock, apart from the enrichment in biotite and locally greater basicity of the plagioclase.

In this marginal gneissoid phase the minerals show slighter microscopic evidence of deformation than would be expected from their megascopic appearance, but the quartz in some specimens is strained perceptibly more, and microcline twinning of the potash feldspar is more general than in the normal rock.

[1] It is to be remembered that this is the ratio between the number of *molecules* of $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$ and is equal to the ratio of the molecular proportions of Na_2O and $2CaO$. The molecular weight of An is 1.061 times that of Ab, hence the ratio between the weights of Ab and An will be a little less than that between their molecular proportions.

[2] Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 182, No. 8.

[3] Idem, p. 184, No. 9.

[4] Idem, p. 182, Nos. 1 and 2.

[5] Idem, p. 164, No. 61.

[6] Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 3, 1897, p. 301.

SECONDARY FOLIATION.

Intense foliation independent of contacts is developed in the granite of the Royal batholith a short distance east of the quadrangle. This is due to forces that act along a zone trending a little east of north and that affect various other intrusives in the vicinity of Danielsville in striking manner. In exposures on Rock Creek, about 2 miles beyond the quadrangle boundary, the granite is transformed to a readily cleavable gneiss with the biotite forming discontinuous films along the cleavage faces. Some of the larger crystals of feldspar have been rounded off to form thick lenses or "eyes" with their longer diameters parallel to the schistosity. These are rarely more than 5 millimeters long, but larger crystals, which have their analogue in the Royal Mine specimen, occur sporadically.

A thin section of this gneiss shows the usual evidences of crushing and shearing. The quartz has very distinct strain shadows. An interesting peculiarity consists in the presence of a few small grains of monazite.

APLITES.

The granite of the Royal batholith is cut by numerous but small aplitic dikes, not of great volume compared to the parent rock. They are fine grained, light gray to nearly white, and composed mainly of quartz and feldspar, with muscovite alone or accompanied by a subordinate amount of biotite.

A specimen from Pikes Peak appears megascopically like a fine-grained two-mica granite. Under the microscope the grains are seen to be almost wholly irregular and very uneven in size. The minerals are plagioclase$\gtrless$quartz$\gtrless$microcline$>$muscovite$\gtrless$biotite$\gg$magnetite$>$apatite$\gtrless$zircon. The plagioclase is strongly zoned; most crystals have a fairly homogeneous core of andesine (An_{45}) and a broad zone of oligoclase (An_{15-25}), whose extinction angle changes gradually and continuously from the inner to the outer edge. The microcline is anhedral to rudely subhedral and somewhat poikilitic, with subhedral inclusions of quartz.

A dikelet about 3 centimeters thick in the contact facies of Goat Mountain is materially different in composition. It is apparently free from biotite, but contains minute spangles of silvery white mica and sparsely distributed tiny bright-red garnets. It is affected by an obscure foliation parallel to that of the inclosing granite but oblique to the contact of the two rocks.

Under the microscope the texture is seen to be panallotriomorphic. Microcline seems rather more abundant than the plagioclase, which is albite. Microscopic particles of chlorite probably represent a small amount of original biotite.

MINOR INTRUSIONS OF ACIDIC GRANITOID ROCKS.

GENERAL FEATURES.

Small masses of granitoid rocks with two micas, not sufficiently similar to those previously described to be safely correlated with them, occur on Foster Creek, Warm Spring Creek, and north of the quarries on Warm Spring Creek. They will be described more briefly than the larger masses.

These intrusions have a certain similarity of composition, which with their proximity one to another may mean that they are genetically related. Except for a variant of the largest mass they are composed essentially of plagioclase, microcline in equal or smaller amount, much quartz, a moderate amount of biotite, and less muscovite. They show, however, a marked variation in texture. Their composition is more like that of the Royal batholith than any other large intrusion, but they have some affinity with the nonporphyritic two-mica granite of the Anaconda Range.

GRANITE OF FOSTER CREEK.

OCCURRENCE.

The most extensive of these minor intrusions forms an area of about 2 square miles on Foster Creek and several small outliers. It is clearly intrusive in diorite and in Devonian and Carboniferous limestones, for its apophyses cut all these rocks and locally develop a garnet contact rock in the limestone. The main mass is fairly well exposed.

CHARACTER.

The rock forming most of the Foster Creek area is a light-gray medium-grained biotite granite resembling that of the Royal batholith in texture, tone, and constitution, but characterized by the development of biotite in very thin, rather broad, ragged flakes. The microscope shows the essential constituents to be perthitic microcline $\gtrless$ quartz $\gtrless$ plagioclase $<$ biotite $\gtrless$ muscovite $\gtrless$ magnetite $>$ apatite $<$ zircon $\gtrless$ titanite. Alkali feldspar is a little more abundant than in the granite of the Royal batholith. The plagioclase is strikingly zoned, with cores of andesine, labradorite, or even sodic bytownite shading into rims of oligoclase and albite. Magnetite and apatite are rather abundant.

In the northeast part of the area, this rock apparently grades into rocks considerably darker, richer in biotite, and containing more or less hornblende. Microcline, which forms poikilitic grains that can be readily detected megascopically, bears about the same proportion to plagioclase as in the rock previously described. The plagioclase, however, is more basic than in that rock. Titanite, magnetite, and apatite are comparatively abundant. A remarkable feature of the rock is the tardiness with which titanite and magnetite have crystallized. Both enwrap plagioclase in many places, and titanite is even penetrated by hornblende. The general sequence of crystallization has been zircon; apatite; plagioclase and magnetite; biotite, hornblende; titanite, quartz, and microcline. Overlapping, of course, has occurred; magnetite, for example, is inclosed in the margins of plagioclase crystals, and hornblende and quartz are locally intergrown.

GRANITE PORPHYRY ON UPPER WARM SPRING CREEK.

OCCURRENCE.

A narrow strip of granite porphyry crossed by Warm Spring Creek northeast of Cable is intrusive in Madison limestone, whose bedding it follows to a considerable extent. It forms a prominent talus on the east side of Warm Spring Creek canyon but has no prominent outcrops.

CHARACTER.

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

The microscope shows the texture to be in reality porphyritic, although the groundmass is coarse by comparison with the size of the phenocrysts, which are mostly 1 to 2 millimeters in diameter. They consist of plagioclase, quartz, and mica—chiefly biotite, but with some muscovite intergrown. In the groundmass, besides a second generation of the porphyritic minerals, is considerable microcline, but this feldspar is less abundant on the whole than the plagioclase. Magnetite, allanite, and zircon are scarce accessories. The plagioclase crystals are distinctly zoned, with a range of composition from about An_{40} to about An_{15}.

Chemically this rock can not be very different from the most acidic granite of Foster Creek, though it is probably poorer in potash, and the two may be genetically related.

MICROGRANITE NORTH OF LOWER WARM SPRING CREEK.

OCCURRENCE.

About $1\frac{1}{4}$ miles nearly due north of the bench mark at 5,606 feet on lower Warm Spring Creek (see map, Pl. II) is a very small area of fine-grained granite intrusive in Cambrian rocks, near which are others, still smaller, that are not mapped. A rock of similar character, also unmapped, forms a dike in coarser granites at the head of Clear Creek.

CHARACTER.

The rock from the mapped area is of a pepper and salt gray, and has a uniform texture like that of typical granite, but finer, few of the constituent grains being more than 1 millimeter in diameter. The minerals readily identified by the naked eye are feldspar, quartz, and biotite.

The microscope shows the chief constituents to be plagioclase $<$ quartz$\gtreqless$potash feldspar $>$ greenish biotite. Muscovite is present in small amount, and magnetite, apatite, titanite, zircon, and allanite occur as rather abundant accessories. A single grain of tourmaline was observed in a thin section. Ordinary epidote that is apparently primary occurs, and apparently secondary epidote is also present, as are a little chlorite, sericite, etc., but the rock is comparatively fresh. The plagioclase is zoned, with a range from An_{50} to An_{20}.

The most interesting constituent is epidote. Most of the pistacite crystals have allanite cores with which they are in parallel orientation. The outline of the allanite core is in general more regular than that of the pistacite shell, but the pistacite forms one grain with no allanite kernel and with partly developed crystal planes. This grain incloses apatite and plagioclase, and is in contact with fresh biotite, as are most of the grains with allanite cores. In view of the fresh condition of the rock, which gives no evidence that it has been either much weathered or much affected by dynamic metamorphism, it seems probable that the epidote described is primary. It is distinct in habit from the small irregular grains associated with chlorite, which are probably secondary.

APLITE NORTH OF LOWER WARM SPRING CREEK.

About a mile north of the great lime quarry on Warm Spring Creek is a small mass of fine-grained rock, which is intrusive in Madison limestone and which contains scapolite, tremolite, and locally orthoclase (p. 69) in the vicinity of the contact.

The rock resembles that just described in general tint, but is of finer, more sugary texture, and is dappled with ill-defined greenish spots about 0.5 centimeter in diameter. Sparsely scattered small flakes of biotite and muscovite are visible. The microscope shows the rock to have a mineral constitution similar to that of the granite porphyry farther up the creek, but its texture is aplitic and it contains relatively more microcline and muscovite. The dappling is due to segregation of a pale grass-green, finely divided mica, partly intergrown with muscovite. Ordinary brown biotite occurs in larger flakes distinct from these.

ALKALINE BIOTITE GRANITE OF LOST CREEK.

GENERAL CHARACTER AND OCCURRENCE.

An alkaline fluorine-bearing granite occupies an area several square miles in extent near the eastern boundary of the quadrangle, which it overlaps near Lost Creek and on the slope north of Warm Spring Creek. The granite is also exposed in a gulch draining to Warm Spring Creek.

This rock is composed chiefly of orthoclase, albite, quartz, and biotite and contains fluorite. The presence of fluorite and the character of the feldspar chiefly distinguish the rock from the nonporphyritic granite of the Anaconda Range (p. 117). These distinctive features are recognizable only by the aid of the microscope; in megascopic appearance the two rocks are very similar.

The most accessible exposures of the rock are certain barren knobs about 10 to 50 feet high rising abruptly from a surface covered with fragments of disintegrated granite on the slopes north of Warm Spring Creek. Some of these knobs are shown by contours on the map. They are steep on the uphill side, less so on the downhill side (fig. 4), and the yellow-stained, deeply weathered granite composing them is thoroughly sheeted about parallel to the slope of the ground.

Better exposures of the granite on the steep glaciated walls of lower Lost Creek canyon, near the east boundary of the quadrangle, are whitish in places where the rock is least weathered, but nearly all of it is stained by iron oxide in dull yellow or orange tints. The glaciated surfaces on the steep canyon walls reveal few joints, but the more weathered portion above is cut by many irregular joints. In both parts a large proportion of the joints are curved and nearly parallel to the surface and appear to be due to weathering, like the sheeting shown in figure 4.

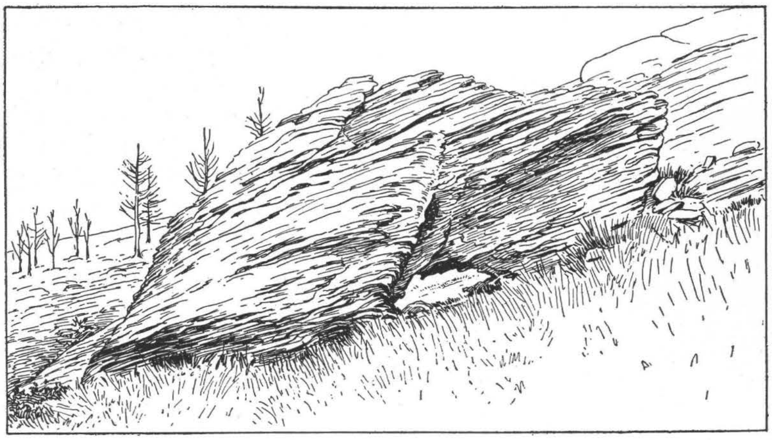


FIGURE 4.—Sheeting and jointing in granite.

The intrusive relation of this granite to the Algonkian Newland formation is vividly shown in Lost Creek canyon, where the surface of the main mass cuts across the bedding at a low angle and dips gently to the west. Dikes of granite or related pegmatite that were not closely examined penetrate both the Newland and the diabase by which it is intruded. On the hill south of Lost Creek the Algonkian rocks are cut by many dikes of tourmaline-bearing aplite and pegmatite. Their distribution makes it probable that they belong to the fluorite-bearing granite.

PETROGRAPHY.

GRANITE.

The alkaline granite is a rock whose tint in mass when fresh is a very light warm gray. The texture is granitic, moderately coarse to rather fine. The constituents visible to the naked eye are feldspar, quartz, and biotite. The quartz has a smoky tint that contrasts with the dull cream-white feldspar, and in relatively fine grained specimens it has an apparently porphyritic development, roundish grains 2 or 3 millimeters in diameter being evenly scattered in a sugary feldspar matrix in which black irregular foils of mica about 1 millimeter in average diameter are also thinly sprinkled. The amount of quartz is here somewhat less than half that of the feldspar. In a coarser, apparently more quartzose specimen quartz and feldspar form grains with a maximum diameter of about one-half centimeter, and the quartz has more irregular boundaries interlocking with feldspar. A very faint greenish tint observed in places may be due to the fluorite, which, however, can not be identified megascopically.

The microscope shows the feldspar to consist of microcline and nearly pure albite ($An_{<5}$), the latter a little in excess. Quartz is about equal to microcline in amount, biotite and fluorite are distinctly subordinate, and magnetite, apatite, zircon, and rutile are scarce accessories. The feldspars form comparatively coarse perthitic intergrowths which contain nearly equal amounts of the two varieties, and the potash feldspar is more clouded than the plagioclase—a reversal of the ordinary condition. The biotite is greenish and is bordered in one specimen by a colorless mica in parallel intergrowth. No alteration to chlorite or epidote was observed.

Fluorite in all specimens forms irregular grains less than 1 millimeter in diameter between the feldspars or inclosed within them. There is no evidence that it is secondary.

PEGMATITE AND APLITE.

One specimen of pegmatite from the rocks cut by the granite is composed chiefly of quartz, white feldspar, and muscovite in grains up to 1 centimeter in diameter. In a matrix of these light-colored minerals are conspicuous black prisms of tourmaline as much as 0.5 centimeter thick by 5 centimeters long. An aplitic facies is illustrated by a whitish rock of sugary texture consisting chiefly of quartz and feldspar, with a little inconspicuous muscovite and numerous black, stumpy prisms of tourmaline about 3 millimeters in maximum diameter. The microscope shows the feldspar to be chiefly microcline. These rocks grade into others composed essentially of quartz and tourmaline with little or no feldspar.

NONPORPHYRITIC BIOTITE GRANITE OF MILL CREEK.

GENERAL CHARACTER AND OCCURRENCE.

Near the southeast corner of the quadrangle, between Tenmile and Mill creeks, is a large area of coarsely granular rock consisting essentially of quartz, oligoclase, potash feldspar, and biotite. This biotite granite is finely exposed on the precipitous glaciated walls of Mill Creek canyon and nearly as well on the south side of Clear Creek. On gentle slopes it is covered with a mantle of coarse sand and partially disintegrated fragments. Although light gray when fresh it discolors by weathering to a tawny hue, which prevails in the exposures along Mill Creek, for example, and forms a contrast to the darker-grayish tone of the acidic granodiorite.

This granite is not in irruptive contact with any sedimentary rock unless it be the mass of quartzite north of Mill Creek tentatively assigned to the Flathead. The contact with the Madison limestone south of Mill Creek is due to a fault, and the force that produced this rupture has also sheared the granite. The shearing is most marked on Mill Creek near the east boundary of the quadrangle, where the granite is transformed to a dark gneiss which splits into thin flags, and which appears at first glance to be a sedimentary rock. The shearing is least marked on the north side of Mill Creek, near the west side of the area.

The igneous rocks with which the nonporphyritic biotite granite is in contact are the acid granodiorite (p. 104), a porphyritic biotite granite (p. 116), and a nonporphyritic two-mica granite (p. 117). The granodiorite sends apophyses into the granite and is clearly of later date. Conclusive direct evidence regarding the relative age of the nonporphyritic biotite granite was not obtained, but as the porphyritic rock is later than the granodiorite (p. 116) it must be later than the nonporphyritic biotite granite. The age relation between this rock and the nonporphyritic two-mica granite on the north was not determined, although careful examination was made in the vicinity of their junction at the head of Clear Creek.

PETROGRAPHY.

The general tone of the freshest specimens of this granite is a light warm gray resulting from the blended tints of the cream-white feldspar, the slightly brownish quartz, and the small quantity of black biotite. The quartz is in very irregular ill-defined masses about 3 millimeters in average diameter. The feldspar forms some fairly well developed crystals about 1 centimeter long, but mostly is in grains not over 2 or 3 millimeters across. The large crystals, which the microscope shows to be of microcline, are of sporadic and irregular distribution, and not conspicuous enough to make the rock porphyritic. There is no marked difference of color between potash and soda-lime feldspar. The biotite forms irregular scales about 1 millimeter in diameter.

The microscope shows the feldspar to comprise nearly equal amounts of perthitic microcline and oligoclase. Quartz is about equal to each of these in amount, brown biotite is subordinate, and magnetite, apatite, and zircon are accessory. There is a minute proportion of muscovite apparently original. The alkali feldspar is in anhedral to subhedral grains. The perthitic intergrowth is of markedly different character from that in the alkaline granite of Lost Creek; the albite is markedly subordinate to the microcline and forms very minute veinlets. The plagioclase is only faintly zoned; its average composition is estimated as near An_{20}, but accurate determination is difficult, owing to undulatory extinction and to rupture and bending of the crystals by pressure, whose effects are further shown in distortion of the biotite flakes and the conspicuous strain shadows of the quartz.

PORPHYRITIC BIOTITE GRANITE.

GENERAL CHARACTER AND OCCURRENCE.

Porphyritic biotite granite, a rock with large phenocrysts of microcline in a coarse granular groundmass composed essentially of quartz, plagioclase, microcline, and biotite, occurs in both the Anaconda and Flint Creek ranges.

In the Anaconda Range it is one of the most abundant rocks and occupies about the same area as the acidic granodiorite described on pages 104–107. Like that rock it is confined to a zone extending about east-northeast, which lies south of the granodiorite zone. One group of areas, which might be continuous except for the drift that covers the valley bottoms, extends from Seymour Creek to the head of the stream into which Carp Lake drains. The rock also forms a narrow strip between Tenmile and Clear creeks. Its occurrence in the Flint Creek Range is confined to comparatively small areas on Racetrack Creek near the point where it leaves the quadrangle.

From a distance the porphyritic biotite granite appears light gray to tawny, being similar in tint to the nonporphyritic rock just described. North of Mill Creek it has been somewhat sheared, and its characteristic features are thereby so much disguised that its boundaries can hardly be drawn accurately. It is darker and warmer in tone than the porphyritic two-mica granite and lighter than the granodiorite and diorite with which it is in contact. In part of the Racetrack Creek area it has been made very schistose by dynamic action.

The rock is intrusive into Cambrian and Algonkian sediments north of Racetrack Creek, and into early Algonkian beds in the Anaconda Range. In this range it has been proved later than any other granular intrusive with the possible exception of the two-mica porphyritic granite. In the Flint Creek Range it cuts the diorite and is cut in turn by the two-mica porphyritic granite.

Its relative age in the Anaconda Range is fixed by its relation to the acidic granodiorite of the Carp Lake type. This is clearly shown about 2½ miles east of Carp Lake, where apophyses from the granite cut the granodiorite, as shown somewhat diagrammatically on the map. On Mill Creek canyon, also, the priority of the granodiorite is shown by the fact that at the junction this rock is normal and uniform, whereas the biotite granite is variable, partly pegmatitic and partly more basic than usual. The contact with the two-mica porphyritic granite on Tenmile Creek is not sufficiently well exposed to reveal the relative age of the two rocks.

The relations of the porphyritic biotite granite on Racetrack Creek are clear. At well-exposed contacts south of Racetrack Creek the diorite is uniform, but the granite varies in texture and in abundance of feldspar phenocrysts and biotite. It is shown to be older than the two-mica granite by similar evidence, and also by the fact that the latter is not schistose.

PETROGRAPHY.

The character of the porphyritic biotite granite in the Anaconda Range and in the Flint Creek Range is identical so far as observed. The general tone of the rock is light brownish-gray, similar to that of the biotite granites described. The phenocrysts of grayish to pinkish white potash feldspar are, as a rule, most prominent on deeply weathered surfaces, from which they project in relief. Few of them are more than 2 centimeters in diameter, and the average is about 1 centimeter. The dimensions in different directions are nearly equal, although there is a slight elongation in the direction of the vertical axis and a slight flattening on the orthopinacoid. The phenocrysts have definite crystal form but carry a considerable number of small inclusions, especially near the margin, so that in detail their boundaries are rough. A small proportion show Carlsbad twinning.

The matrix of these crystals, which constitutes about two-thirds of the bulk of the rock, has the texture of a fairly coarse granite, and accordingly the rock is classified as porphyritic granite rather than granite porphyry. The visible constituents of this groundmass are quartz, feldspar, and biotite. The quartz, which constitutes about half the groundmass, forms irregular patches about 3 millimeters in diameter. It has a smoky tinge in strong contrast to the paler hue of the feldspar. Biotite forms irregular foils, generally near 1 or 2 millimeters in diameter, with a slight tendency to aggregate in clusters. This groundmass is richer both in quartz and biotite than is the nonporphyritic biotite granite as a whole, partly because these minerals have been crowded together by the formation of phenocrysts.

The microscope shows the phenocrysts to be of perthitic microcline. Their inclusions are chiefly of plagioclase but comprise biotite, accessories, and, near the margin, quartz. In the groundmass this alkali feldspar recurs in subhedral or irregular masses, much inferior in amount to the soda-lime feldspar. The plagioclase, unlike that of the nonporphyritic biotite granite, is characterized by rather conspicuous zonal banding. The range of composition in successive zones is sometimes as wide as from andesine near An_{40} to oligoclase-albite near An_{10}; the average composition is probably that of a calcic oligoclase between An_{20} and An_{30}. Biotite is commonly inclosed in the outer parts of plagioclase crystals. Accessory constituents are muscovite, magnetite, apatite, titanite, allanite, zircon, and rutile. Allanite occurs rather more abundantly in this rock than in other granites and granodiorites of the region. The muscovite is scarce and visible only by the aid of the microscope.

The strongly sheared granite on Racetrack Creek is of the "augen gneiss" type, with the lines of schistosity curving about the phenocrysts. It appears darker than the unsheared rock and of a cooler gray, inclining rather to blue than to brown, the feldspar being pure white and the quartz water-clear, without a smoky tint. Microscopic study fully proves the identity of this rock in mineral constitution with the one described. The large masses of quartz have, however, been drawn out into lenses, the distribution of the biotite has become streaky, and much of the feldspar and quartz in the groundmass has been crushed to a fine mosaic. The feldspar phenocrysts have been least affected. The biotite is somewhat greenish.

The apophyses cutting the granodiorite east of Carp Lake are of a rock enough finer in texture than those above described to be called a granite porphyry rather than a porphyritic granite. It contains phenocrysts of orthoclase up to 2 centimeters long and smaller ones of smoky quartz, plagioclase, and biotite in a perceptibly crystalline groundmass. Under the microscope the rock, though composed of the same essential minerals as the parent granite, appears a little more acidic, having relatively more potash feldspar and a more sodic plagioclase.

NONPORPHYRITIC TWO-MICA GRANITE.

GENERAL CHARACTER AND OCCURRENCE.

A granite of which muscovite as well as biotite is an essential constituent, and which contains no large and prominent feldspar crystals, is one of the chief rocks in the eastern part of the Anaconda Range. The several areas are aligned in a northeasterly direction. One lies south of Mount Howe; a second at the head of Twelvemile Creek; a third, which is divided on the surface by moraines, at the head of Mill Creek; and the fourth, which is the largest, north of Mount Haggin.

This granite is clearly intrusive into Algonkian sediments in all but the largest area. North of Mount Haggin it adjoins Devonian and Mississippian limestones along contacts that are probably intrusive, though not definitely proved to be so.

The nonporphyritic two-mica granite is in contact with the acidic granodiorite of the Carp Lake type, with nonporphyritic biotite granite, with porphyritic two-mica granite, and with diorite. If all the areas enumerated above represent contemporaneous intrusions they are older than any of these rocks except the diorite and possibly the biotite granite, their age relation to which, as already stated, was not determined. That this granite is later than the diorite is strikingly shown on the north face of Mount Haggin, where the dark rock of the summit is cut by apophyses of the granite and by related dikes of pegmatite. That it is older than the acidic granodiorite is shown by the apophyses of granodiorite which cut it northeast of Mount Haggin and south of Mount Howe. It was proved older than the porphyritic two-mica granite at the head of Twelvemile Creek, where the porphyritic rock varies at the contact and the other remains normal (p. 119).

The general appearance of the granite as seen in the field is much like that of the biotite granite, though it is somewhat lighter and shows less of yellowish discoloration. Northeast of Mount Haggin, however, where it is considerably sheared and deeply weathered, it has much the same tawny hue as the granite without muscovite, and the boundary between them is not visible at a distance.

Much pegmatite and aplite are associated with this granite, particularly near its margins.

PETROGRAPHY.

A typical specimen from the talus south of Hearst Lake shows a very light gray mass tint and a rather coarse, typically granitic texture. Feldspar constitutes nearly two-thirds of the rock and quartz the greater part of the remainder, the other minerals visible to the naked eye being muscovite and biotite in nearly equal quantity. The feldspar is almost pure white, and there is no conspicuous difference in color or habit between potash and soda-lime feldspar. The largest crystals are some of unstriated feldspar about 1 centimeter long, but the size dwindles from this by gradations, so that the aspect of the rock is not porphyritic. The quartz is sugary and gray, not smoky, as in much of the biotite granite. Of the micas muscovite forms the larger and more conspicuous foils, some of these being as much as 0.5 centimeter in diameter, with partially developed hexagonal outlines.

In the thin section the microscope shows that the feldspar consists of perthitic microcline and plagioclase in nearly equal amount, the alkali feldspar possibly in slight excess. The soda-lime feldspar is rather faintly zoned oligoclase, its composition ranging approximately from An_{20} to An_{10}, with an estimated average of An_{15}. It shows myrmekite fringes at the contact with microcline. The quartz occurs in granular aggregates and is of later date than the alkali feldspar. The micas, which are partly intergrown, are earlier than the plagioclase. The accessory constituents are magnetite, zircon, and a little apatite. Curved and broken twin lamellæ of plagioclase and marked bending of the mica flakes show the effect of dynamic stresses.

A specimen obtained south of Mount Howe is finer in texture and slightly less acidic. It contains a little more biotite, and the thin section shows perceptibly less alkali feldspar than plagioclase. The plagioclase, moreover, is more calcic and ranges from An_{30} to An_{12}, with an average composition about An_{20} or An_{25}. The mass at the head of Twelvemile Creek is similar in character but still finer in texture, its average grain being about half that in the Hearst Lake specimen.

Pegmatite and aplite intrusions cutting this granite are well exposed near the head of Sullivan Creek. The aplite is the more abundant. It is cut by pegmatite veins and also passes by gradations to pegmatite with feldspar individuals several inches across. There is apparent gradation also in places to the normal granite. The essential constituents of the typical aplite and pegmatite are perthitic microcline, albite, quartz, and muscovite; red garnet crystals up to 5 millimeters in diameter occur also in small amount.

PORPHYRITIC MUSCOVITE-BIOTITE GRANITE.

GENERAL CHARACTER, DISTRIBUTION, AND GEOLOGIC RELATIONS.

In both the Flint Creek and Anaconda ranges occurs a rock with large porphyritic crystals of alkali feldspar in a coarse granitic groundmass containing both muscovite and biotite. The largest mass of this porphyritic muscovite-biotite granite overlaps the east border of the quadrangle from Lost Creek to Rock Creek. It embraces the top of Mount Powell, a lofty peak a mile east of the quadrangle, and may be called, therefore, the Mount Powell batholith. In the

Anaconda Range a considerably smaller mass is exposed about the heads of Twelvemile and Tenmile creeks. This will be called the Twelvemile batholith.

The sedimentary rocks cut by the Twelvemile batholith are the Algonkian Prichard and Neihart formations. An irregular irruptive contact with the latter is well exposed at the head of Tenmile Creek. The Mount Powell batholith has been observed in contact with sedimentary rocks of Algonkian to early Cretaceous age, and it sends apophyses into Cretaceous rocks east of Twin Peaks. The contact metamorphism produced by this intrusion is everywhere powerful but is perhaps most striking south of Thornton Creek. The minerals developed in the Cambrian rocks of this locality have already been mentioned on page 60. Among the most characteristic are those of the humite group, which indicate that the magma gave off fluorine.

The relation of the porphyritic muscovite-biotite granite to other intrusives in the Anaconda Range has not been clearly determined except with respect to the nonporphyritic two-mica granite. A good exposure at the head of Tenmile Creek shows the porphyritic granite to be the later; its porphyritic character fails about 3 feet from the contact, nearer to which there is a diminution in coarseness and a gradation to aplite. The other rock shows no change related to the contact.

In the Flint Creek Range the porphyritic two-mica granite is later than the other granitoid rocks to which its relation is known. The evidence that it is later than the Royal batholith is given on page 108. The same evidence—namely, that the one is schistose and the other not—shows it to be later than the porphyritic biotite granite. More direct evidence appears at the contact north of Racetrack Creek, where, although the biotite granite is uniform, the two-mica granite is highly variable in texture for about 5 feet from the contact and apparently grades into pegmatite. The schistosity of the diorite south of Racetrack Creek proves its greater age; it is, moreover, cut by the aplites and pegmatite of the two-mica granite south of Thornton Creek. The contact with the small granite intrusion south of Lost Creek is ill exposed and the age relations of the two rocks are not known.

PETROGRAPHY.

The porphyritic granite with two micas in the Anaconda Range is essentially the same, so far as observed, as that in the Flint Creek Range. In both ranges it varies somewhat in character and composition, but its general features are fairly well represented by a specimen obtained about 1 mile southeast of Mount Evans.

The rock in mass is very light gray. It contains many well-defined oblong phenocrysts of snow-white unstriated feldspar about 3 centimeters long, and these constitute perhaps one-fourth the bulk of the rock. They are embedded in a groundmass that has the character of a rather coarse grained granite. About half of it consists of white feldspar in grains less than one-half centimeter in diameter, some of which are visibly striated. Grayish quartz is abundant in conspicuous irregular masses, some of which are nearly 1 centimeter across. Muscovite and biotite, which are present in moderate and nearly equal amount, occur in irregular scales about 2 millimeters in maximum diameter.

The microscopic section shows no phenocrysts. In the groundmass quartz and plagioclase are more abundant than microcline and orthoclase. The potash feldspar is perthitic but not strikingly so. The plagioclase is slightly zoned and ranges in its composition approximately from An_{25} to An_{10}, the average being about An_{15} or An_{20}. The accessories are magnetite, apatite, and zircon. The rock is only moderately fresh, and the plagioclase is considerably sericitized.

The following determinations of silica and alkalies were made from a piece of this rock about half the size of an ordinary hand specimen, probably large enough to represent the composition fairly.

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

[W. T. Schaller, analyst.]

SiO_2	72.50
Na_2O	3.97
K_2O	4.06

These percentages are similar to those in the granite of the Bitterroot Mountains described by Lindgren.[1] In that rock they are 72.07, 4.02, and 4.09 respectively. The rock from the Anaconda Range, according to the American quantitative classification, would probably be a toscanose (I.4.2.3).

It is difficult to obtain thin sections of this rock that show the phenocrysts as well as their matrix. Abundant weathered-out phenocrysts were obtained, however, on the ridge north of Dempsey Lakes. They are of a very simple form, with the faces 001, 010, 110, and 201; a few of the large ones are twinned according to the Carlsbad law. The faces of the crystals are a little rough in detail, and small inclusions project from them.

Microscopically the phenocrysts are seen to be perthitic; locally, and especially near the albite veins, they show microcline twinning. In the basal section the untwinned portion extinguishes parallel to the trace of 010. Inclusions of plagioclase are numerous, especially near the margin, and inclusions of quartz and biotite are not uncommon. Most of the plagioclase inclusions near the center are irregular in orientation and arrangement, but those near the periphery are zonally arranged, and mostly lie with either 010 or 001 parallel to the nearest crystal face of the host.

The variations from this type most readily observed in the field are textural, the composition of the rock being substantially uniform. The phenocrysts are commonly a good deal larger than in the specimens described, and some attain a length of 3 inches. They vary in abundance from place to place. Locally they are crowded closely together, but elsewhere, especially in the western part of the Mount Powell batholith north of Racetrack Creek, the porphyritic texture is not conspicuous. It is possible indeed, that a nonporphyritic granite corresponding to that of Hearst Lake (p. 117) occurs here, but if so its areal extent is relatively small. The porphyritic texture is commonly absent near contacts with older rocks, though the granite generally keeps its normal character to within a few feet or even a few inches of such contacts.

A granite porphyry affiliated with this granite east of Racetrack Peak contains abundant phenocrysts of potash feldspar, plagioclase, quartz, and both micas in a microgranular groundmass consisting chiefly of potash feldspar and quartz.

The pegmatites and aplites associated with this granite have for chief constituents quartz, microcline, and albite. They also contain considerable muscovite, generally some red garnet, and locally a little biotite.

PYROXENE APLITE.

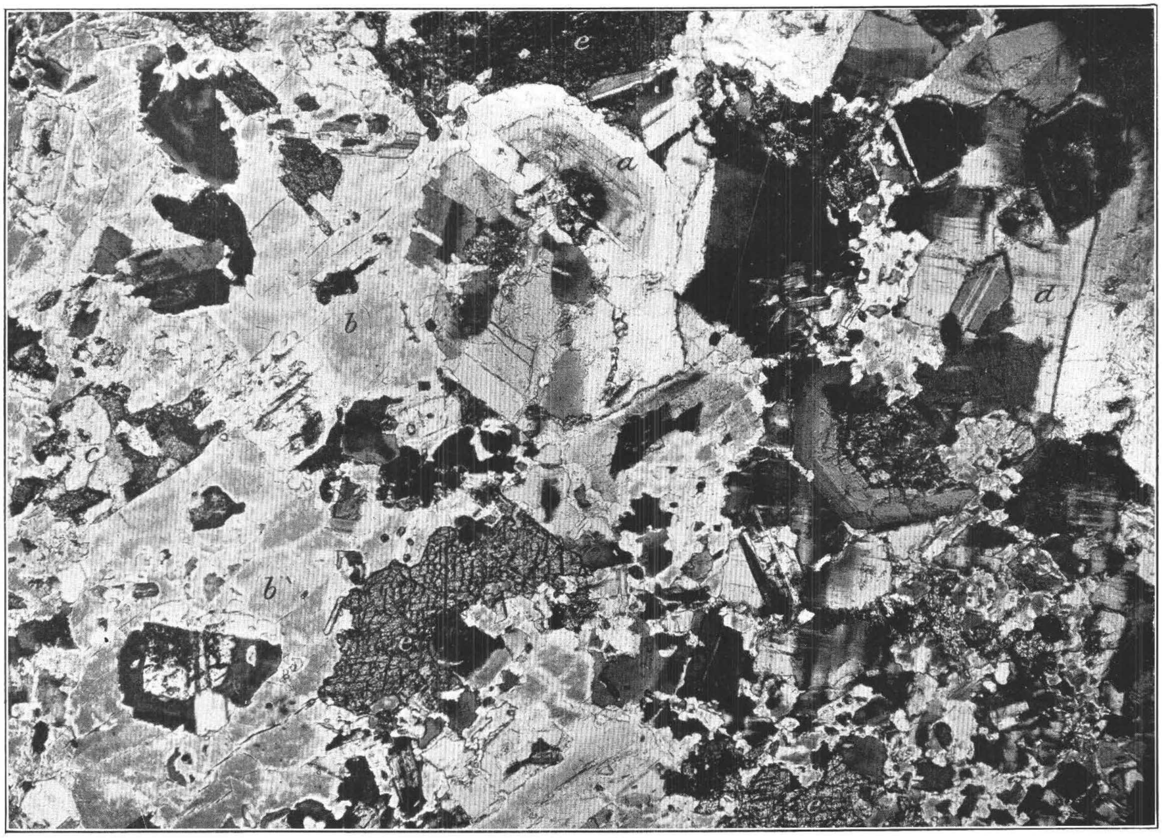
OCCURRENCE.

The most unusual intrusives in the Philipsburg quadrangle are certain fine-textured greenish-gray rocks of aplitic facies, in all of which the chief constituents are plagioclase, alkali feldspar, quartz, and diopsidic pyroxene. Their chief interest lies in the fact that some also contain primary scapolite, for occurrences of this mineral that are undoubtedly pyrogenic are extremely rare. Some contain also a soda feldspar apparently pseudomorphic after microcline.

These rocks, for the most part, bear much the same geologic relation to the granodiorites of the Philipsburg and Cable batholiths that the ordinary pegmatites essentially composed of alkali feldspar, quartz, and mica do to the batholiths of more acidic granitoid rocks. They form dikes or small stocklike intrusions and also occur irregularly mingled with more basic material at the contact with sedimentary rocks. In one noteworthy and significant respect the distribution of the pyroxene aplites differs from that of the ordinary aplites; they are not found in the central portions of batholiths, but, so far as observed, are near contacts with calcareous sediments.

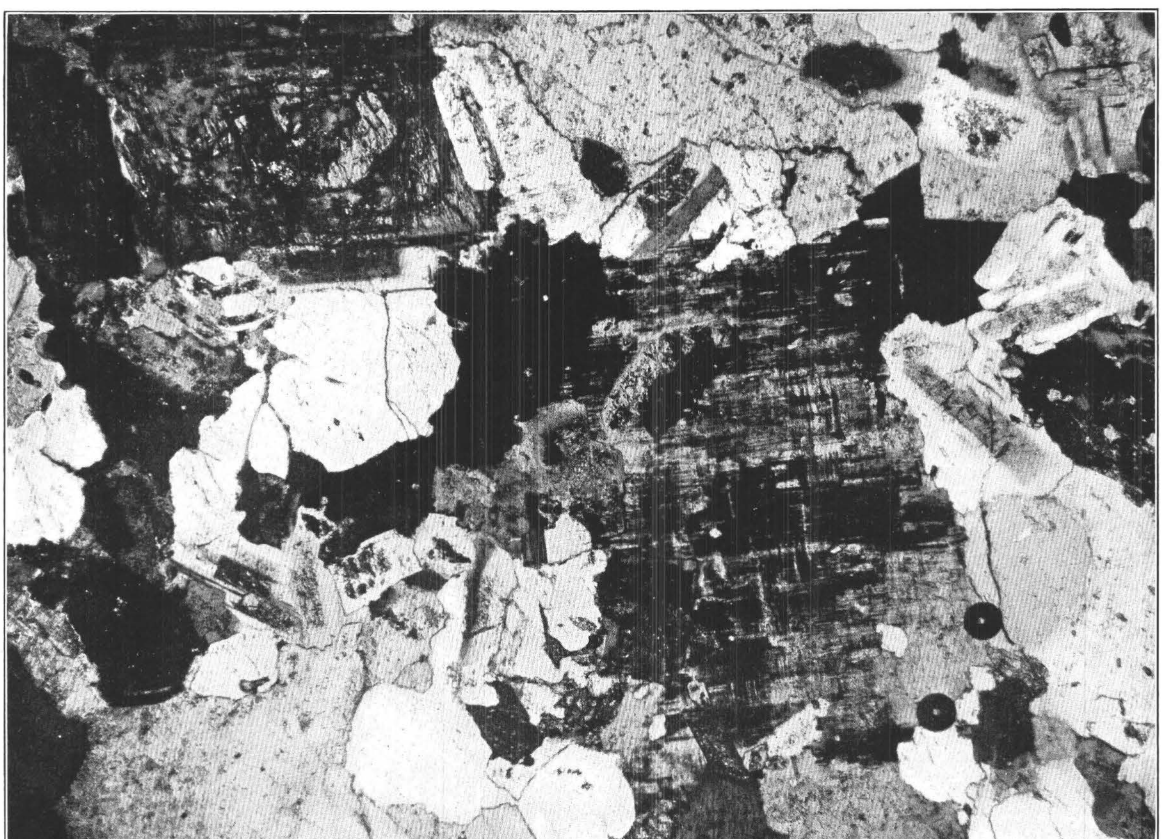
This peculiar pyroxene aplite intrusion has not been distinguished on the map from the granodiorite. It forms a small dike in the granodiorite near its contact with the Madison limestone,

[1] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904.



A. THIN SECTION OF SCAPOLITE APLITE FROM DIKE ON FOSTER CREEK.

The scapolite (*b*) forms a single individual inclosing and interpenetrating with plagioclase (*a*), microcline (*d*), and pyroxene (*e*). Calcite and a zeolite (*c*) form an irregular mass, probably a cavity filling. Crossed nicols. Enlarged 60 diameters.



B. THIN SECTION OF PYROXENE APLITE, SHOWING SODA FELDSPAR RESEMBLING MICROCLINE. CROSSED NICOLS. ENLARGED 60 DIAMETERS.

south of the Bimetallic mill, near Philipsburg. A large dikelike mass cuts the granodiorite outlier of the Philipsburg batholith exposed on Boulder Creek and extends into limestone on the northwest. This rock is well exposed in a gorge cut through it by Granite Creek. Another comparatively large mass, which crops out rather more prominently than the diorites with which it is in contact, is roughly mapped northeast of Rumsey Mountain. A very small dike about 1 foot thick, which was traced for about 50 feet, cuts Devonian limestone east of Foster Creek somewhat less than 1 mile north of Deer Lodge County line. At its contact is a reaction zone of garnet, epidote, magnetite, and other metamorphic minerals from 3 inches to 1 foot in width. It is in this dike that scapolite is most abundant. In addition to these more prominent or important occurrences there are others of sufficient interest to deserve mention. At the base of the cliff below the dike just mentioned, the granodiorite, supposedly a variant of the granite of Foster Creek, is separated from the limestone by a narrow, somewhat irregular zone of the pyroxene aplite, which appears to grade sharply into the granodiorite. On the east side of the Cable batholith the intrusive rock at the contact with calcareous shales and limestones consists of intricately mingled hornblende rock and pyroxene aplite. Pyroxene aplite has also been found near the south margin of the Cable batholith as float whose distribution indicates that it forms a dike in the granodiorite. It occurs in the Cable mine and in the Golden Gate tunnel to the north, where it is associated with a coarse-grained rock consisting chiefly of diallage and hornblende.

Rocks of somewhat similar character occur in the marginal part of the Storm Lake batholith (p. 93), and as float on the plateau south of Thornton Creek.

PETROGRAPHY.

GENERAL FEATURES.

Although specimens of the pyroxene aplite from any two localities show notable differences, the great majority of them have so many features in common that it is possible to give a composite picture of the group by a generalized description.

The rocks are greenish white to moderately deep greenish gray. The texture is, roughly speaking, granular, and the grain ranges from fine and sugary to about the same as in average granite. Feldspar evidently forms the greatest part of every specimen, and in many it is possible to recognize, by the heliograph signals they give when they catch the light, poikilitic individuals of alkali feldspar as much as 1 centimeter in diameter, crowded with inclusions of lath-shaped plagioclase and of the other constituents. (See Pl. XIV, *B*.) The minerals which aside from feldspar are on the whole most abundant and which are always present are quartz and pyroxene, but neither of these is conspicuous. The pyroxene is of a very pale green variety, and where it is not intergrown with hornblende the outlines of its small, evenly disseminated crystals are difficult to trace, and the only hint of its presence that the eye receives at a glance is the tinge it gives to the rock. More or less amphibole is present in nearly all specimens and is conspicuous by reason of its darker tone. Biotite is less common than amphibole.

The constituents revealed by the miscroscope in all varieties of the pyroxene aplite are soda-lime feldspar, alkali feldspar, quartz, pyroxene, titanite, apatite, magnetite, and zircon, their order of abundance being generally as named. Titanite is always prominent and almost abundant enough to deserve the rank of an essential constituent; apatite and zircon also are more abundant than in most aplitic rocks. Some amphibole is present in most specimens and biotite in many.

The plagioclase is characterized by very marked zoning. The cores locally contain material as basic as sodic bytownite near An_{75}; but the greater part of each crystal is commonly andesine near An_{40} or An_{45}, and this is about the average composition. The outermost portion of the crystal is almost invariably a rather narrow zone of oligoclase-albite (near An_{10}), limited by crystal planes on the inner side but very irregular on the outer side. The alkali feldspar is in some specimens potassic, in others sodic. It will presently be described more fully. The pyroxene is very pale green in thin section. The amphibole, which is pale to moderately deep grass-green, is mostly intergrown with the pyroxene; its abundance is likely to be in inverse ratio to that of the pyroxene, and it is certainly in great part secondary, though clearly original hornblende partly bounded by its own crystal planes also occurs. The other minerals have no noteworthy peculiarities except as regards their crystallographic development.

Some idea of the highly characteristic fabric of these rocks is conveyed by Plate XIV, *A* and *B*. The plagioclase and to a less extent the ferromagnesian minerals and titanite tend to crystallize with some approach to idiomorphism. Alkali feldspar and quartz, however, are almost wholly allotriomorphic; where they are abundant they form large poikilitic grains, and where they are scarce they form interstitial anhedra. Close scrutiny shows that the minerals can not be simply divided as of a first and a second generation, for a characteristic general sequence can be traced through the whole list. The minor accessories, zircon, apatite, and magnetite, separated early and in the order named. Plagioclase usually came next, being commonly enwrapped in titanite, which is itself inclosed in the ferromagnesian constituents. The biotite is virtually contemporaneous with amphibole and pyroxene and is commonly intergrown with them. Quartz and alkali feldspar are evidently the latest constituents of all and are as a rule nearly contemporaneous, though some of the quartz is partly idiomorphic against microcline. The usual order, therefore, is zircon, apatite, magnetite, plagioclase, titanite, ferromagnesian constituents, quartz, and alkali feldspar.

There are exceptions to this order, however, and the minerals tread on one another's heels. Intergrowths of the ferromagnesian minerals with quartz and alkali feldspar are common, and in one place veins of alkali feldspar penetrate the soda-lime feldspar. The relative amounts of alkali feldspar, quartz, and diopside vary somewhat widely, the two first named being in some specimens very subordinate.

The general features of the pyroxene aplites having been described, some account will now be given of the alkali feldspar, which is partly of an uncommon kind, and of the scapolite, wholly or partly primary, which occur in some of these rocks.

ALKALI FELDSPAR.

The alkali feldspar of some of the aplites is orthoclase, or more commonly microcline, as in the rock shown in Plate XIV, *A*. Some is but slightly perthitic; a part is considerably veined with albite.

In about half the specimens, however, the alkali feldspar is of a peculiar sodic variety. Plate XIV, *B*, shows two features in which this feldspar resembles the microcline—the interstitial relationship to other minerals and the fine cross-hatching that appears in sections nearly normal to the *a* axis. That the feldspar is not microcline, however, is proven by comparison of its refractive indices with those of the oligoclase-albite rims of the soda-lime feldspar crystals. Although the average index of the interstitial feldspar was distinctly the lower, its maximum was greater than the minimum for the other, whereas the maximum for microcline is less than the maximum for pure albite. Further optical and chemical tests led to the conclusion that the feldspar is anorthoclase, richer in soda than most that have been described and optically near to albite. Its optical sign is positive.

SCAPOLITE.

Scapolite was found in two areas of pyroxene aplite.

The rock in which scapolite is most abundant, and in which the evidence of its primary character is strongest, forms a small dike in limestone east of Foster Creek. When a hand specimen is turned about the light flashes from the bright cleavage faces of many highly poikilitic grains, some of which are as much as 2 centimeters across. The microscope shows that the largest of these, at least, are scapolite.

A thin section is shown in Plate XIV, *A*. The microscope shows the prominent constituents of the rock to be scapolite, plagioclase, microcline, diopside, hornblende, and titanite. The morphologic features of the minerals apart from scapolite are those already described as characteristic of the group, except for the extremely ragged forms of the pyroxene and amphibole; and the plagioclase has its usual character. Quartz in poikilitic grains is moderately abundant. The alkali feldspar is a clear fresh microcline with very little perthitic veining, and also forms poikilitic individuals whose greatest observed diameter is about 6 millimeters, nearly the same as that of the quartz.

The most remarkable exemplification of poikilitic habit, however, is presented by the scapolite, whose character is somewhat inadequately shown in Plate XIV, *A*. The thin section is simply a slice from a single individual of this mineral crowded with inclusions. In polarized light its uniform interference color shows it to be crystallographically continuous over the entire diameter of the slide—about 2.5 centimeters.

The scapolite is not merely poikilitic with respect to the other constituents, but with respect to most of them pegmatitic as well. It interpenetrates with plagioclase, diopside, hornblende, and titanite. The single essential mineral not thus penetrated is quartz, and the exception doubtless depends on the fact that scapolite differs from soda-lime feldspar chiefly in containing less silica. The boundaries between scapolite and the other minerals are irregular. In parts of the slide the scapolite is abundant and forms a continuous area in which the other minerals lie scattered; but elsewhere it is subordinate and lies in fragmentary lacelike patches, whose luminous yellow interference color sets them in a vivid and beautiful contrast to the cool gray tones of the feldspar, which can not be rendered by an ordinary photograph.

The proportion of scapolite in the rock, though difficult to measure precisely, has been estimated from measurements by the Rosiwal method at about 25 per cent. Its double refraction is about 0.020, which indicates a combination containing more of calcic than of sodic molecules.

One of the points bearing on the origin of the scapolite is the degree of freshness of the rock. The principal alteration is uralitization of the pyroxene, the amphibole intergrown with it being much more abundant in certain parts of the slide than in others and evidently for the most part secondary. Some deep-colored, undoubtedly primary hornblende appears, however. The basic parts of the plagioclase are a little sullied with sericite, zeolite, flecks of calcite, and grains of epidote. Curious patches of calcite and zeolite, mostly inclosed in scapolite, may possibly be due to alteration, but they are more probably either inclusions or cavity fillings. (See Pl. XIV, *A*.) On the whole, the rock impresses one as more than ordinarily fresh.

The other scapolite-bearing pyroxene aplite occurs about 1 mile northeast of Rumsey Mountain. It is a greenish-white rock of sugary texture, in which neither ferromagnesian constituents nor any poikilitic mineral are conspicuous.

The original constituents revealed by the microscope are, in estimated order of abundance, soda-lime feldspar, quartz, alkali feldspar, scapolite, pyroxene, titanite, hornblende, apatite, and zircon. The alkali feldspar is of the sodic variety described on page 122.

The scapolite is far less abundant than in the other rock. It appears in lacelike patches intergrown with both soda-lime feldspar and alkali feldspar, but chiefly with the more calcic parts, and is most abundant in the cores of the zoned crystals. It maintains the same orientation over areas of as much as 5 millimeters in variously oriented grains of feldspar. The rock is even fresher than the other, for the pyroxene is not at all uralitized and the feldspar but slightly clouded.

The chemical composition of the two scapolite-bearing aplites is shown in the following detailed analyses:

Analyses of scapolite-bearing pyroxene aplites.

[W. F. Hillebrand, analyst.]

	1.	2.		1.	2.
SiO_2	68.00	57.98	Li_2O	None.	Trace.
TiO_2	.43	.66	H_2O-	0.06	0.57
ZrO_2	.02	.04	H_2O+	.25	.67
Al_2O_3	16.33	19.32	P_2O_5	.22	.17
Cr_2O_3	None.	None.	CO_2	None.	.53
Fe_2O_3	.26	.44	S	.01	.01
FeO	.70	.83	Cl	.13	.17
MnO	.02	.07	F (high?)	.07	.07
CaO	5.90	8.87			
SrO	.03	.05		100.45	100.13
BaO	.03	.12	Less O for Cl and F	.06	.07
MgO	1.41	1.93			
K_2O	.38	4.01		100.39	100.06
Na_2O	6.20	3.62			

1.—Pyroxene aplite with a little scapolite, from a point 1½ miles northeast of Rumsey Mountain.
2.—Pyroxene aplite with much scapolite, from dike on east wall of Foster Creek canyon, 1 mile north of Granite-Deer Lodge county boundary.

The analyses were made on powder of 100-mesh size; hence the results for H_2O and FeO are probably very near right.

The norms of the rock, calculated in order to determine their position in the American quantitative classification, are as follows:

1. *Pyroxene aplite northeast of Rumsey Mountain.*

Quartz	19.98		Salic, 89.08
Orthoclase	2.22	Feldspar, 69.10	
Albite	50.30		
Anorthite	16.68		
Halite (NaCl)	0.47		
$CaSiO_3$	4.06	Diopside, 7.75	Femic, 10.71
$MgSiO_3$	2.90		
$FeSiO_3$	.79		
$MgSiO_3$	.80	Hypersthene, 1.06	
$FeSiO_3$	.26		
Magnetite	.46		
Apatite	.67		
Ilmenite	.61		
Fluorite	.16		
Total	99.79		

The rock is amadorose (I.4.3.5).

2. *Pyroxene aplite east of Foster Creek.*

Quartz	4.56		Salic, 83.18
Orthoclase	23.91	Feldspar, 77.53	
Albite	27.77		
Anorthite	25.85		
Halite	.59		
$CaSiO_3$	6.15	Diopside, 12.67	Femic, 16.83
$MgSiO_3$	4.80		
$FeSiO_3$	1.72		
Wollastonite	1.39		
Magnetite	.70		
Ilmenite	1.22		
Apatite	.34		
Fluorite	.11		
Total	99.91		

The rock is a monzonose (II.5.2.3), not far from shoshonose, which is less alkalic.

The most striking common feature of the two chemical analyses is great richness in lime opposed to comparative poverty in iron and magnesia. In both, also, titanium and chlorine are rather high. The rock richer in scapolite is notably richer in lime and a little richer in magnesia and iron. The most striking contrast is in the alkalies; the Rumsey Mountain rock is remarkably poor in potash, but contains about twice as much soda as the other. It is noteworthy, however, that the total molecular proportion of alkalies is nearly the same in the two rocks (0.091 for specimen 1; 0.104 for specimen 2).

In the norms, the differences of the analyses are again expressed by differences in the proportion of feldspars and pyroxenes. The presence of scapolite is not suggested in the norm of 1 except by the halite; the soda molecule of scapolite being equivalent to three molecules of albite plus one of halite. In specimen 2, the rock richer in scapolite, the norm contains not only halite but wollastonite, which indicates an excess of lime over the proportion that might combine with magnesia and iron as diopside and with alumina as anorthite. The quartz in the norm is probably lower than that in the mode, for the wollastonite and anorthite of the norm are equivalent to lime scapolite plus quartz, as is shown by the following equation:

$$CaSiO_3 + 3CaAl_2Si_2O_8 = Ca_4Al_6Si_6O_{25} + SiO_2.$$

GENESIS.

Three questions of genesis are raised by the pyroxene aplites. First, is the sodic alkali feldspar original or secondary? Second, is the scapolite original or secondary? Third, what is the cause of the chemical peculiarities of the rocks?

Although the sodic alkali feldspar has no features that obviously suggest a secondary character, more than one difficulty stands in the way of supposing it original. To support that hypothesis it is necessary to explain why a group of rocks so similar in most features should display extreme variation in the proportion of alkalies, and to account for the sharp contrast between the subhedral and interstitial feldspar where the latter is sodic.

An alternative hypothesis is that the sodic interstitial feldspar has been formed by the replacement of potash feldspar, a reaction which seems to be possible under certain conditions. That such a replacement has taken place in the pyroxene aplites of this quadrangle is suggested by the similarity in habit between the potassic and sodic alkali feldspars, and the complementary relation between the alkalies in the two specimens analyzed. On the other hand, it is hard to conceive how a thorough replacement of one constituent could be effected without considerable alteration of the others, yet the alkali feldspar is sodic in some of the freshest specimens. Again, the question arises where the displaced potash found a lodgment. It was not in the rocks themselves, but it may have been in the orthoclase-rich hornstones to which some parts of the Newland formation have been metamorphosed.

The most direct evidence of replacement would be given by a series of sections that showed several stages in the process. In the sections examined the alkali feldspar is either all sodic or predominantly potassic. There is, however, a notable difference in the amount of soda feldspar intergrown with the potash feldspar; the freshest microcline, that of the Foster Creek dike, is hardly at all perthitic, but in other specimens the perthitic character is marked, and soda feldspar forms some comparatively large patches in the potash feldspar. The perthitic veins can sometimes be observed to have the same orientation as the large subhedral crystals to which they are adjacent. These phenomena suggest the incipience of a process which, carried to its limit, would result in the conditions observed in the rocks where the alkali feldspar is wholly sodic.

The evidence on the whole is believed to indicate the secondary character of the interstitial soda feldspar.

The pyroxene aplites are remarkable in containing soda feldspar that may be secondary and in containing scapolite. A possibility naturally suggested by the association of these two soda-rich minerals is that both may have been formed by the action of sodic vapors or solutions upon the rock after its solidification. This hypothesis, however, seems contradicted by the fact that scapolite is most abundant in the rock where the alkali feldspar is microcline free from perthitic veining. The scapolite, therefore, does not appear to be intimately related in origin to the soda felspar, and its genesis may be considered separately. The best material for study of the scapolite problem is the aplite of the Foster Creek dike, where the mineral is most abundant.

Nothing obviously suggests that the scapolite of this rock is secondary, yet the hypothesis of its secondary origin should be examined. If the mineral is secondary, it must have been formed either by replacing other minerals or by filling in cavities or fissures. The only fact suggesting replacement is the intimate penetration of most of the other minerals by veinlets of scapolite not unlike those sometimes formed by calcite when it partly replaces feldspar. The main part of the scapolite occurs, however, not in these veinlets, but in large poikilitic masses whose textural relation to the plagioclase and other minerals of early crystallization is similar to that of the quartz and microcline. The only mineral that the scapolite can conceivably have replaced to any considerable extent is the microcline. There is not the least evidence, however, that it has done so; its contacts with the microcline are sharp, and the microcline is about as abundant as the alkali feldspar in any other specimen of the pyroxene aplite.

It is even more difficult to imagine the formation of the scapolite by filling of open spaces. The aplite can never have contained original cavities of such great bulk and such intricate form as the space now occupied by the scapolite; and there is no indication that the rock has been shattered, as it must have been to an extreme degree if the scapolite was deposited in fissures.

Secondary formation of the scapolite in the Foster Creek dike is, in short, impossible to conceive, and the mineral must be regarded as primary. The rock of the area near Rumsey Mountain does not in itself present so plain a case. Essentially, however, it differs from the rock already discussed only by being less rich in scapolite.

Despite the extreme rarity of primary scapolite, there is no inherent reason why it should not occur in rocks sufficiently low in alumina, iron, and magnesia, and rich in lime and chlorine. If not enough alumina is present to combine with the lime as feldspar, and silica is abundant, it would seem on theoretic grounds that the lime and silica should form feldspar and wollastonite. The determining factor, however, may be the presence of considerable chlorine in the magma and its retention throughout the process of solidification. The fact that the Rumsey Mountain scapolite-bearing rock contains enough alumina, theoretically, to form feldspar indicates that this is true.

That abundant chlorine was given forth by the Philipsburg and Cable intrusions is shown by the local abundance of scapolite in their contact zones.[1] Little or none of this gas was retained in the granodiorites, but favorable chemical or physical conditions caused some of it to become fixed in the aplites.

Whatever the relative importance of the factors determining the formation of primary scapolite, a certain richness in lime seems to be favorable, if not essential. At any rate, the pyroxene aplites as a group have an abnormal richness in lime. The general explanation of this can not be unrelated to the fact that these rocks are always found near calcareous sediments. It is strongly believed that they have been formed by the absorption of limestone in siliceous alkaline magmas resembling those of normal aplites. The only other primary scapolite of which a description has been found occurs in rocks that have absorbed limestone.[2]

[1] It has been shown by A. Brun (Recherches sur l'exhalaison volcanique, Geneva and Paris, 1911, p. 74) that abundant chlorine is given off by most volcanoes.

[2] Adams, F. D., The nepheline and associated alkali syenites of eastern Ontario: Trans. Roy. Soc. Canada, 3d ser., vol. 2, section 4, 1909, p. 19.

CHAPTER VII.

SOME FEATURES OF THE IGNEOUS METAMORPHISM.

GENERAL PHENOMENA.

The effects of igneous metamorphism upon each of the sedimentary formations has been described more or less fully in the preceding pages. The most extended descriptions of particular metamorphic rocks are to be found in the following places:

Pure quartzites, in the descriptions of the Neihart and Flathead quartzites (pp. 37, 52).

Rocks consisting essentially of quartz and mica, in the descriptions of the Ravalli and Spokane formations (pp. 40, 47).

Rocks containing abundant cordierite, andalusite, or sillimanite, in the descriptions of the Prichard, Spokane, and Silver Hill formations (pp. 38, 48, 54).

Rocks characterized by abundant lime silicates, including pyroxene, amphibole, garnet, vesuvianite, epidote, scapolite, etc., particularly in the description of the Newland formation (pp. 43–44), but also in that of the Silver Hill formation (pp. 54–55), and of the shale member of the Hasmark formation (pp. 60–61).

Rocks characterized by forsterite together with other magnesian silicates in an abundant matrix of carbonate, in the descriptions of the Hasmark, Jefferson, and Maywood formations (pp. 60, 65, 66).

Limestones with abundant tremolite, in the descriptions of the Madison and Jefferson limestones (pp. 66, 69).

Limestones subjected to strong metamorphism without any considerable development of silicates, in the descriptions of the Madison and Jefferson limestones (pp. 66, 69) and the Hasmark formation (p. 60).

Notes on the distribution of particular minerals are to be found in the chapter on mineralogy (pp. 152–162).

In this chapter an attempt will be made to throw into relief some of the more interesting features of the metamorphism.

Perhaps few districts of equal size exemplify the phenomena of igneous metamorphism so richly as the Philipsburg quadrangle, where sedimentary rocks comprising almost every common type are to be seen both in their unaltered state and in a state of extreme alteration. The abundance and diversity of the phenomena are indeed so great as to be in some degree unfavorable to fruitful study of metamorphism. The heterogeneity of the sedimentary mass and the overlapping effects of various intrusions make it hard to disentangle the several factors that have determined the character of any given metamorphic rock. The conditions forbid the quantitative study of certain familiar changes that do not necessarily involve transfer of material, as, for example, the simple recrystallization of pure quartzites and limestones and the recombination of the original elements to form new minerals in calcareous or aluminous shales.

More especial interest attaches to changes that involve transfer of material from magma to sedimentary rock, and of this action there is much clear evidence in the Philipsburg quadrangle. The minerals that most clearly show transfer of material are those containing elements not found in the unaltered sedimentary rocks but common in exhalations from igneous magmas. Such minerals are those of the humite group and fluorite, containing fluorine; tourmaline and ludwigite, containing boron; and scapolite, containing chlorine.

The magnetite bodies found at the contacts of igneous rocks with limestones give equally clear evidence of transfer accompanied, however, by replacement. Replacement of limestone by quartz has been clearly proved, but it is not clear that igneous metamorphism has been concerned in the process.

Of more doubtful bearing are minerals whose constituents are found in the unaltered rocks but which are so abundant in the altered rocks as to suggest accession of certain constituents from the magmas. Such minerals are tremolite, which is most abundant in the Madison, the least magnesian of the Paleozoic limestones; alkali feldspars, abundant in some of the metamorphosed calcareous sediments; and quartz, so abundant on the whole in these same sediments as to suggest that they have derived silica from magmatic solutions.

MATERIALS TRANSFERRED IN METAMORPHISM.

To recapitulate, there is evidence that metamorphism has involved the transfer to the sediments of chlorine, fluorine, boron, iron, soda, potash, magnesia, and silica. Each of these in turn may be briefly considered.

CHLORINE.

The only metamorphic mineral in the quadrangle that contains chlorine is scapolite. This mineral is most abundant in the metamorphic collar of the Philipsburg granodiorite batholith and that of the slightly more basic but similar Cable batholith, but it is localized even within these contact zones, being absent, so far as observed, from the north side of the Philipsburg mass and from the south side of the Cable mass. Outside these contact zones, the mineral occurs rather sporadically; small quantities are present in the basin of Warm Spring Creek, but none has been found in the high part of the Anaconda Range. These facts of distribution are independent of the distribution of the sedimentary rocks. Scapolite occurs most abundantly in calcareous shales like those of the Newland formation and less abundantly in certain fairly pure limestones. These rocks are abundant in the areas of metamorphism where scapolite does not occur, and afford evidence, if evidence were needed, that the chlorine is of magmatic, not sedimentary, origin.

The chlorine of scapolite is in combination with sodium, and proportional to it in quantity. In a scapolite with the composition Me_2Ma_1, which is near the average composition of the metamorphic scapolites of the Philipsburg quadrangle, the chlorine percentage is 1.35. A hornstone containing 20 per cent of such a scapolite, a proportion not uncommon, therefore contains 0.27 per cent of chlorine by weight. This, if released under ordinary conditions of temperature and pressure, would occupy a volume about twice that of the containing rock; the Philipsburg batholith, therefore, has given off a quantity of chlorine measurable in cubic miles. Locally the proportion of chlorine is considerably higher than that just estimated. Some of the Newland rocks contain about 50 per cent of scapolite almost purely sodic, and their chlorine content therefore amounts to about 2 per cent.

FLUORINE.

Fluorine is a constituent of the humites, fluorite, and ludwigite. These minerals have a more restricted distribution than scapolite and are less abundant. The humites have been found mainly in the area south of the great Mount Powell batholith of porphyritic granite. They are abundant in the immediate vicinity of its contact, and also occur several miles away from it, in an area where the effects of several intrusions overlap. The intrusion most nearly central to the chief area in which humites are found is the soda-granite of Lost Creek, which contains fluorite, and therefore seems the most probable source of the fluorine in this area.

The only other part of the quadrangle in which humites have been found is near Philipsburg, where they occur in association with the rare magnesium-iron borate ludwigite. This occurrence indicates that the magma that solidified as the Philipsburg batholith gave off fluorine, though in far less abundance than chlorine. The humites, indeed, form on the whole much smaller portions of the rocks in which they occur than do the scapolites.

Fluorite as a constituent of a metamorphosed sediment has been found only at one locality, near the head of Mill Creek, where it occurs in an altered calcareous shale with oligoclase, lithia mica, margarite, corundum, etc. The source of the fluorine here, again, is uncertain, for the area is one of superimposed contact zones, but much fluorine has been found in a somewhat decomposed two-mica granite a mile or two eastward. Possibly the fluorine emanated from this magma while it was cooling and attacked a part of the intrusion.

BORON.

Boron is a constituent of tourmaline and ludwigite. Ludwigite is known to occur in the quadrangle only at the Redemption iron mine near Philipsburg. Tourmaline, on the contrary, is one of the most common and widely distributed metamorphic minerals. It occurs chiefly in metamorphosed noncalcareous shales and sandstones throughout the quadrangle, even in places where there is little other evidence of igneous metamorphism. For this reason, its metamorphic origin is not altogether evident. The secondary nature of the mineral is clear, however, from its development in crystals that show no sign of attrition and that are larger than the associated clastic grains of quartz. Although the amount of tourmaline is by no means proportional to the intensity of metamorphism, the mineral is, broadly speaking, incomparably more abundant in the areas where some metamorphism is manifest than in those where no traces of metamorphism appear. Moreover, the common occurrence of tourmaline in pegmatites attests the presence of boron in magmas and indicates the only probable source of that in the metamorphic rocks.

IRON.

There is no clear evidence that iron has been abundantly transferred to the sediments except in the form of magnetite, though it has probably been transferred in small quantity as sulphide and as a constituent of garnet and other silicates close to igneous contacts. The magnetite deposits alone will be discussed in detail.

All the magnetite bodies of the Philipsburg district occur at or near the contact of calcareous sedimentary rocks with intrusive rocks, and their metamorphic genesis is therefore manifest. The formation of the iron ore differs radically, however, from that of scapolite in this respect: Scapolite is formed by the combination of elements in the rock with others emanating from the magma, whereas the iron ore, the purest masses of which are developed in limestone free from iron, is formed essentially by replacement.

That replacement is the process by which these ores are formed is indicated by the forms of the magnetite bodies, which are irregular in the large, and also in detail, as shown in Plate IX, *B* (p. 60). The same illustration shows, on a small scale, irregular masses completely surrounded by limestone. Replacement is further indicated by the fact that the highly impure masses of iron ore associated with the metamorphosed calcareous shales preserve traces of the bedding. None of the magnetite has been observed to form fissure fillings.

The invariable association, in relations that indicate contemporaneous growth, of the magnetite with various metamorphic silicates (Pls. IX, *A;* XV, *B*), indicates that the deposition is a phase of contact metamorphism in the strict sense, rather than an after effect.

Two facts of paragenesis appear specially significant as indicating in what sort of solutions the iron was transferred. These are the constant occurrence of forsterite or iron-poor olivine in the purer bodies of magnetite, and the abundance of scapolite in the contact zones that have magnetite bodies, the scapolite being in a few places intimately associated with magnetite. These facts indicate that the iron-bearing solutions contained silica, soda, and chlorine. The iron may have been transported as chloride and deposited according to reactions suggested by Leith and Harder [1] for similar magnetite bodies in Utah. Oxidation is supposed by these authors to be effected by water according to the following reaction:

$$3FeCl_2 + 4H_2O = Fe_3O_4 + 6HCl + H_2.$$

[1] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: Bull. U. S. Geol. Survey No. 338, 1908, p. 77.

Limestone effects the precipitation of magnetite by neutralizing the hydrochloric acid, in which Fe_3O_4 is soluble. The entire reaction may be written thus:

$$3FeCl_2 + 4H_2O + 3CaCO_3 = Fe_3O_4 + 3CaCl_2 + 3H_2O + 3CO_2 + H_2.$$

The resulting $CaCl_2$, generally after further transportation, may go to form scapolite. A possible reaction is:

$$4CaCl_2 + 15Al_2O_3 + 78SiO_2 + 16Na_2O = Ca_4Al_6Si_6O_{25} + 8Na_4Al_3Si_9O_{24}Cl.$$

SODA.

The abundance of sodic feldspar and of scapolite in certain of the metamorphic rocks suggests a transfer of soda in the process of metamorphism. Inasmuch as soda is also an essential constituent of tourmaline, it is possible that the presence of this mineral likewise implies transfer of soda, but the maximum amount of soda in the tourmaline of any rock is so small that it is difficult to prove that it was not all contained in the unaltered rock.

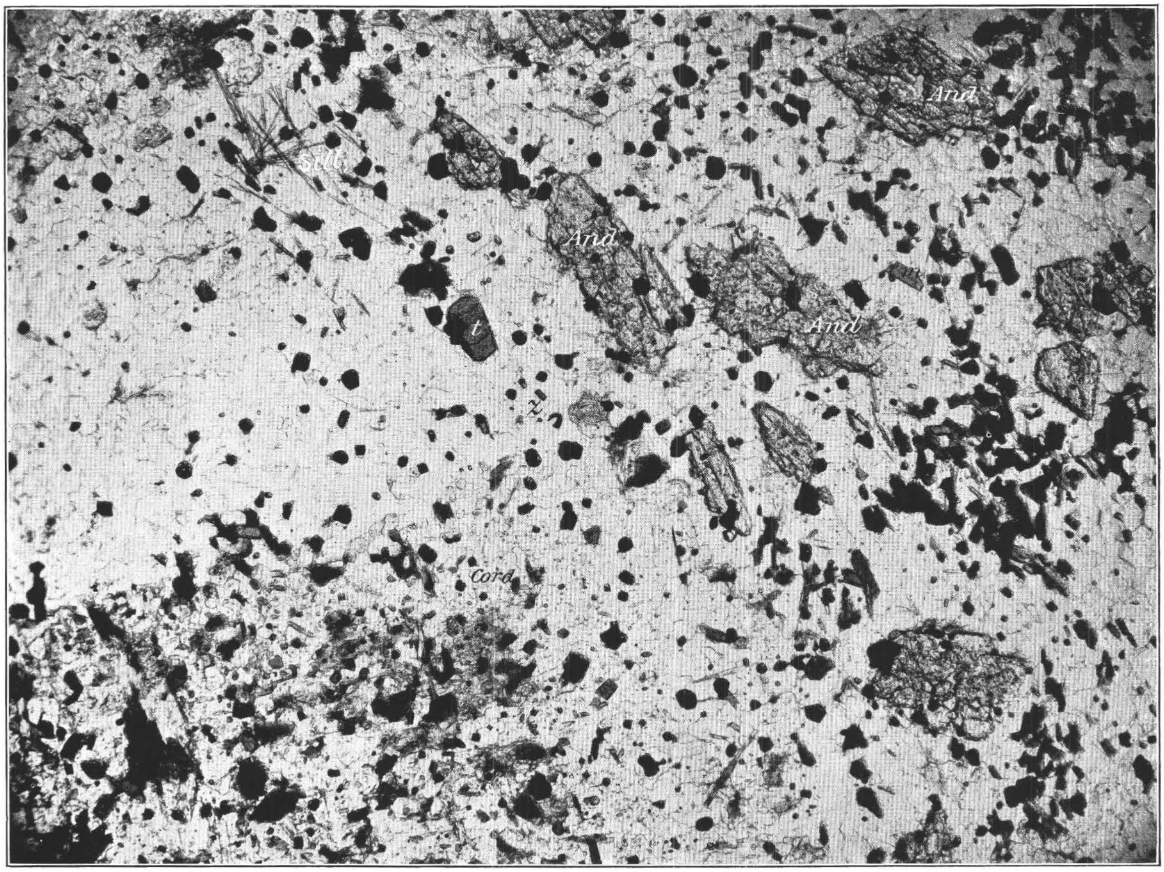
Scapolite, on the contrary, is locally so abundant as virtually to prove the transfer of soda, even though the chemical data for a quantitative demonstration are wanting. In a specimen of metamorphosed Newland rock obtained near Rumsey Mountain estimated to contain 50 per cent of almost purely sodic scapolite, the soda content should be about 7 per cent. Even with 20 per cent of the scapolite Me_2Ma_1 there would be nearly 2.5 per cent of soda. The soda in the unmetamorphosed Newland rock, an analysis of which is given on page 44, amounts only to 0.43 per cent, and in two hornstones rich in orthoclase it does not exceed 1 per cent. It is possible that much of the sodium given off by the magma was in the form of sodium chloride. Apparently, however, an excess of soda over the amount required to form halite was imported locally, for albite occurs in association with the scapolite. Albite is also found in some scapolite-free hornstones in the Newland in sufficient quantity to suggest, though hardly to prove, accession of soda.

POTASH.

The potash-bearing minerals of the metamorphic rocks are micas and feldspars. As both sericite and orthoclase are present in most of the rocks except pure quartzites and limestones, even where they are not perceptibly metamorphosed, it is difficult to prove accession of potash even in the metamorphosed rocks that are especially rich in potash-bearing minerals, except by a large number of chemical determinations. Such conclusive evidence is not at hand, and in its absence the belief that metamorphism has locally been attended by transfer of potash must rest on impression rather than proof.

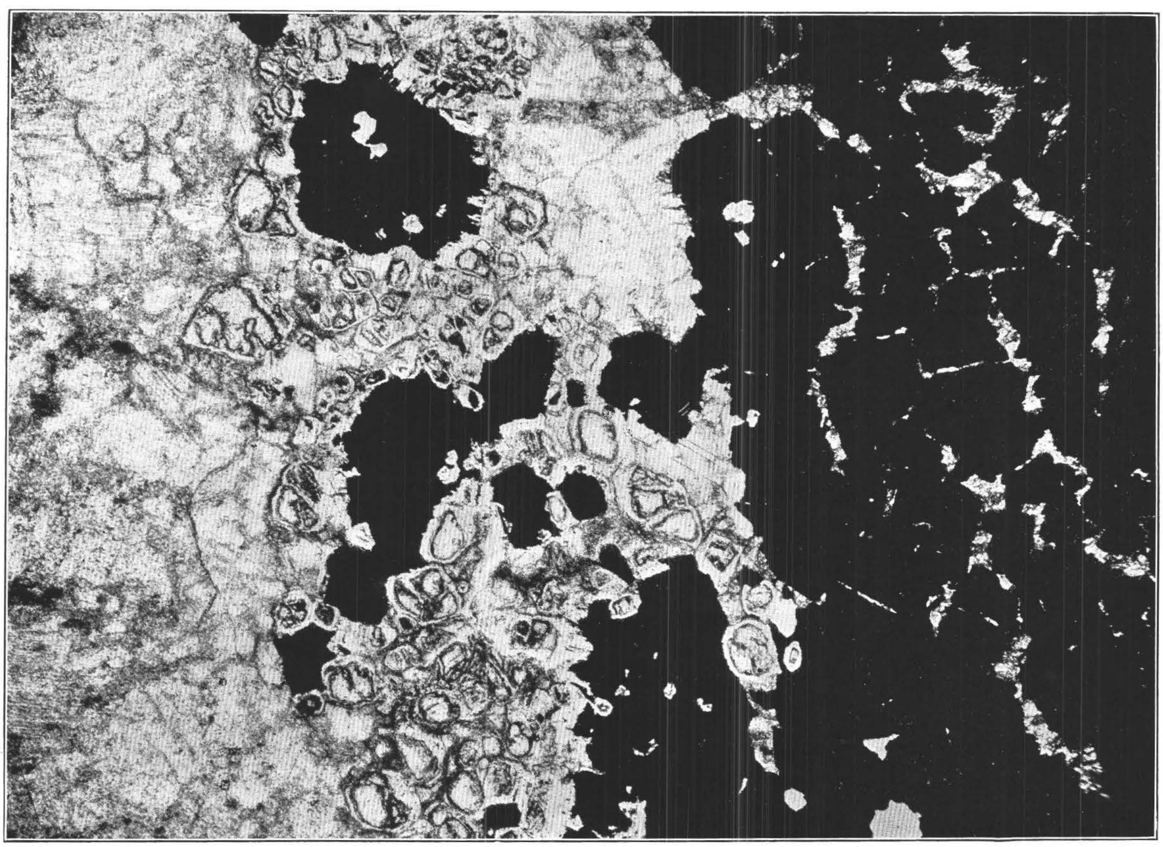
Potash enrichment is strongly suggested in certain hornstones derived from shales in the Newland, Spokane, and Silver Hill formations, in which orthoclase occurs abundantly with little or no quartz. (See Pl. XV, *A*.) Chemical evidence in regard to them is not conclusive, however. Analyses of an orthoclase-rich hornstone derived from the lower part of the Silver Hill and of an almost unaltered specimen from the same horizon showed no appreciable difference in the potash content, which had the remarkably high value of more than 7 per cent. On the other hand, partial analyses of two feldspathic hornstones from the Newland showed potash percentages of 3.6 to 4.9, about twice as great as that in a specimen of unmetamorphosed Newland rock, which was 2.1 per cent. A comparison based on analyses of two or three specimens from the thick and somewhat heterogeneous Newland formation has less value than in the case of the relatively thin and homogeneous lower shale of the Silver Hill formation. So far as it goes, however, the evidence confirms the impression of potash enrichment in the Newland.

A still stronger suggestion of potash enrichment is given by large poikilitic microclines in certain hornstones rich in diopside and amphibole, close to the contact with granitoid rocks whose pegmatites contain microcline of similar habit. This phenomenon, however, is rather sharply localized, and may be considered a mere marginal reaction between sedimentary and igneous rock.



A. THIN SECTION OF CORDIERITE HORNFELS RICH IN ORTHOCLASE, FROM LOWER PART OF SILVER HILL FORMATION, NEAR CONTACT WITH CABLE BATHOLITH.

Shows large poikilitic crystal of cordierite (*Cord*), and smaller crystals of andalusite (*And*), sillimanite (*Sill*), tourmaline (*t*), magnetite (*m*), zircon (*z*), and biotite (dark, partly transparent), in a matrix composed essentially of polyhedral grains of orthoclase. Ordinary light. Enlarged 55 diameters.



B. THIN SECTION ACROSS MARGIN OF MAGNETITE BODIES SHOWN IN PLATE IX, *B.*

Shows magnetite (black) with veins of calcite and serpentine, separated from the main mass of limestone by aggregates of round grains of iron-poor olivine, altered to serpentine on margins and cracks. Ordinary light. Enlarged 55 diameters.

That potash has been carried far from contacts is more definitely indicated by the remarkable occurrence of orthoclase crystals in the lower Madison limestone. Their association with scapolite is significant, for the presence of this mineral indicates the importation of soda and chlorine by magmatic emanations which may well have imported potash also. The unaltered limestone of this horizon contains a little finely divided mica, but this does not appear sufficient in quantity to furnish potash for the orthoclase, which is fully as great in quantity as the total material insoluble in hydrochloric acid of the partial analysis on page 68.

MAGNESIA.

Possible importation of magnesia deserves consideration as regards cordierite, which develops in hornstones derived from shales with little or no carbonate, and tremolite, which is most abundantly developed in the magnesium-poor Madison limestone.

With respect to cordierite, the chemical evidence in hand does not confirm the hypothesis that it indicates importation of magnesia; on the contrary, comparison of the two analyses of rocks from the lower part of the Silver Hill formation (p. 57), shows a distinctly lower percentage of magnesia in the cordierite hornstone than in the little-altered shale.

In regard to the abundance of tremolite in the Madison limestone, a partial analysis of which gives only 0.74 per cent MgO compared with 50.48 per cent CaO, two explanations are possible. One is that magnesia is imported; the other is that the small proportion of magnesia in the rock is segregated in tremolite. For the former interpretation no support can be offered beyond the fact that the tremolite is too abundant in places to have been formed by concentration of less than 1 per cent of MgO in the adjacent part of the rock mass. The hypothesis of segregation is supported by independent evidence that magnesia tends more strongly than lime to combine with silica. In the magnesian limestones of the Hasmark formation, for example, the lime-free magnesian silicates, forsterite and phlogopite, form abundantly and lime silicates are scarce or absent.

On the whole there is no strong evidence of the importation of magnesia by magmatic solutions. Even if magnesia has been added to certain limestones it may have been derived from other limestones rather than from magmatic sources.

SILICA.

As silica is a constituent of nearly all sedimentary rocks, the proof of its importation, more than of that of most other substances, must depend on quantitative chemical work, of which little is available for the present purpose. The only sedimentary rocks in which silica is not quantitatively important are the purer limestones, and it is in these that acquired silica is most likely to be detected without comparative analyses.

Evidence of local silicification has been observed at two or three places where limestones are transformed to rocks rich in garnet and diopside for a few inches from igneous contacts. Action of this sort, however, does not invariably occur at the irruptive contacts with limestone.

Wider diffusion of magmatic silica is suggested by the presence of the isolated crystals of silicates in limestones apparently almost free, before metamorphism, from any minerals but the carbonates. Among these are scapolite, diopside, tremolite, and forsterite. In respect to most occurrences of these minerals, the argument regarding silica must follow the same lines, and reach the same indefinite conclusion, as that regarding magnesia in tremolite. This mineral is most abundant in the vicinity of chert nodules, and these nodules furnish a conceivable source for the silica, although it must have migrated considerably if thus derived. The strongest evidence, perhaps, for influx of magmatic silica is presented by the forsterite of the magnesian limestones, particularly that associated with magnetite. The microphotograph shown in Plate XV, *B*, may almost be said to furnish ocular proof of the formation of forsterite in limestone virtually free from silica. The fact that silica has been introduced here furnishes a presumption that the formation of silicates elsewhere has depended in a measure upon influx of magmatic silica.

The few analyses bearing on this problem are those of rocks from the Newland formation and the lower part of the Silver Hill formation, already several times referred to. The analysis of unaltered Newland rock shows 45 per cent SiO_2, compared with 56 to 59 per cent in the metamorphosed Newland rock; that of the little-altered shale of the Silver Hill formation shows 53 per cent, compared with 63 per cent in the hornfels derived from it. A substantial increase of silica, greatest for the highly calcareous Newland rocks, appears in each case. So consistent a difference in the silica content of the altered and unaltered rocks must be considered as inductive evidence that silicification was one of the factors of metamorphism. Obviously, it is not conclusive proof; that could be supplied only by many analyses of material collected with the purpose clearly in view. It is well, however, to consider whether there is any deductive evidence that metamorphism of all rocks or of certain species should be attended by enrichment in silica.

It is probable, in the first place, that the solutions emanating from a cooling supersilicated magma are siliceous. Pegmatites may be considered as concentrated aqueous solutions rich in silica and alkalies, and it is probable that the more widely diffused emanations carrying the materials deposited in the metamorphosed sediments are more attenuated solutions of the same nature, related to the pegmatites in composition and therefore siliceous.

If such a solution percolates through heterogeneous sedimentary rocks, in what kinds of rock would the greatest part of the dissolved solids be deposited? If the rocks varied only in being more and less porous, the more porous rocks, by imbibing more of the solution, would presumably retain the larger portion of its load. The porosity of the rocks before metamorphism, however, is not the only matter to be considered. Suppose a shale composed mainly of quartz and carbonates of lime and magnesia to be in process of change to a diopsidic hornstone. In the combination of lime with silica, if no silica were brought in, as Barrell[1] has pointed out in discussing a similar rock, there would be a diminution in volume of about 40 per cent.[2] Now if this reaction could take place under slight pressure, the result would be a sort of highly porous sinter. In fact, of course, the reaction took place under great pressure, which would tend to render the mass compact. It would not do so instantaneously, however, particularly if a liquid or vapor were circulating through the mass, ready to occupy all available spaces. During some period, therefore, though possibly a very brief one, the altering mass of sedimentary rock would be like a sponge saturated with a solution of silica and other substances, some part of which would be added to the rock mass. The same process would take place to a less extent in noncalcareous shales, whose constituents recombine under metamorphic influence to form heavier minerals than the original ones. In chemically simple rocks, such as pure quartzite and limestone, this action would not take place.

If the loss of volume attendant upon metamorphism of silica-carbonate rocks were not compensated by accession of material, there should be some field evidence of the shrinkage. Shrinkage commensurate with that which would occur if there were no accession of magmatic material is certainly not indicated by any conditions observed in the Philipsburg quadrangle, but on the other hand no evidence appears of sufficiently large additions of magmatic material wholly to compensate the loss of volume attendant on simple recombination. The hypothesis here advanced is that a part, but not the whole, of the shrinkage was offset by accessions chiefly of silica and alkalies. It seems possible that considerable shrinkage may have taken place, but that its traces have been obliterated by downward settling and lateral flow of the material, which during the process of metamorphism must have been relatively plastic.

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[1] Barrell, Joseph, Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 149.

[2] See also Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 882.

CHAPTER VIII.

TERTIARY AND QUATERNARY FORMATIONS.

TERTIARY VOLCANIC AND SEDIMENTARY ROCKS.

GENERAL GEOLOGIC RELATIONS.

Rocks of Tertiary age, apart from the intrusives, occupy a relatively small area in the Philipsburg quadrangle. They occur in the valleys of Rock and Willow creeks near the western border of the quadrangle, in Philipsburg Valley, along the lower part of Warm Spring Creek, and in the southeastern corner of the quadrangle on the flank of the Anaconda Range.

All these rocks are strongly unconformable on those that have been described in the preceding pages. They lie on various older formations indiscriminately, are not metamorphosed by the intrusions, and, though they have been tilted and faulted, are much less deformed than the Cretaceous and earlier rocks. The Philipsburg quadrangle does not afford the best opportunity to determine either the absolute or the relative age of the Tertiary formations. Near Drummond and Anaconda the rocks of late Cretaceous and Tertiary age are much more completely represented, and although time could not be taken to study these localities thoroughly the results of some observations made there will be utilized for the following brief discussion of the Tertiary rocks within the Philipsburg quadrangle.

The units adopted for mapping are early gravels, andesitic tuff-breccia and lava, volcanic ash, and terrace gravels.

The early gravels are more or less consolidated, considerably tilted and faulted, and much eroded. In places they have been beveled and are overlain by later gravel. The several occurrences of these are probably of different ages, for some are underlain and some overlain by volcanic rocks that, so far as known, are of one age.

On Warm Spring Creek, for example, east of the boundary of the quadrangle, are conglomerates with many volcanic pebbles, interbedded with sandstones, shales, and tuffs. These rocks are overlain with apparent conformity by a thick mass of tuff without conglomerate, and all these unconformably by soft conglomerate with almost no volcanic pebbles. The upper and perhaps the lower conglomerate are represented in the quadrangle.

Tuffs and tuff-breccias, chiefly andesitic, probably corresponding to those between the two conglomerates, occupy several areas in the southeastern part of the quadrangle. Far to the northwest, on Willow Creek, are a few small remnants of andesitic flows, which may tentatively be supposed contemporaneous with these tuffs.

In Philipsburg Valley and Willow Creek valley are exposures of light-colored silty material, which microscopic examination shows to be chiefly volcanic ash. These deposits correspond in character to beds well exposed near New Chicago, north of the quadrangle, from which Douglass (p. 24) has collected vertebrate fossils indicating late Miocene age. The relation of these beds to the early gravels and volcanic rocks is not clear in the quadrangle, but they are underlain north of the quadrangle, according to Mr. Pardee, by andesite.

The volcanic ash and other Tertiary rocks are overlain by gravels whose upper surface is one of aggradation and which have not been much modified by erosion except where they have been completely removed, as in valley bottoms. These gravels are mostly older than the final glaciation but may be in part of Quaternary age.

EARLIER GRAVELS.

AREAS ON ROCK CREEK.

On Rock Creek are several remnants of a gravel that once deeply filled an old stream channel, and one of these overlaps the western edge of the quadrangle. The surface underlain by the gravel is in large part flat, but probably is not in any case the original surface of aggradation; Plate XVI, *B*, shows that it truncates the bedding of the gravel. It is partly covered with later gravel, which is omitted in mapping because its boundaries are difficult to trace. On the slopes of the ravines that cross the gravel area old landslides recognized by their hummocky surface and undrained hollows, are common.

Remarkably fine exposures of these gravels appear on cliffs whose base is washed by Rock Creek a short distance north of the mouth of Sluice Gulch. (See Pl. XVI, *B*, p. 144.) The plate well shows the considerable degree of induration, the thick, somewhat irregular bedding, the unconformable contact with the Newland formation on a surface that evidently once formed the sloping side of an old channel, the gentle but very perceptible tilting, and the planation at the top. Another characteristic feature, more strikingly exemplified a little east of this exposure, is erosion into spires, capped by concretions or fragments of concretionary layers firmly cemented with calcium carbonate and iron oxide.

The pebbles of this conglomerate are in general well rounded; the largest are about a foot in diameter, but the average diameter is only a few inches. Nearly all of them are of whitish or dull-red quartzitic sandstone of the Spokane formation; a few are of a fine-grained porphyry and others of a scoriaceous lava. The matrix for the most part is siliceous coarse sand, mixed with a whitish dust that has the aspect of volcanic ash. Interbedded with and overlying the conglomerate, and not mapped apart from it, are some dark-red and white, rather fine grained, flaggy beds, whose texture and composition indicate that they are essentially tuffaceous and probably of andesitic composition. Cattle have made "licks" in banks of the shaly red rocks. At the base of these, near the Elkhorn ranch, are blocks of a red scoriaceous lava. West of Rock Creek the conglomerate is silicified and breaks down in great angular blocks.

The conglomerate is overlain by small remnants of a lava flow. This fact, and the intimate association of pyroclastic rocks with the gravels, makes it appear probable that they correspond in age to the older gravels with volcanic pebbles in the section near Anaconda.

AREAS ON WARM SPRING CREEK.

Gravels occur both north and south of Warm Spring Creek near the point where it leaves the quadrangle; also south of that stream and west of Barker Creek. In the eastern areas they are associated with tuffs, and although there is no section that clearly shows the contact of the two formations, their areal relations indicate that the conglomerate is the younger. The character of the pebbles, which, like those of the later gravel near Anaconda, are free from volcanic rocks, supports this view. The conglomerate is deformed, however, and a veneer of younger gravel is spread out on the terraces that have been cut into it. Hills of considerable height have been carved from it, so that it must be several hundred feet thick. It has no very extensive outcrops.

The earlier gravel on Warm Spring Creek is chiefly composed of well-rounded pebbles and bowlders of sandstone of the Spokane formation, locally attaining a diameter of 2 feet, and of unmetamorphosed rocks of the Newland formation, which are smaller and decompose much more readily. In the area west of Barker Creek pebbles of Newland predominate, and the fragments produced by their disintegration are so abundant in the soil as to suggest that the Newland is the country rock. Thin sandy beds have locally been observed in the gravels.

As there are no unmetamorphosed Newland rocks in the present drainage basin of Warm Spring Creek, the abundant pebbles derived from them that appear in the early gravels show clearly that the stream once drained the area about Georgetown Lake—a fact also indicated by independent physiographic evidence.

AREAS ON THE SOUTHEAST SLOPE OF THE ANACONDA RANGE.

A very large area on the southeastern flank of the Anaconda Range is underlain by gravels which are probably to be correlated with those on Warm Spring Creek. The gravels have been raised, on the top of Grassy Mountain, to a height of 8,000 feet above sea level, and their thickness appears on the east side of that mountain to be at least 500 feet, although the fact that the gravel creeps down over the contact with the underlying rocks detracts from the value of the observation. The areal distribution of the gravel indicates clearly that it overlies the tuff.

The gravel area is characterized by landslides, some of which, notably one just east of the point where Sixmile Creek leaves the quadrangle, are indicated by the contours. The eastern face of Grassy Mountain is a landslide escarpment, and affords one of the best exposures of the gravels. It shows them consolidated to a moderate degree with pebbles and bowlders, some of which have diameters up to 2 feet but most of which are well under 1 foot, only fairly well rounded, and not well graded as to size. The pebbles and bowlders consist for the most part of Spokane and Newland rocks and various Paleozoic limestones, but include also some of quartzite, various metamorphosed sedimentary rocks of the hornfels type, and a porphyritic rock probably an intrusive rather than a lava. In other exposures a few pebbles of granitoid rocks appear, but these are on the whole very scarce, a fact which makes it easy to distinguish these gravels from the moraines and their outwash aprons, in which granitoid rocks preponderate overwhelmingly. Some exposures show the conglomerate beds to be intercalated with thinner beds of cream-colored, pink, and brownish clay and sand, some of which is firmly cemented with lime.

In certain parts of the largest gravel area, especially south of Mount Haggin, red sandstone bowlders showing the characters typical of the upper part of the Spokane formation preponderate strongly. These are in general not well rounded and have diameters of as much as 5 feet. The supposition was entertained for a time that these subangular pieces were waste from underlying sandstone of the Spokane formation in place, but as careful search has failed to reveal any outcrops, and as the accumulation is exposed to a depth of 15 feet in an old ditch, this supposition has received no strong support from field evidence. The deposit may well be of a considerably different age from the conglomerate forming the top of Grassy Mountain.

It is noteworthy that in general the pebbles in the old gravels of this tract are largely of rocks different from those that form the adjacent part of the Anaconda Range, and must have been carried a considerable distance.

ANDESITIC ROCKS.

LAVAS NEAR ROCK AND WILLOW CREEKS.

Occurrence.—A pink andesitic lava forms a group of small areas of which the largest covers about 1 square mile on Willow Creek, near the western boundary of the quadrangle. This area lies in a depression, probably part of an old valley, in the Spokane formation. About half a mile south of Antelope Gulch two small masses of lava overlie the old gravel. Although these are so fine grained that their composition can not be determined well enough to establish their correlation with the masses on the north, it is a reasonable presumption that they are of the same age, and if this is true they indicate the relative age of the andesite and the gravel. Another small cap of andesite lies on the Newland formation near the place where the East Fork of Rock Creek leaves the quadrangle. All these remnants of andesite lie at a comparatively low level, as if they were parts of an eruption that flowed out on the floor of an ancient valley.

Petrography.—The rock on Willow Creek is a typical biotite andesite, showing dull-white crystals of feldspar, mostly about 1 or 2 millimeters in diameter, and somewhat smaller sparkling black flakes of biotite rather thickly sprinkled in a fine-grained lusterless pink groundmass.

The microscope shows plagioclase and deep-brown biotite to be the only phenocrysts. The plagioclase forms three fairly distinct generations, the last being of slender microlites which make up the greater part of the groundmass. The phenocrysts of the first generation are somewhat zoned and consist mainly of andesine near An_{40}. Those of the second and third generations are chiefly oligoclase near An_{20}. The groundmass contains obscurely polarized poikilitic patches, possibly of orthoclase, or of both orthoclase and quartz. No glass was detected.

The mass on the East Fork of Rock Creek is essentially identical with that described, except that the groundmass has a drab color.

The small masses overlying the gravels are apparently of flow breccia, composed of angular lithoidal fragments of rhyolitic appearance, without phenocrysts, which the microscope shows to have a microfelsitic texture.

TUFFS NEAR WARM SPRING CREEK.

General character and occurrence.—The volcanic rocks north and south of Warm Spring Creek, near the eastern edge of the quadrangle, are chiefly light-colored andesite tuff. The rocks are rather fine grained, though coarse enough to show the characteristic texture of tuff.

At the contact with the Carboniferous rocks north of Warm Spring Creek the tuff contains near its base fragments of quartzite and limestone, a fact which indicates that the tuff rests on the pre-Tertiary rocks with strong unconformity and overlap. It is apparently overlain by the heavy gravel deposits mentioned on page 134.

Petrography.—The prevailing rocks in the area near Warm Spring Creek are dull olive-green and gray to cream-colored tuffs without distinct stratification, but locally showing an obscure flaggy parting. They are composed of fine-grained white or grayish, more or less compact fragments of andesite, which show small phenocrysts of feldspar, biotite, and a few of hornblende, in an ashy matrix composed of smaller crystal and rock fragments.

The microscope shows the groundmasses of the fragments to have the hyalopilitic texture of typical andesites. Crystals and fragments of quartz occur, but none of orthoclase were identified. These rocks are not apparently widely different in composition from the lava on Willow Creek.

A specimen of whitish decomposed biotite andesite was obtained south of Warm Spring Creek. A rock resembling a small remnant of a flow just north of the road at the eastern boundary of the quadrangle is of a more basic type. It is a dark-red porphyritic andesite, with conspicuous phenocrysts of andesine, and inconspicuous ones of biotite, hornblende, and pyroxene.

PYROCLASTICS SOUTH OF GRASSY MOUNTAIN.

General character and occurrence.—The volcanic rocks near the southeastern corner of the quadrangle are mostly tuff-breccias of much coarser texture, on the average, than those exposed to the north. The surface of the bench is strewn with blocks of light-colored lava up to 10 feet in diameter, and although it seems at first sight possible that these are remnants of a flow, it is more probable that they are weathered-out fragments from an accumulation of material blown with great explosive force from some ancient crater not far distant. In the landslide just east of Sixmile Creek appear great blocks of coarse tuff-breccia composed of angular fragments of gray and red andesite up to 3 feet in diameter, as well as some fine-grained soft tuff like that in the more northerly areas.

Petrography.—The rocks of this area range in composition from rhyolite-dacite to hornblende-hypersthene andesite.

The rhyolite-dacite forms the very large blocks already mentioned as being possibly parts of a flow. It is a pale-drab rock with very irregular fracture, and contains many rather large phenocrysts of quartz and feldspar and smaller, comparatively inconspicuous, phenocrysts of biotite. Its many irregular amygdaloidal cavities are more or less completely filled with chalcedony, quartz, and opal.

The microscope shows the more numerous phenocrysts to be of zoned plagioclase, mostly andesine. The rock is differentiated from the biotite andesite by the presence of a few quartz and sanidine phenocrysts but appears to have some affinity with it.

A specimen from a block of coarse breccia proves to be a hornblende-hypersthene andesite. Megascopically it shows abundant and conspicuous phenocrysts of yellowish-white, more or less glassy feldspar 5 millimeters or less in diameter, and small inconspicuous prisms of hornblende and pyroxene in a very dark gray groundmass of resinous appearance.

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

VOLCANIC ASH.

Occurrence.—The soft, pale-tinted, obscurely stratified volcanic-ash beds, of Miocene age, occur at the north boundary of the quadrangle, west of Flint Creek, on Willow Creek, near the west border of the quadrangle, and in Philipsburg Valley, with its southern continuation across the East Fork of Rock Creek.

This formation is perhaps the least resistant to erosion and the most poorly exposed in the quadrangle. It is rarely uncovered except on steep slopes below the brinks of terraces capped by protecting gravel. Among the better exposures are some about 3 miles northwest of Philipsburg, which are visible from the town because of their whitish tint, and one in a gully about 1 mile north of Quinlan's ranch, at the head of Philipsburg Valley. Most of the large area mapped along Trout Creek is covered by a thin veneer of gravel and rock waste, but a few very small outcrops in gullies and fragments of white silt from badger holes indicate the presence of ash beds beneath, and much of the mapping in other areas is based on similar slight indications. The ash probably underlies the terrace north of Philipsburg and that between Gird and Flint creeks.

Petrography.—The prevailing rock of this formation is a soft buff fine-grained homogeneous earthy material, sufficiently indurated to be made into hand specimens without shattering. It differs from dried clay in having a noticeably low specific gravity, and in feeling harsh rather than unctuous to the touch. It shows only obscure traces of bedding in outcrops, and none in most specimens. Locally this material includes small angular fragments of older rocks near contacts with them, but it is associated with no true sandstones or conglomerates. Dust scraped from this rock and examined under the microscope is seen to consist essentially of minute isotropic angular fragments of volcanic glass.

A pale-greenish specimen of coarse grain from the north edge of the quadrangle shows its tuffaceous nature more clearly, for white particles of pumice can be detected with the naked eye.

TERRACE GRAVELS.

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

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

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

The gravel between Gird and Flint creeks is rather coarse and is composed for the most part of well-rounded bowlders of quartzite and metamorphosed Mesozoic rocks, such as occur in the Boulder Creek drainage. Granite is scarce, though it predominates in the moraines of this vicinity, and this condition gives reason for believing the terrace to be preglacial. The slopes in this gravel area are characterized to a striking extent by landslides, probably because they are underlain by soft, fine-grained Tertiary deposits. Some outcrops of clayey beds too small to map were found north of Gird Creek, and according to Mr. Pardee the Kolbeck placer diggings about 3 miles north of the quadrangle show light-colored beds of volcanic ash like those in the quadrangle beneath the gravel. This terrace gravel is very extensively developed as a capping on the earlier Tertiary deposits in the broad valley of lower Flint Creek.

QUATERNARY DEPOSITS.

As already indicated, some of the gravel deposits described in preceding pages are probably in part Quaternary. It remains to describe very briefly those which are clearly of glacial and postglacial age. Under the head "Glacial deposits" only those supposed to have been brought to place by ice will be considered, and such features as outwash aprons, in so far as they are noticed at all, will be described in connection with strictly fluviatile deposits and material that has filled in certain small lakes.

GLACIAL DEPOSITS.

The higher mountains of the Philipsburg quadrangle were once perennially mantled with ice. The former existence of glaciers in this region is clearly evident to one accustomed to interpreting land sculpture. The amphitheater-like basins that flank the high peaks, the steep-sided, broad-bottomed canyons that lead down from them, and the rock-rimmed lake basins that many of these depressions contain attest the handiwork of moving ice masses. Very typical examples of such forms, well expressed by the topographic contours, may be observed along the Continental Divide in the southern part of the quadrangle, in the vicinity of Racetrack Peak, and all about the borders of the elevated tract of nearly flat land upon which Fred Burr and Racetrack creeks have their source. These three tracts were centers of dispersion, and upon them precipitation accumulated in the form of ice, which pushed its way down the valleys as far as the increasing warmth of the lower layers of air would permit.

No less characteristic than the depressions to which ice has given their peculiar features are the accumulations of detritus removed during the excavation of these depressions. These deposits are in general designated moraines and are classifiable as ground moraines, deposited beneath the moving ice; lateral moraines, left upon the sides of the valleys at the junction of their slopes with the upper surface of the glacier; and terminal moraines, formed at the ends of the glaciers by the accumulation of the material carried slowly down upon the upper surface of the ice and deposited where it melted. In general all these types are accumulations of bowlders, some of which are too large to be moved by streams. The glacial deposits are furthermore distinguished from those of streams by their ill-sorted character, coarse and fine material being mixed indiscriminately, and by their rough topography without definite drainage lines. No attempt will be made here to give a thorough discussion of the several kinds of deposits above mentioned. On the map they are not distinguished from one another, nor are the smaller areas shown. Some evidence will be given to show that there was more than one glacial advance and retreat, but the deposits of different ages are not distinguished on the map. Considerable stream-laid material, chiefly worked-over moraine, is included in the areas mapped as glacial, especially on the floors of the large mountain canyons.

The characteristic features of moraines are nowhere more strikingly displayed than on Fred Burr Creek a short distance south of Philipsburg. At the mouth of the canyon is the terminal moraine, with its irregular heaps of loose granite bowlders interspersed with undrained hollows. On its west or outer side, it falls abruptly to the smoother surface of preglacial terrace gravel. The lateral moraines, which appear on the maps as lobes branching from the roundish area of the terminal moraine, are ridges with crest lines sloping gently westward, likewise built up of loose granite bowlders on the bedrock spurs north and south of the canyon, which the glacier overtopped and even in places overflowed.

Phenomena of the same nature are to be seen elsewhere in the quadrangle on a grander scale. The topography of the terminal moraine formed by the great Rock Creek glacier near the head of Philipsburg Valley, for example, is rugged enough to be suggested by the map contours, and some of its undrained hollows contain lakes. The benchlike form of the lateral moraines built against the canyon sides too high for them to overtop is exemplified in the upper and middle parts of Boulder Creek canyon, on the south side. In places, especially where the country rock is limestone, the lateral moraines are inconspicuous and are represented only by thinly strewn bowlders or small remnants. Where the moraines were built on a steep slope of limestone, they must have been sapped by the rapid solution and erosion of the underlying rock.

The greatest moraines are on the flanks of the lofty Anaconda Range, and their character is especially well displayed in the eastern part, where most of the timber has been removed. The view southwestward from the valley of Warm Spring Creek toward Mount Haggin is peculiarly instructive. At the mouth of Grays Gulch the steep front of the moraine rises abruptly to a rudely semicircular ridge crest like a gigantic earthwork; behind this, chaotic heaps of bowlders are strewn over an area of several square miles, and in the distance is the great concavity from which most of this material was excavated—the amphitheater on the north face of Mount Haggin.

The extent of the glaciers when they were largest is fairly well indicated by the distribution of the moraines, which show that the longest glacier was that of Rock Creek, and that the greatest glacier system was that of Warm Spring Creek. The glacier that reached the lowest level was that of Boulder Creek, which seems to have pushed down Flint Creek valley beyond the limits of the quadrangle to a level of about 4,500 feet. The material mapped as moraine below the junction of Flint and Boulder creeks consists of large bowlders chiefly of granite, whose arrangement suggests a terminal moraine modified by the action of an impetuous torrent. The Boulder Creek glacier, which was about 1,000 feet deep 2 miles from the mouth of the canyon, must have dammed Flint Creek, as pointed out by Mr. Pardee, so as to form a lake large enough to fill part of Philipsburg Valley, and the withdrawal of the dam must have let loose a stream of ample force to smooth out the terminal moraine and spread the material composing it over the valley floor to the north.

That there were at least two periods of glaciation in this quadrangle, separated by one or more periods during which glaciers were either absent or very small, requires no proof, for it has long been established that the glacial history of the entire continent has been of this composite character. It may be worth while, however, to indicate briefly some of the evidence that there was more than one general advance of the ice.

The clearest evidence was found at the end of the moraine on Fred Burr Creek. The older moraine at this place seems to have been overridden almost completely by the later moraine, but a small lobe of it projects at the northwest margin, and a cutting for an abandoned railway exposes a section of it. A striking contrast appears in the preservation of the granite bowlders. The bowlders of normal granodiorite in the new moraine are strikingly fresh and retain most of their original smooth surface, and those of dioritic rock are but little weathered. In the old moraines, on the contrary, those of acidic granodiorite are all noticeably weathered and more or less rusty, the greater part of their smooth outer surface having scaled off, and those of dioritic rock are thoroughly softened by decay.

This deep decay of the bowlders in the old moraine may explain the scarcity of granite bowlders in some isolated patches of what are regarded as deposits of the early glaciation. One such deposit, for example, 2 miles southeast of the mouth of Meadow Creek, is mapped, and near the north edge of the quadrangle are several not shown on the map. The granite predominates in the newer moraines because of its abundance in the high mountains and its resistance to attrition, in which it competes successfully with quartzite and the tough metamorphic hornstones. The granite, however, is the more vulnerable to decay. Although it has withstood disintegration fairly well since the last advance of the ice, yet in mounds exposed to weathering and erosion since the first advance it would probably have crumbled to sand while the sedimentary rocks survived.

Topographic evidence of more than one advance is exemplified near the end of the moraine on the Middle Fork of Rock Creek. For about a mile from the north end of the area mapped, the morainal topography is feebly accented, but this gives way abruptly to the much rougher topography that characterizes the vicinity of the Potato Lakes. Similar extension of old moraine beyond the new is exemplified on the lower parts of Lost Creek and Mill Creek. In other places, as on Fred Burr Creek, the early advance does not seem to have been appreciably greater than the last. On Warm Spring Creek, for example, near the mouth of Olson Gulch, the terminus of the rough and new-looking moraine is sharply defined, and downstream from it the valley has a smooth gravel floor with no morainal features.

AQUEOUS DEPOSITS.

The materials laid down by water in glacial and postglacial time include glacial outwash, valley alluvium, and lacustrine deposits, but these have not been mapped separately.

Outwash aprons are recognizable at the foot of the moraines north of Mount Haggin. Those that are spread out on terraces and gentle slopes are more conspicuous than those that merge with the alluvium of the broad valleys.

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

Some of the many flat meadows that lie among the glacial deposits are essentially of lacustrine origin, having been formed by the filling up of lakes that once lay in the hollows of the moraines. The largest meadow that seems to have had such origin is one about 2 miles long on the East Fork of Rock Creek.

CHAPTER IX.

DEFORMATION.

GENERAL FEATURES.

In discussing the geologic structure of the quadrangle it is convenient to separate the deformations of the pre-Tertiary rocks from those of the Tertiary rocks. The unconformity at the base of the Cambrian shows, to be sure, that the Algonkian suffered deformation which has not affected the Cambrian, but for the present purpose this fact may be neglected, for this early Cambrian or Algonkian warping (discussed on page 50) was of relatively small extent, and its effects can be disentangled from those of later deformations only in exceptionally favorable exposures. The overlying rocks, from Cambrian to Cretaceous inclusive, are structurally conformable inasmuch as they show no visible angular discordances. This enormous accumulation of Algonkian, Paleozoic, and Mesozoic rocks has been far more violently deformed than the granitoid rocks and the partly or wholly postgranitic fluviatile, lacustrine, and volcanic deposits of Tertiary age. From this it follows that an important deformation took place in the late Cretaceous or early Tertiary, beginning presumably at about the same time as the intrusion of the granites. The faults and folds in the pre-Tertiary rocks expressed on the map are doubtless ascribable for the most part to this deformation.

Some of the Tertiary gravels and volcanics are affected by later movements, but owing to the conditions of exposure the effects of these movements can neither be completely worked out nor satisfactorily expressed on the map. Some of the granular intrusives have been strongly sheared along more or less definite zones.

DEFORMATION IN PRE-TERTIARY ROCKS.

GENERAL CHARACTERISTICS.

The deformation of the pre-Tertiary rocks by folding and by faulting has been so extremely complex that it can not be characterized briefly. Such general statements as can be made, however, may aid in interpreting the structure and in explaining the map and sections, which express the main facts.

The prevailing trend of the folds is nearly north-northeast. They exemplify all degrees of intensity and complexity, from the broad, simple, and open folds exemplified west of Philipsburg Valley to the closely appressed and overturned folds of the northeast part of the quadrangle and the intricate contortions shown in the cordieritic gneisses of the Prichard formation in the Anaconda Range. A feature common to most of them is a northward plunge. Many, especially those most closely appressed, are unsymmetrical, and the axial planes of most of these dip eastward; the anticlines, that is, generally have a steeper dip on the west side than on the east, whereas the reverse is true of synclines. There are, however, some striking exceptions to this general rule.

The faults are even more diverse in character than the folds. In direction most of them follow the prevailing strike, though a great many are transverse to it. Although for many of the faults it has been impossible to measure the dip or even to tell its direction, enough facts have been collected to show the existence of thrusts with gentle dip, of reverse faults with steep dip, and of normal faults with steep and with flat dip.

No general statement can be made concerning the prevailing direction of downthrow on the faults. The aggregate throw of the faults across the strike neither appreciably helps nor opposes the effect of the prevailing northward pitch of the folds, which is to expose the oldest rocks farthest south and the youngest pre-Tertiary rocks farthest north. As for the faults more nearly parallel with the strike, the majority seem to cause downthrow on the east. This is true, at any rate, of the faults that have by far the greatest throw, which are those that form the eastern boundary of the great Algonkian mass out of which the hills across the valley from Philipsburg are carved.

It would be impossible to describe in detail all the structural features in the district or to give fully the evidence on which their mapping is based. Some account will be given, however, of the folds and faults having special interest and importance. The folds will be described first, because they are for the most part older. They are more persistent than would appear at first glance, a fact which indicates that although folding and faulting were probably in part contemporaneous, the folds were first formed and afterward broken by faults. On the other hand, certain flat overthrusts of the district have been folded and faulted, and therefore must have been formed at a relatively early date.

PRINCIPAL FOLDS AND FAULTS.

PRINCIPAL FOLDS.

MARSHALL CREEK SYNCLINE.

One of the simplest and largest folds is a syncline in the Algonkian rocks northwest of Philipsburg. As a large part of its area is drained by Marshall Creek, it may be called the Marshall Creek syncline. Its general character, which is clearly expressed by the plotted dips and by the form of the boundary between the Spokane and Newland formations west and southwest from Philipsburg, is that of a north-pitching, flat-floored trough. Over a large area in its central part the rocks are nearly horizontal, and this is the only considerable area in which such a condition obtains. The dips on the west limb of the syncline are at most about 25°; but on the east limb they are somewhat steeper, attaining 60° on the side of Henderson Mountain. The fold is therefore unsymmetrical, with the usual dip of the axial plane toward the east.

This syncline would appear at first glance to terminate at Philipsburg Valley, but it probably persists much farther, though broken by faults. A fault under the valley floor raises the west limb, but the synclinal structure is plain at the head of Philipsburg Valley. Its east limb is probably represented by the strip of the Newland and Spokane formations extending from Rumsey Mountain southwestward to the crest of the Anaconda Range.

ROCK CREEK SYNCLINE.

One of the folds most apparent in the mapping is a syncline on the East Fork of Rock Creek. It is clearly marked by the outcrop of the quartzite of the Quadrant formation. This fold has a strong northward pitch, which increases so much to the south that the nose of the syncline is flattened, and anticlinal structure develops in line with its axis. The syncline divides toward the south into two lobes, of which the more westerly is the more pronounced, and persists until cut off by the granite near the boundary of the quadrangle.

The main syncline has the steeper dip on the west side. This limb is nearly vertical through most of its course and in places slightly overturned.

The fold is somewhat broken by minor faults and has itself effected a great overthrust that has caused Algonkian rocks to overlie those of Pennsylvanian and Jurassic age. This syncline may be a continuation of the Marshall Creek syncline, but the break between them is so great that this assumption is not altogether safe. It would seem by its character to be more probably the equivalent of that open fold than the narrow and closely appressed syncline on the west.

FOLDS WEST OF THE EAST FORK OF ROCK CREEK.

The folds between the East Fork of Rock Creek and the great fault along Meadow Creek valley are two anticlines and a syncline. The axis of the greater and more easterly anticline runs along the ridge of Algonkian quartzitic sandstone east of the Carp mine. The fold has a nearly level crest and is steeper on the east than on the west.

The other anticline, which also is steeper on the east side, is less simple. The mapping is well substantiated by observations on its east flank, but the exposures are poor near its crest, where there are some indications of faulting which were not well worked out.

PHILIPSBURG ANTICLINE.

The north-pitching anticline which is the main feature of the structure about Philipsburg is expressed on the map by the U-like form of the bands that represent the Paleozoic formations. In the field it can readily be perceived by following the outcrop of certain well-exposed, comparatively thin, and strongly individualized formations.

The Flathead quartzite, for example, forms a flat-topped arch on the north side of Frost Creek. The outcrop of the cherty-banded limestone of the Red Lion formation may be readily followed along the north side of Camp Creek below Tower, and the strongly cropping quartzite of the Quadrant formation, whose S-shaped area shows how the anticline is succeeded on the east by a syncline, defines the west flank of the fold.

The Philipsburg anticline is virtually symmetrical, having dips on either limb near 45°. The northward pitch is marked, for dips near the axis attain 25°, though the average pitch is considerably less.

The anticline is well defined from the head of Wyman Gulch to the top of Franklin Hill, where granodiorite cuts across the crest. Though broken by faults, it can be traced southward beyond the mouth of Fred Burr Creek, but it seems to die out near Rumsey Mountain. North of the head of Wyman Gulch it is nearly obliterated by faulting. If, however, the Algonkian rocks west of Georgetown Lake really belong with the east limb of the Marshall Creek syncline, the Philipsburg anticline should be continued in that which underlies Henderson Mountain.

FOLDING NEAR LOST CREEK.

The character of the folding in the complexly deformed rocks north and south of Lost Creek is best seen on the walls of Lost Creek canyon. A fine view of the north wall in particular is obtainable from the brink of the high plateau on the south. In a broad way, the boundary between the Newland and the Spokane formations here appears in profile as a sigmoid curve, but the Algonkian beds have been thrown into extremely intricate small folds recumbent mostly toward the west, but partly toward the east, especially near the border of the quadrangle. On the south side of the canyon the Flathead quartzite is overturned, and the Cambrian limestone shows a close fold which is not only recumbent toward the west but has its crest curled over like that of a breaking wave.

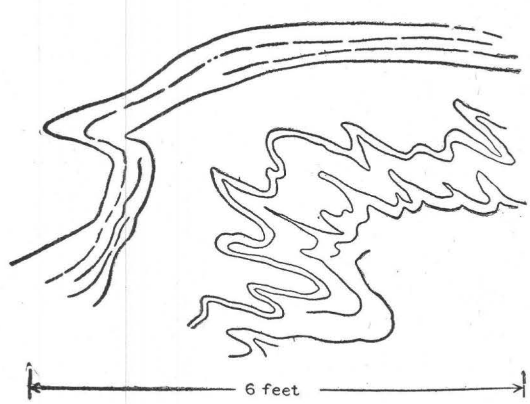


FIGURE 5.—Detail of folding south of Thornton Creek.

The mapping on the plateau north of Lost Creek is largely hypothetical except where it is guided by exposures on cliffs. The gently sloping surface is mantled by a sheet of waste composed of fragments of the more resistant rocks. One feature clearly established is a strong overturn which makes the Silver Hill formation overlie the Hasmark formation on the cliff south of Thornton Creek. This is associated with an overthrust discussed on page 149 and is complicated by small folds whose character is illustrated in figure 5.

FOLDING NEAR LOWER WARM SPRING CREEK.

On the high slopes north of Warm Spring Creek the deformation by folding is essentially the same as that observed on Lost Creek, but it is much obscured by faulting. On the lower slopes the country rock is chiefly Madison limestone, in which complex folding, such as here prevails, is very difficult to work out. In the lime quarries the general structure is an anticline with the steeper dip on the west side. The western quarry known as the "white-lime quarry" is chiefly in the light-colored upper Madison, and the eastern, known as the "blue-lime quarry," in the dark blue-gray limestone of the lower part of the formation. To the east near the "silica quarry" the Quadrant is thoroughly shattered and folded into an anticline.

In the hill east of the lower part of Barker Creek the principal folds are two anticlines with a syncline between. Both anticlines have overturns on the east side.

FOLDING NEAR FOSTER AND WARM SPRING CREEKS.

The folds in the vicinity of Foster Creek are so complex and so much broken by faulting that few anticlines or synclines can be traced far. One of the more persistent folds is a syncline west of Foster Creek, complex at the north end, as shown by the sinuous outcrop of limestone of the Red Lion formation, which is clearly visible in a distant view and which is indicated, though necessarily in generalized fashion, on the map. The structure just east of this syncline is interpreted as a sharp anticline and syncline.

The Carboniferous and Devonian rocks in the basin of upper Warm Spring Creek are complexly folded, but the folds for the most part can not be traced. The relations to the Devonian indicate a general northward pitch.

The fold most distinctly shown in the mapping in the east part of Foster Creek basin is a syncline of Carboniferous and Devonian rocks. The mapping of this feature, however, is necessarily much generalized. On either side the limestone is thrown into overturned folds, which are beautifully displayed on the face of the high cliff east of Foster Creek near the county line. (See Pl. XVI, *A*.)

MOUNT EVANS ANTICLINE.

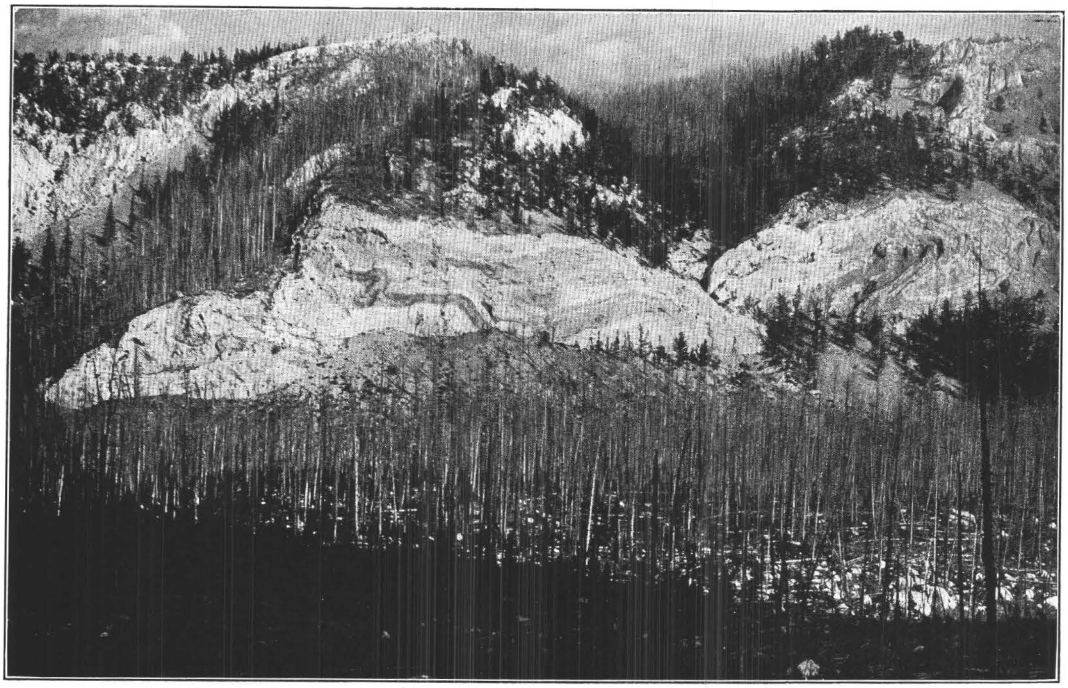
The largest structural feature of the Anaconda Range is a northward-pitching anticline, so much modified by minor deformations and so much veiled by moraines and by granitic intrusion that it is not very obvious on the map. Its general expression in the distribution of the rocks is as follows: The oldest formation in the district is exposed farthest south in its axis, on Sullivan Creek. A group of Prichard areas partly surrounds this area, though mostly separated from it by moraine and granite, on the east, north, and west. Beyond these to the west and north are areas of quartzite of the Ravalli formation, but on the east this formation does not appear, having been depressed below the surface by folding and faulting. Beyond the Ravalli are successive zones of the Newland and Spokane formations, the latter very incomplete on the east. Still farther north, beyond Silver Lake Creek and even to a point within a mile or two of the county boundary, the Cambrian rocks are distributed with a suggestion of the same concentric arrangement. The anticlinal structure is further brought out by the dips, but these, even though somewhat generalized, show this fold to be much more complex than most of those in the northern part of the quadrangle.

FOLDS IN THE NORTHEASTERN PART OF THE QUADRANGLE.

The structure of the area along Boulder Creek and northeast is strongly characterized by its folds, which are close and which have a nearly north-south trend, a general northward pitch, and a marked lack of symmetry. The dip of the axial planes is generally toward the east. The closeness of the folds and their unsymmetrical character are most pronounced in the vicinity of Goat Mountain. (See structure sections A and B on geologic map.)

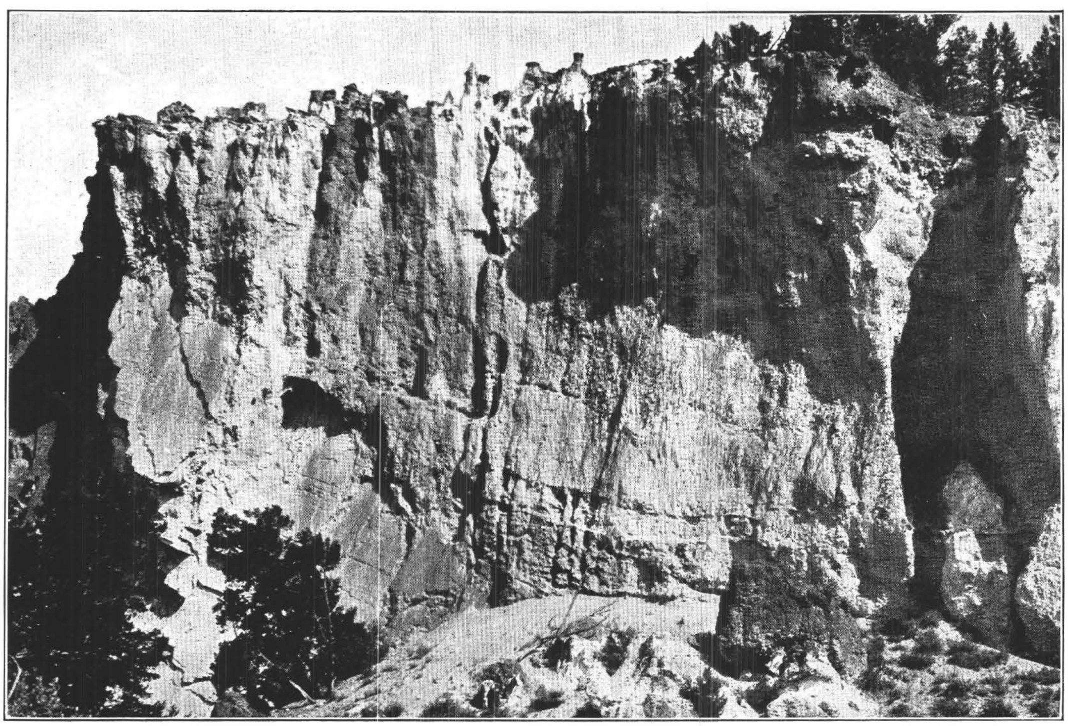
A typical anticline is that in whose axis Princeton lies. This feature is best seen in the field near its northern end, where the bold reefs of quartzite of the Quadrant formation run along the flanks, converging more and more toward the north until they meet and disappear beneath the surface. The overturned west limb between Douglas and Gird creeks has a dip of 60° E. Toward the south this anticline is less easily traced, for it is complicated by faults and small folds, but it persists as far as the east-west fault in the saddle between Swamp and Copper creeks.

The structure in the area of Quadrant formation and Mesozoic rocks is a syncline which separates into two lobes at the north. These are closely pressed together, and have both limbs



A. FOLDED AND FAULTED LIMESTONES ON EAST SIDE OF FOSTER CREEK CANYON.

The shallow gulch at the left is eroded along a normal fault which brings Carboniferous limestone against contorted banded Devonian limestones. Granite at base of cliff; dike of scapolite aplite at top of cliff, just to right of deep gulch.



B. TILTED EARLY TERTIARY GRAVELS RESTING ON PRE-CAMBRIAN SEDIMENTS AT RED CLIFF ON THE SOUTH SIDE OF ROCK CREEK.

Unconformable contact runs diagonally downward from point near brink of cliff at left.

dipping eastward at nearly the same angle. This structure has a curious and striking expression in the outcrop of alternate lighter and darker beds on the cliffy walls of the glacial amphitheaters, particularly in the view southeastward from the top of Goat Peak (fig. 6). The most conspicuous of these beds are the whitish cherty limestone in the middle of the quartzite of the Quadrant formation and the rusty black shales near the top of that formation. The clue to the structure here is given by a view along the face of the cliff (fig. 6, *a*). The outcrops on the north face of Racetrack Peak form a similar recumbent chevron with the point toward the west, and the alternating white and gray bands of the upper Madison limestone form another, pointing east, on the barren west slope of the spur north of the Powell mine.

Were it not for the guidance afforded by these distant views the structure in this vicinity would be rather baffling. When sections are studied at close range the structural axes are likely to be passed unawares. The country rock in the trough of a syncline is generally metamorphosed Kootenai without distinct banding. The stratification, however, is marked by linear distribution of calcareous nodules somewhat flattened on bedding planes, and at the axis of the fold these obscure lines of stratification are sharply bowed into an arch never more than

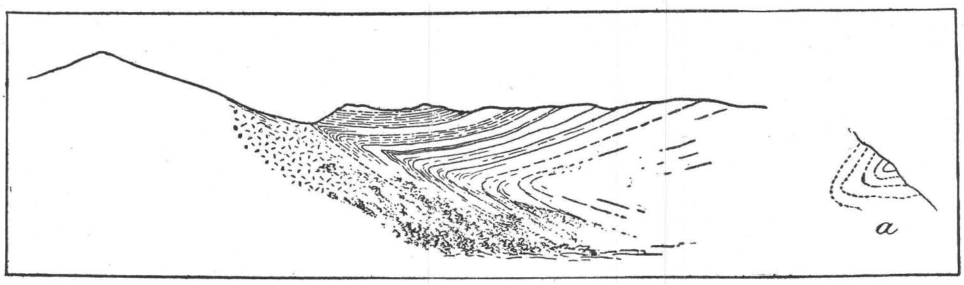


FIGURE 6.—Recumbent syncline near Goat Mountain.

a few feet across. Cleavage about parallel to the axis of the fold is especially pronounced near the axes and tends still further to obscure the bedding.

The syncline so distinct north of Racetrack Creek continues south for several miles to the vicinity of the county boundary but is much broken by faults, chiefly by a very great one which cuts off part of the western limb. The structure to the east of Twin Peaks is obscure in many details, and the beds appear to be considerably thinned, as is common on the limbs of close folds.

CABLE MOUNTAIN ANTICLINE.

The mapping at the south end of Cable Mountain clearly reveals a south-pitching anticline. Northward the axis of the anticline converges toward a great fault, which cuts away its east limb. The west limb is much broken by minor faults and lies against a great fault that follows the valley of the north fork of Flint Creek. Farther north the margin of the granodiorite of the Philipsburg batholith closely follows the course of the west limb, which finally tapers out between the intrusive contact and the fault.

The anticline, while showing no lack of symmetry at the south end of the mountain, becomes strongly unsymmetrical toward the north, with a dip of the axial plane toward the east. This is shown by the plotted dips of the west flank, which become vertical southeast of the Red Lion mine, and are overturned north of that point. The reverse dips are about 60° near the Twin Peaks, and to the south dips believed to be reversed are as low as 25°.

The Cable Mountain anticline does not really terminate at the south end of Cable Mountain. In line with its axis, an anticlinal fold more or less broken and with undulating crest persists nearly to the Continental Divide, where, like the Rock Creek syncline which it flanks on the east, it assumes a marked northward pitch and becomes indefinite.

PRINCIPAL FAULTS.

CENTRAL FAULT ZONE.

General character and possible equivalence to the Lewis thrust.—The most obvious and striking fact in the areal geology of the Philipsburg quadrangle is that the western part is occupied almost wholly by Algonkian rocks, while the remainder is chiefly occupied by later rocks. The great Algonkian tract is bounded on the east by faults, the movement on which has been relatively upward on the west and downward on the east, and whose dip is to the west in most of the places where it has been observed. The quadrangle, then, is traversed from north to south by an overthrust, or a zone of thrust faults whose throw has been sufficient to bring the Newland formation (Algonkian) into contact with the Carboniferous rocks in many places, and with the Jurassic south of Georgetown Lake.

This fault zone derives an interest more than local from the probability that it is a southerly continuation of the Lewis overthrust described by Willis.[1] This immense dislocation, which is known to follow the east front of the Rockies from some point well north of the 49th parallel to about latitude 47, has the same direction of throw and about the same general course as the central fault zone of the Philipsburg quadrangle.

This zone of thrust faulting offers a striking exception to the general rule that the faults are subsequent to the folds, for it has been folded and has been dislocated by normal faults to nearly the same extent as the rock strata, and is therefore one of the oldest tectonic features of the quadrangle. Although this deformation has unquestionably occurred, its precise character is much obscured by surficial deposits and igneous intrusions, which have concealed or obliterated the faults at many critical points. After careful consideration of the data, it has been concluded that these best accord with the hypothesis that two nearly parallel overthrusts were produced and that their deformation was effected chiefly by folding.

In explaining how the structure of the fault zone has been interpreted, it will be convenient to begin at the south and to consider in turn the several portions of it that can be continuously followed.

Observations along Meadow Creek and farther south.—A great fault parallel to the general course of Meadow Creek brings the Newland on the west against folded rocks on the east ranging from the Spokane formation (Algonkian) to the Madison limestone (Carboniferous). Its dip on the main branch of Meadow Creek is westward at a moderate angle. In this place it is accompanied by a complex of subsidiary faults.

Observations near the East Fork of Rock Creek.—The clearest evidence that the overthrust has been deformed is to be seen along the large branch that enters the East Fork of Rock Creek near the hill marked "7781" on the map (Pl. II, in pocket). The structure displayed in the fairly good exposures along the steep slope north of that branch was at first regarded as a simple syncline in a conformable succession of strata comprising Madison limestone and rocks of the Quadrant formation at the base, with a great thickness of thin-bedded limy rocks above. This interpretation, however, proved untenable. The rocks in the trough of the syncline are lithologically identical with the Newland formation and are continuous with the chief area of that formation. They do not everywhere lie on beds of the same horizon and locally they exhibit crumpling and brecciation near their base. It is therefore clear that they belong to the Newland formation and have been thrust, probably for a distance of several miles, upon rocks as young as Jurassic.

Although it is obvious that the thrust plane here has been deformed, the exposures along this section do not give the means of deciding whether its chief deformation has been by folding or by faulting. But the facts observed are best harmonized not only here but elsewhere by supposing that the great thrust occurred before the rocks had suffered much folding; that the movement followed a plane of relatively low resistance nearly parallel to the bedding; and that the rocks thus superimposed were folded together. Immediately northwest of this locality the

[1] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305-352.

fault is strongly offset in an area where it is covered by Quaternary deposits. It is assumed that the offset is the result of folding, as indicated on the map.

On the east limb of the syncline, near Georgetown Lake, the trace of the overthrust is jogged by several cross faults, most readily detected where they offset the well-defined boundary between the Madison limestone and the Quadrant formation upon which the Algonkian rocks have been thrust.

Observations northeast of Georgetown Lake.—A great fault with relative upthrow on the west runs along the west wall of the canyon of upper Flint Creek parallel to Cable Mountain. In the more northern part of its outcrop, the contact is at the junction of a steep slope of tough metamorphosed Newland rocks with a rude bench carved from softer Paleozoic limestones chiefly Cambrian. Farther south it is concealed under the Quaternary deposits of the canyon floor. Its stratigraphic throw increases in this direction, and at Georgetown Lake it brings Carboniferous rocks against beds near the middle of the Newland.

The trace of the fault from Georgetown Lake to the point where it is cut off by the granodiorite of the Philipsburg batholith is nearly horizontal, which makes it impracticable to determine the direction of dip.

Observations in the upper part of Philipsburg Valley.—The fault which is cut off by the Philipsburg batholith is supposed not to reappear north of that intrusion as the fault next east of Princeton. It is believed that a higher and presumably later overthrust has been formed nearly parallel to it, which follows in general the course of Philipsburg Valley.

That the deposits on the floor of the southernmost part of Philipsburg Valley cover a fault with downthrow on the east is shown by the fact that the base of the Spokane formation west of the valley is nearly in line with the top of that formation east of the valley. In a locality where the Algonkian red beds are developed in enormous thickness, these areal relations imply a fault amounting to many thousands of feet. The most striking evidence of the fault, however, is on the west slope of the hill opposite the mouth of Fred Burr Creek, where the Newland formation (Algonkian) has been brought into contact with Pennsylvanian rocks.

Observations north of Philipsburg.—The locality in which the dip of this fault is best shown is on the east side of Flint Creek canyon, a short distance from the north end of Philipsburg Valley, where the trace of the fault plane shows it to have, in general, a westward dip of about 20° or 30°. It has suffered some deformation here, however. The sharp bend in its outcrop near bench mark 5,005 is regarded as due to a small fold that has affected the thrust plane. Where the overthrust reaches Flint Creek there is an outcrop of quartzite west of the stream, and the relations here are interpreted as showing that the thrust plane has been jogged by a transverse fault. A short incline has been driven near the north end of the outcrop on a fissure about 5 feet wide filled with gouge, whose course is northeasterly and whose dip is 25° NW. The Newland formation and the Madison limestone in this vicinity are silicified.

To the north, the overthrust passes under the alluvium, and for some distance its course can not be actually followed. It is believed, however, that the overthrust is folded into an anticline and a syncline east of Flint Creek, as shown in structure section A (Pl. I). The high ridge between Flint Creek and Wyman Gulch is carved from rocks beneath the overthrust exposed by erosion of the crest of the anticline. It is noteworthy that these Carboniferous and younger rocks are themselves anticlinally folded, so that if the structure is rightly interpreted the thrusting at this locality, as well as near Rock Creek, occurred before strong folds had been developed.

The great fault that crosses Wyman Gulch, considered by itself, would naturally be interpreted as an overthrust from the east, and the existence, in neighboring parts of the quadrangle, of close folds whose axial planes dip eastward makes it probable that thrusts from this direction should be developed. But the structural phenomena of the quadrangle as a whole may be better interpreted on the assumption that this apparent overthrust from the east is on the east limb of an anticline affecting an overthrust from the west. The critical area for testing this hypothesis lies north of the lower part of Boulder Creek, where the trace of the fault is shown as sharply curving so as to define the end of a northward-pitching anticline. Unfortunately the structure is here concealed by Tertiary and Quaternary deposits.

The thrust is supposed not only to be anticlinally folded, but to be brought up again by a syncline near the mouth of Swamp Gulch. The thrust thus brought to the surface is thought to be represented by the fault that crosses Swamp Gulch obliquely near its mouth and is offset to the east by a cross fault. This fault is peculiar in that, although in most places the older rocks are on the west side, this condition is locally reversed. Such independence of minor antecedent structures would be a natural characteristic of a major fault.

FAULTING NEAR MOUNT TINY.

The faults south and west of Mount Tiny are not especially large or conspicuous. The one of greatest throw is that at the head of Blodgett Creek, which brings the Hasmark formation against the Newland. The one nearest the peak marked "10100" on the map is distinctly shown by the jog in the Flathead quartzite on the north side of the ridge, but is obscure on the flat crest to the west, where it is so completely covered by waste that its relation to the northeasterly fault is not clear.

All these faults have steep dips and would therefore ordinarily be assumed normal, but the only ones whose exact dip is known show that such an assumption is not always safe. A short fault north of the peak at the head of Seymour Creek, marked "10068" on the map, is perfectly exposed, and one may ascend its fissure and in places touch quartzite of the Ravalli formation on the west and Newland formation on the east with either hand, the fissure walls being separated only by a narrow zone of brecciation. The Ravalli strata are gently turned up, and the Newland strata, much contorted, are abruptly turned down, the relations being the opposite of those commonly illustrated in textbook diagrams. The dip of the fissure is 70° to 80° W., and the dislocation is therefore a steep reversed fault. The fault about a mile northwest is clearly of the same character.

FAULTS NEAR BOULDER CREEK.

The faults near Boulder Creek are mostly strike faults. They are in general poorly exposed, but so far as observed they have rather steep dips. It is noteworthy that the most persistent have the downthrow on the east side, which indicates that they are due to some force that acted later than the pressure that produced the principal folds, with their east-dipping axial planes.

FAULTS ON THE FLANKS OF CABLE MOUNTAIN.

One of the greater faults is that which cuts away part of the Cable Mountain anticline and brings Madison limestone against beds far below the top of the formation. Observations on the spurs south of Twin Peaks indicate that the dip is steeply southeastward and that the fault is therefore normal.

The Paleozoic rocks on the west flank of Cable Mountain are dislocated by a large number of comparatively small faults, some nearly parallel to the strike and some transverse to it. Those most readily verifiable in the field are the transverse faults at the south. These were detected chiefly by following the very characteristic purple beds near the base of the Red Lion formation, which is offset repeatedly to the southeast. Two or three more faults were found than are indicated on the map, whose scale does not permit of representing them fully. The transverse faults farther north are shown by evidence rather less clear, chiefly by jogs in the Flathead quartzite and the Red Lion and Maywood formations. All the transverse faults are apparently of steep dip and presumably normal. The principal strike fault is at the head of the creek; its downthrow is in the same direction as that of the great fault farther west, to which it may be subsidiary, but its dip is not known.

FAULTS BETWEEN FOSTER AND WARM SPRING CREEKS AND NEAR GOAT MOUNTAIN.

A fault which is traceable for 7 miles or more south of Indian Meadows is possibly continued toward the north by the fault that crosses Finley Basin. If so, it is one of the longest faults in the district, but it is not one of those with the greatest throw. Along most of its course it brings the Madison limestone on the west against the Quadrant, Ellis, and Kootenai formations on the east, though near the south end it brings the limestone of the Cambrian Hasmark formation against the Madison limestone. The fault is well exposed in a notch southeast of Racetrack Lake, but not so well, as a rule, farther south, the contact with the Madison limestone being largely concealed by fragments of the quartzite of the Quadrant formation and by the tough metamorphosed Mesozoic sediments. Its dip in this vicinity is apparently steep but of unknown direction.

The existence of the fault in Finley Basin is shown most clearly on the slope to the north, where the quartzite of the Quadrant formation dips toward the Madison limestone. The trace of the fault as drawn on the map and the aspect of the exposures as seen from the south indicates that the fault has a steep west dip and is therefore reversed.

OVERTHRUST SOUTH OF THORNTON CREEK.

A section of the overthrust south of Thornton Creek is given in figure 7. On the face of the cliff overlooking that stream the thrust has cut out the Flathead quartzite except for a very small fragment. The bedding of both formations has in common a general dip, much complicated in minor folds, of about 35° SE., and the attitude of the fault plane is here about the same.

The chief interest of the fault comes from the fact that it has been strongly folded. The evidence of folding is to be seen in the glaciated canyon next south of Thornton Creek. On the south side of the canyon the thrust causes the Spokane formation (Algonkian) to overlie contorted and broken Cambrian rocks. At the head of the canyon the thrust plane bends abruptly downward; the sharp contact between the green metamorphosed flaggy beds of the Spokane and the whitish magnesian limestone of the Hasmark is, on the average, nearly vertical, but very sinuous in detail. It is closely welded and not marked by any distinct gouge, and both rocks are fairly firm though somewhat brecciated.

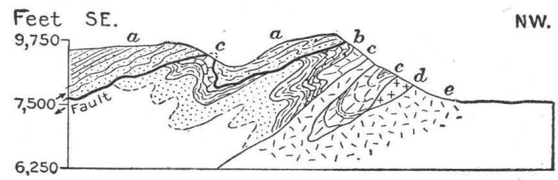


FIGURE 7.—Folded thrust fault south of Thornton Creek. *a*, Spokane formation (Algonkian); *b*, Silver Hill formation (Cambrian); *c*, Hasmark formation (Cambrian); *d*, acidic diorite (Tertiary); *e*, porphyritic muscovite-biotite granite (Tertiary).

The supposed continuation of the fault to the south seems to have an eastward dip, but not a steep one, a condition assumed to be the result of deformation.

FAULTS BETWEEN LOST CREEK AND WARM SPRING CREEK.

The fault mosaic from which the plateau south of Lost Creek is carved is essentially a series of step faults with repeated downthrow on the south and east. This character is most clearly shown in the field along the boundary between the Hasmark and older rocks, where the Flathead quartzite and Silver Hill formation are found to be frequently jogged. It is also expressed in the sky line to the southeast of peak 8861, as viewed from near the mouth of Barker Creek, for erosion has been arrested at the surface of the Flathead quartzite, which forms three distinct low hogbacks. A numerous group of divergent faults is well exposed in a gulch directly north of peak 5605, which has steep cliffy sides that underwent at least the earlier glaciation. These faults can best be traced by the contacts between the pale-greenish beds of metamorphosed Newland and the darker, more rusty beds of the Spokane. The mapping of the faults on the top of the plateau is based on many laborious traverses, but as the exposures, like those on the similar plateau north of Lost Creek, are poor, it is possible that errors have been made in the interpretation of the few outcrops.

One of the more extensive faults on the south slope of these hills is a normal fault which brings Carboniferous and Devonian rocks down against the Cambrian for a distance of several miles. Its course is most readily traced on the slope north of the quarries, where its dip is seen to be very low, probably not more than 30°. It is jogged by a cross fault near the middle of its course.

A noteworthy feature of the faulting in the drainage basin of Olson Gulch is the manner in which two blocks of Jefferson and Madison limestone have been let down into masses of Cambrian limestone. This curious type of faulting is probably connected with the intrusion of the diorite, which has many inclusions of limestone. These larger blocks may have slidden down on the sides of the chamber filled with molten magma without becoming completely separated from the walls.

FAULTS SOUTH OF LOWER WARM SPRING CREEK.

Very complex fault structure is shown in the hill south of the lime quarries. Some of the faults are normal, and the overturned folds are accompanied by slight overthrusts parallel to the bedding. The most considerable fault in this hill is a flat overthrust near the east end, which brings Carboniferous Madison limestone upon black shale of the Colorado (Cretaceous). It has a westward dip of about 20° and is jogged by a cross fault. A cross section is well exposed in the gulch followed by the road.

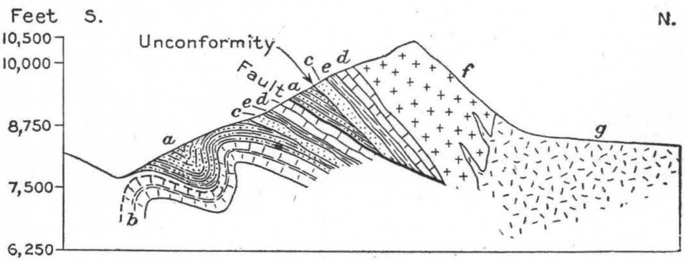


FIGURE 8.—Section across Mount Haggin Ridge. *a*, Spokane formation (Algonkian); *b*, Newland formation (Algonkian); *c*, Flathead quartzite (Cambrian); *d*, Hasmark formation (Cambrian); *e*, Silver Hill formation (Cambrian); *f*, acidic diorite (Tertiary); *g*, nonporphyritic muscovite-biotite granite (Tertiary).

On the south slope of Mount Haggin is an overthrust of which a section is shown in figure 8. It has a dip of about 30° N. and where its stratigraphic throw is greatest brings the Newland formation (Algonkian) over the Hasmark formation (Cambrian). At the west the Newland is anticlinally folded, but toward the east the fault cuts away the south limb of the anticline and is nearly parallel to the bedding of the rocks both above and below.

DEFORMATION OF TERTIARY ROCKS.

EASTERN PART OF FLINT CREEK RANGE.

Shearing of granite and diorite.—Near the east boundary of the quadrangle, along Racetrack and Rock creeks, the biotite granite of the Royal batholith and the porphyritic biotite granite and quartz diorite exposed to the south are locally very schistose. The schistosity in the diorite between Racetrack and Thornton creeks strikes about northeast and dips 30° SE., or about parallel to the thrust fault of Thornton Creek.

Fault cutting alkaline biotite granite of Lost Creek.—The contact of the alkaline biotite granite with the Madison limestone, though ill exposed south of Lost Creek, is apparently a fault, for the limestone is little metamorphosed and locally shows brecciation. The contact dips rather gently eastward. On Lost Creek a little east of the quadrangle the evidence of faulting is more conspicuous. A gulch has been eroded on the north side along the contact, and the granite near it is much brecciated and chloritized.

Folding and faulting of tuffs and gravels.—Along Warm Spring Creek and Lost Creek the tuffs and underlying gravels are thrown into open folds and are cut by faults. The prevailing dip is eastward and amounts to 70° in the tuff at the place where Lost Creek enters the broad Clark Fork valley. Not only are the tuffs much deformed, but the gravels that overlie them unconformably are gently tilted and affected by many small faults; the dips locally amount to 20°, and some of the faults, among which both the normal and the steep reversed type are represented, have throws of about 5 feet.

Within the quadrangle, north of lower Warm Spring Creek, some small exposures of the gravel show rather steep dips.

EASTERN PART OF ANACONDA RANGE.

Deformation of gravel near Grassy Mountain.—The great elevation which the gravel attains on Grassy Mountain, where it is much higher than it has been seen elsewhere, indicates in itself a considerable deformation by tilting. The bedding on the summit is sensibly horizontal, and in only one place has a pronounced inclination been detected. On Sevenmile Creek sandy layers show a dip of 15° upstream, or away from the general direction of tilting, which indicates that real folding has taken place.

Faulting of diorite and granite.—At the head of Mill Creek brecciated limestone is in contact with diorite that has an east-west and vertical schistosity. The two rocks are probably faulted together, but there is no means of measuring the throw of the fault.

All along Mill Creek, shearing in the granites and granodiorite is general, but it is not expressed by a very definite schistosity except in the lower part of the canyon. Near the eastern boundary of the quadrangle, however, an exposure in the stream channel shows a very marked and regular schistosity in biotite granite striking N. 70° E. and dipping 23° S., which is doubtless related to a fault between the granite and the Madison limestone. The evidence for this fault is very clear on the south side of Mill Creek canyon about a mile from the quadrangle boundary, where limestone breccia and extremely sheared and chloritized granite are exposed within a hundred feet of each other.

North of Mill Creek the schistosity becomes less definite, but beyond Clear Creek it is again distinct and has a dip of about 30° N. The contact with the tilted Tertiary gravels at the

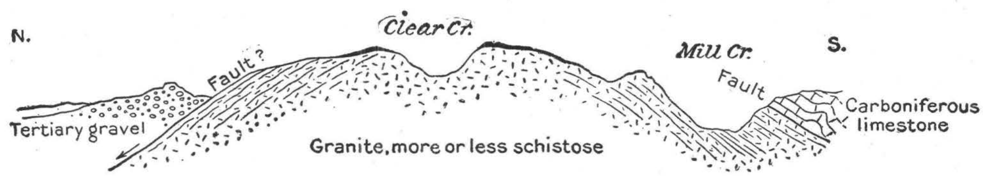


FIGURE 9.—Schistosity and faults in granite.

foot of the mountain follows a remarkably straight, smooth facet, which bevels the gentle slope above and dips about parallel to the schistosity in the granite. This contact is taken to be a fault. The phenomena here present a striking analogy to those along the great Bitterroot fault described by Lindgren.[1]

A section showing the structure as interpreted is given in figure 9.

FLINT CREEK AND ROCK CREEK BASINS.

Deformation of the earlier gravel on Rock Creek is illustrated in Plate XVI, *B*. In the exposure of which this is a view the dip is about 25° E. The dip has not been measured elsewhere.

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

The terraces about Philipsburg have a marked inclination, but this is chiefly due to the fact that the wash from the hills has accumulated most deeply at the base of the bedrock slopes. A strong suggestion that there has been warping of at least the older part of the terrace gravels is given by the position of the remnant near the pass at the head of Trail Creek.

[1] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 47.

CHAPTER X.

MINERALOGY.

LIST OF THE MINERALS.

The rocks and ores of the Philipsburg quadrangle contain an exceptionally large number of minerals, but nearly all those that occur in the igneous rocks and the less altered sediments could probably be found in most areas of similar size that are not unusually poor in lithologic types. The remarkable mineralogic richness of this field is due mainly to the fact that it abounds in metamorphosed calcareous rocks and in ore deposits widely diverse in character. More than 90 species of minerals have been satisfactorily identified; a few additional species are indeterminate, and the identity of a few others is in doubt.

The minerals of definite commercial value, which alone will be of special interest to many readers of this report, have been marked with asterisks in the list of minerals below and in the headings throughout this chapter.

It is evident, however, that no sharp line of separation can be drawn between valuable and nonvaluable minerals. Those marked as valuable contain the metals for which the deposits have been or may be exploited, or furnish metallic by-products of some value when smelted. Zinc blende, which is marked as valuable, and which contributes as much as 12 per cent zinc to some of the ores, is valueless with the present method of treatment, but may become a source of profit if an economical method of extracting it can be employed. Hübnerite, platinum, zircon, wolframite, and monazite, minerals of economic utility when they can be gathered in sufficient amount, occur very sparingly either in mill concentrates or in black sands from sluice boxes. They are not marked as valuable minerals, because they are not known to be present in commercial quantities. Many of the minerals that are not marked valuable may under certain conditions have a commercial value. Some of them, such as those containing iron or lime, are desirable constituents of the ore on account of their fluxing properties. Relatively low-grade ores may be made to pay when lime and iron are present in sufficient quantity to form an ore suitable for mixing with more highly siliceous ores. Where the proportion of quartz is unusually high the ore may have an additional value for converter linings. Such rare minerals as ludwigite and hübnerite may have a certain value to collectors of minerals.

In the following list and the subsequent notes on occurrences the minerals are arranged in the same order as in Dana's "System of mineralogy":

Minerals of the Philipsburg quadrangle.

[* Valuable commercially.]

Carbonaceous matter.	*Pyrrhotite (auriferous).	*Cuprite.
Sulphur.	*Chalcopyrite.	Corundum.
*Gold.	*Bornite.	Hematite (specularite).
*Silver.	*Pyrite (auriferous).	Ilmenite.
*Copper.	*Arsenopyrite (auriferous).	Spinel.
Platinum.	*Pyrargyrite.	*Magnetite.
Realgar.	*Proustite.	Rutile.
Orpiment.	*Tetrahedrite.	*Pyrolusite.
Stibnite.	*Gray copper.	Limonite.
*Galena.	*Enargite.	Brucite.
*Argentite.	*Cerargyrite.	Calcite.
*Tellurides.	Fluorite.	Dolomite.
*Chalcocite.	Quartz.	Siderite.
*Zinc blende.	Chalcedony.	Rhodochrosite.
Cinnabar.	Opal.	*Cerusite.

Minerals of the Philipsburg quadrangle—Continued.

*Malachite.	Vesuvianite.	Margarite.
*Azurite.	Zircon.	Clinochlore.
Orthoclase.	Zoisite.	Pennine.
Microcline.	Pistacite.	Serpentine.
Anorthoclase.	Clinozoisite.	Talc.
Plagioclases.	Allanite.	Kaolinite.
Hypersthene.	Andalusite.	*Chrysocolla.
Diopside.	Sillimanite.	Titanite.
Augite.	Prehnite.	Monazite.
Wollastonite.	Minerals of the humite group.	Apatite.
Rhodonite.	Tourmaline.	*Pyromorphite.
Tremolite.	Dumortierite ?	*Pseudomalachite.
Actinolite.	Zeolites (sp. indet.).	Ludwigite.
Hornblende.	Muscovite.	*Sulphates of iron and copper.
Cordierite.	Lepidolite ?	Barite.
Garnet.	Biotite (common).	Wolframite.
Olivine (forsterite).	Biotite (green).	Hübnerite.
Scapolite.	Phlogopite.	

OCCURRENCE.

Carbonaceous matter.—Carbonaceous dust is abundant in some of the shales and limestones, particularly in the lower part of the Madison limestone and in the shale member of the Colorado formation. Coal has been found in the latter beds near Drummond, but not within this quadrangle.

Sulphur.—In the Bunker Hill mine small crystals of native sulphur coat the fragments of crushed siliceous ore.

**Gold.*—Native gold is widely distributed in the ore deposits. It occurs in relatively large masses at the Cable and Gold Coin mines and in small leaves or flakes in many other deposits, but in the main it forms a fine dust included in quartz, pyrite, and arsenopyrite. The iron sulphides are nearly always somewhat auriferous.

**Silver.*—Native silver is an important ore mineral in the silver-gold fissure veins in granite and in the silver-bearing replacement veins in calcareous rocks. It occurs as thin sheets or as flakes which cut the quartzose ore, and has presumably been formed through the reduction of silver sulphides and other silver-bearing minerals. It is most abundant in the upper portion of the enriched zones of the lodes, but was encountered as far as 700 feet below the surface. Inasmuch as the unaltered primary ore in the lowest levels does not contain native silver, the mineral is probably wholly of secondary origin.

**Copper.*—Native copper is rare in the ores of this quadrangle. A few small particles of this metal have been found in the upper levels of the Cable mine, where it is presumably an oxidation product of copper-bearing sulphides.

Platinum.—According to Mr. L. U. Loomis, of Philipsburg, platinum has been identified in the gold of ores of the Gold Coin mine. The black sands from the sluice boxes of placer deposits in Princeton Gulch which were sent to the testing laboratory of the United States Geological Survey were also found to carry traces of this metal, but no occurrences of platinum were observed by the writers.

Realgar.—Realgar, the red arsenic monosulphide, is widely distributed in small amounts in the silver-gold fissure veins near Philipsburg. It occurs in the lower levels of the Granite mine, where it is a primary mineral.

Orpiment.—Orpiment, the yellow trisulphide of arsenic, occurs here and there in the ore of the Granite-Bimetallic and other silver-gold lodes near Philipsburg, where it is associated with the red arsenic sulphide, realgar.

Stibnite.—The antimony sulphide is abundantly developed in the primary ore of the silver veins near Philipsburg.

**Galena.*—Galena is present in the ore of each group of silver deposits and in some of the gold ores. Although of wide distribution, it rarely occurs in sufficient amount to make its lead content a source of profit to the miner. Parts of the Granite-Bimetallic lode carried a notable quantity of argentiferous galena, but on the whole it is comparatively an unimportant ore. The galena of the Royal vein is said to carry much gold.

**Argentite.*—Argentite (silver glance) is a common mineral in the silver deposits, especially in the upper part of the sulphide zone, where it is presumably a secondary mineral deposited by sulphate solutions, which were formed by the oxidation of sulphide ore. At the Hope mine it is possibly in part a primary mineral.

**Tellurides.*—Tellurides are very rare in the ores of the Philipsburg quadrangle, but a gold-bearing telluride is said to be present in some of the gold ores. A sulpho-telluride of bismuth has been found in ores from the Southern Cross and Cable mines.[1]

**Chalcocite.*—Chalcocite is of local occurrence in practically all the silver mines, but it is not abundant in any of the deposits. It occurs as thin films, coating fragments of pyrite and chalcopyrite, and as fillings of secondary fractures of the lodes. A sooty amorphous substance which occurs in considerable abundance in the Combination and Hope ores, and which is confined to fracture planes and drusy cavities, is presumably a mixture of chalcocite and the silver sulphide argentite. Some of the copper ore of the Cable mine is fractured pyrite and chalcopyrite coated with films of chalcocite.

**Zinc blende.*—Zinc blende is present in considerable quantity in all the silver-bearing fissure veins near Philipsburg and has been noted in the Combination vein and in the silver deposits of Boulder Creek. It is rarely present in the gold mines and has not been formed in the bedding plane deposits of siliceous silver ores. It is in the main, and possibly altogether, a primary mineral.

Cinnabar.—The sulphide of mercury is said to have been found in the sluice boxes of placers on Gold Creek. It is not abundant.

**Pyrrhotite.*—Pyrrhotite, or magnetic iron pyrite, is present in large quantities in the contact-metamorphic deposits of Cable, where it is associated with pyrite, magnetite, calcite, and other minerals. It is present also in some of the gold-bearing replacement veins in limestone, but does not occur in the ore of the silver-gold fissure veins or in the silver ore replacing limestone. It is locally abundant in highly metamorphosed schists, where it may be a metamorphic mineral.

**Chalcopyrite.*—Chalcopyrite forms masses of considerable size in the Cable mine, where it is present as a primary ore. It is not abundant in the silver-gold lodes. In some of these veins it appears locally in well-formed crystals coating cavities, where it is unquestionably of secondary origin. It is also developed as disseminated grains in an aplite mass between Red Lion Mountain and the Twin Peaks.

**Bornite.*—Bornite is not an abundant ore mineral in any of the deposits, but it occurs in small quantity in the ore of the Cable, Queen, Modoc, Granite, and other mines. In the lower levels of the Cable mine films of secondary bornite coat fragments of crushed chalcopyrite.

**Pyrite.*—Pyrite is apparently a primary constituent of the granitic rocks, and also forms disseminated grains of secondary origin in various igneous and sedimentary rocks. It is present in varying proportion in all the gold and silver deposits that have been exposed at any considerable depth. It is disseminated in the marbleized limestones near igneous contacts, and, with calcite and other minerals, forms large bodies of gold ore in the Cable mine. It is the most abundant metallic sulphide in all the gold lodes, and it is present, though less abundantly, in all the silver lodes as well.

**Arsenopyrite.*—Arsenopyrite is an abundant primary mineral in the lower zones of the silver-bearing fissure veins near Philipsburg, and it contains a large proportion of the gold of these deposits. It is present but not abundant in the Cable mine. Arsenopyrite is not known to be a constituent of secondary ores deposited by descending sulphate solutions.

**Pyrargyrite.*—Dark ruby silver is probably the most important ore mineral in the Granite-Bimetallic lode and in some other silver veins near Philipsburg. The silver sulphantimonate is much more abundant than light ruby silver, the silver sulpharsenate, with which it

[1] Sharwood, W. J., Notes on tellurium-bearing gold ores: Econ. Geology, vol. 6, No. 1, 1911, p. 29.

is in places associated. Pyrargyrite occurs massive, filling fracture seams which cut the older minerals and forms crystals as big as a cherry, lining cavities in the vein. Small specks of pyrargyrite are intimately intergrown with quartz and gray copper in the primary ore, but the fact that most of it is found filling cracks cutting across the primary ore shows that it is in the main secondary, and its greater abundance in the upper levels indicates that it has been deposited by cold descending waters.

**Proustite.*—Proustite, light ruby silver ore, is a silver sulpharsenate corresponding to the sulphantimonate, pyrargyrite, whith which it is sometimes associated. Where noted in the Granite-Bimetallic lode its occurrence is secondary.

**Tetrahedrite.*—Tetrahedrite, in part of the argentiferous variety freibergite, is a common ore mineral of the silver deposits and an important constituent of the Granite-Bimetallic lode. It is in the main a primary mineral, though it may also be secondary.

**Gray copper.*—Gray copper is a term applied somewhat loosely in this report to mixtures of the copper sulphantimonate, tetrahedrite, and the copper sulpharsenate, tennantite. The crystal forms of these minerals are rarely developed, and the massive mixture is very generally known to contain both arsenic and antimony. Tetrahedrite is probably an important source of silver and is presumably the argentiferous variety freibergite.

**Enargite.*—This copper sulpharsenate may be present in the massive form in some of the arsenical silver ores, but the crystallized enargite which occurs extensively at Butte has not been observed in the mines of this quadrangle.

**Cerargyrite.*—Cerargyrite, or horn silver, is an important ore mineral of the deposits of the Granite and Hope mines, where it is limited to a relatively shallow depth in the oxidized ore. In this zone it supplied a large proportion of the values in the bonanza ore. As a rule it is associated with native silver. In the Granite vein it does not occur at such great depth as secondary ruby silver. It is probably secondary altogether.

Fluorite.—Fluorite of metamorphic origin is abundant in a banded rock derived from shale of the Silver Hill formation near an intrusive contact at the head of Mill Creek. The mineral is apparently a primary constituent of an alkaline granite occurring on Lost Creek and also occurs in a decomposed granite on the north wall of Mill Creek canyon, but is here probably secondary.

Most of the ores of this quadrangle do not contain fluorite, but it is present in the lower levels of the Hope mine, in association with quartz and pyrite. It was also noted in the ore of the Albion mine.

Quartz.—Quartz is the most abundant constituent of the sandstones and quartzites, and of the greater part of the shaly sediments. In cryptocrystalline form, possibly mingled with some opal, it is the dominant substance in chert, which occurs abundantly in the Madison limestone and in limestones of the Red Lion formation and more sparingly in the other Paleozoic limestones and dolomites. It is contained in all the igneous rocks of the quadrangle, its invariable presence in these being a regional character of notable importance.

It is present in considerable quantity in all of the ores, and in some of them it is the principal gangue mineral. The proportion of quartz is lowest in the ores of contact metamorphic origin; in the somewhat similar ores of the gold replacement veins the quartz content is somewhat greater, and it is higher still in the fissure veins, where it constitutes 75 per cent of the ore. It is highest in the silver-bearing replacement deposits of Hope Hill and in the silver ores from the Combination mine. Pyrite is most abundant in the gold deposits and less abundant in the silver deposits; quartz, on the other hand, is most abundant in the silver deposits and less abundant in the gold deposits.

Quartz locally replaces carbonates in the limestones, and much of the chert may have been formed in this way.

Chalcedony.—Chalcedony, a fibrous cryptocrystalline variety of silica, is locally formed in the granitic rocks by alteration at relatively shallow depths. It also forms veinlets in a quartzose vein rock collected at the surface of Hope Hill and occurs in the amygdules of lava.

Opal.—Opal, very impure from admixture of brown and yellow iron oxides, is the chief constituent of a presumably veinlike mass on which a prospect shaft has been sunk $1\frac{1}{2}$ miles east-southeast of bench mark 5,005 (see map, Pl. II), north of Philipsburg. It has doubtless been formed here at relatively slight depth. Opal was not found in the ore-bearing veins.

**Cuprite.*—Cuprite, or copper oxide, is present in small amount in the oxidized zone of many of the deposits.

Corundum.—Although sapphires, a variety of corundum, are washed from placers in the mountains west of the Philipsburg quadrangle,[1] corundum has been found within the quadrangle at only one point. It forms microscopic grains rather sparingly distributed in a rock derived from the Silver Hill formation, containing fluorite, feldspar, lithium mica, and margarite, at the head of Mill Creek. It is not probable that this rock would furnish sapphires of commercial value, or that the Rock Creek sapphires are derived from a similar rock.

Hematite.—The anhydrous ferric oxide, hematite, forms microscopic red transparent plates in some of the igneous and metamorphic rocks. It has not been identified in the ore deposits except as the micaceous variety, specularite. The oxidized surface ores, especially those of the replacement deposits in limestone, contain an iron oxide which gives a cherry-red streak, but this amorphous red ore contains some water and is probably turgite, a hydrated iron oxide, which contains less water than limonite. Of similar nature, probably, is the finely divided red iron oxide which colors most of the Spokane formation, a great part of the Kootenai formation, and the lowest division of the Quadrant formation.

Ilmenite.—Microscopic flakes of ilmenite, transparent in a purplish-brown tint, occur in some diorites and metamorphosed sediments. Some of the iron ore forming larger grains in the diabasic rocks is probably ilmenite or titaniferous magnetite, but has not been positively identified. Ilmenite occurs associated with magnetite in the metamorphosed limestones.

Spinel.—Green spinel has been found at a few places in sedimentary rocks that have suffered exceptionally intense contact metamorphism. It is associated in one specimen with cordierite, quartz, and micas, and in others with calcite, diopside, forsterite, garnet, humite, phlogopite, and a pale chlorite.

**Magnetite.*—In the form of small, usually microscopic, grains magnetite occurs in most of the igneous and sedimentary rocks. It is also developed in many large masses through replacement of limestones near igneous contacts. Where it occurs thus it is always associated with olivine or forsterite and sometimes in addition with a mineral of the humite group or with ludwigite. The crystallization of the mineral in these masses is relatively coarse; the individuals, which are irregular in form, have dimensions ranging from a few millimeters to about 5 centimeters. They commonly have a distinct octahedral parting. Some magnetite occurs with pyrrhotite and specularite in certain gold-bearing replacement veins, and minute magnetic dark specks in some of the silver lodes suggest the possibility that particles of magnetite may have been formed by oxidation of sulphides. The large masses of magnetite which replace limestones, however, are clearly not due to such oxidation, but are without exception of contact-metamorphic origin.

Rutile.—In many specimens of igneous rocks, notably some from the diorites of the Anaconda Range, the quartz and feldspar contain slender microscopic needles, which may be of rutile. The mineral occurs more commonly in the igneous rocks as a product of the decomposition of biotite, which alters to chlorite with included rutile needles crossing one another to form the familiar "sagenite webs." Rutile is also widespread as a microscopic constituent of the sedimentary rocks, particularly of the metamorphosed shales and sandstones. It is developed in the wall rock near some of the ore veins.

**Pyrolusite.*—Amorphous manganese oxides constitute a large part of the ore in the upper zones of lodes rich in the manganese carbonate, rhodochrosite. They are especially abundant in the upper part of the Cliff, Trout, and other veins of silver ore near Philipsburg. These oxides have been mined to a small extent for manganese. They are not primary and in depth will probably grade into rhodochrosite.

Limonite.—The yellow or brown hydrated oxide of iron is formed abundantly in the decomposition of sedimentary rocks that contain ferruginous carbonates. It is also extensively pro-

[1] Sterrett, D. B., Mineral Resources U. S. for 1907, pt. 2, U. S. Geol. Survey, 1908, p. 822.

duced by the alteration of pyrite, chalcopyrite, magnetite, and other iron-bearing minerals of the ore deposits, and where thus derived it occurs as a dull ocher-yellow or yellowish-brown earthy material confined to the outcrops and oxidized portions of the deposits.

Brucite.—Brucite, the hydrate of magnesia, occurs in a few specimens of highly metamorphosed limestone, where it forms aggregates of microscopic fibrous or scaly individuals, evidently pseudomorphic after some mineral not identified.

Calcite group.—Calcite is one of the most abundant minerals in this quadrangle, for a large part of the sedimentary column is built up of limestones and other calcareous rocks. The largest and purest masses occur in the Madison limestone, which is quarried for the Anaconda smelter on Warm Spring Creek. It is common as a decomposition product of feldspars and ferromagnesian minerals in the igneous rocks. It is the principal gangue mineral in the Cable mine, and is present in varying amounts in all the ore deposits of the quadrangle. It is associated with the ores of many of the lode deposits, and occurs chiefly in the wall rocks near the veins, where it has been deposited through replacement by the vein-forming waters.

Dolomite is a constituent of the Hasmark formation, and is present more or less abundantly in the limestones and shales of the Jefferson, Newland, and other formations. In thin sections of these rocks it generally displays the characteristic tendency to form crystals. It is not an important gangue mineral in the ore deposits. Crystals of dolomite intergrown with secondary chalcopyrite line cavities in some of the veins.

In some of the calcareous sediments a considerable part of the carbonate is ferruginous.

In these rocks the carbonate is probably original. Siderite occurs, however, together with calcite, as a secondary constituent of certain granites and aplites. In the Flathead quartzite, about 3 miles west of Mount Tiny in the Anaconda Range, siderite has been developed by a mode extremely common in the Cœur d'Alene district.[1] It has formed grains about 1 millimeter in diameter, with more or less completely developed crystal form, evenly disseminated through the rock, but these are replaced by limonite in weathered specimens. Examination of the thin section shows that these crystals are larger than the clastic grains of the rock and that their faces cut across the grains, both of which facts clearly indicate that the siderite has replaced quartz.

Rhodochrosite.—Rhodochrosite, or manganese carbonate, is an abundant gangue mineral in the silver-gold veins near Philipsburg, in some of which it forms a matrix for brecciated silver-bearing quartz. It was presumably deposited by ascending waters and is not regarded as a secondary mineral.

**Cerusite.*—Lead carbonate is present in the oxidized ore of some of the deposits, presumably as an alteration product of galena.

**Malachite.*—Malachite, the hydrated copper carbonate, is present here and there in the zones of oxidation of nearly all deposits, and is confined to such zones.

**Azurite.*—Azurite, the blue copper carbonate, occurs in the oxidized zone of many of the deposits but is not abundant in any of them. It is a product of oxidation of copper minerals, especially of gray copper, and is much less abundant than malachite, the green carbonate.

Feldspars.—The potash feldspars (microcline and orthoclase) and the soda-lime feldspars occur as principal constituents of igneous rocks, as clastic grains in sedimentary rocks, and as products of contact metamorphism.

The soda-lime feldspars observed in the igneous rocks of the Philipsburg quadrangle range in composition from nearly pure albite to a compound more than 90 per cent anorthite.

Feldspars probably belonging to the anorthoclase series occur in the pyroxene aplites.

Clastic grains of feldspar occur rather commonly in the sandy shales and sandstones that have not been very thoroughly worked over by water, orthoclase and microcline being more common in such rocks than plagioclase.

Pyroxenes.—Hypersthene occurs in a few specimens of basic igneous rock, and a pale rhombic pyroxene in a calcareous inclusion in diorite.

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[1] Lindgren, Waldemar, Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 680. Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 97.

Augite is a chief constituent of the diabases and occurs in many of the diorites and granodiorites. It has not been identified in the sediments. Nearly all of it is pale green; some of that in the diabases is faintly brownish.

Diopsidic pyroxenes are probably the most widespread and abundant constituents of the metamorphosed calcareous rocks. They are developed by contact metamorphism in some of the relatively pure limestones but far more abundantly in the calcareous shales. They are almost invariably associated with amphiboles and quartz and commonly with calcite, mica, garnet, epidote, scapolite, forsterite, or other minerals, according to the conditions under which they were formed. The maximum distance from contacts at which metamorphic diopside forms is considerably less than that of the micas, perhaps a trifle less than that of the amphiboles, somewhat greater than that of scapolite, and much greater than that of garnet.

Wollastonite.—Wollastonite has been identified in only a very few specimens from the Philipsburg district, and all these were collected within a short radius of Twin Peaks in close proximity to irruptive contacts. The mineral is in microscopic laths forming a feltlike aggregate and is associated with garnet, vesuvianite, diopside, and calcite.

Rhodonite.—Rhodonite, a manganese silicate, occurs in the massive form in the Granite mine but is much less abundant there than rhodochrosite.

Amphiboles.—Hornblende is an essential constituent of many of the igneous rocks of the district. In most of these it is of the common green variety, but in some of the diorites and andesites it is in part greenish brown, usually with zonal banding. Deep-brown hornblende occurs in some of the andesite. Uralitic hornblende occurs in many of the augite-bearing rocks and has completely replaced the pyroxene of some specimens of diabase. In specimens from the great sill on Lost Creek the principal ferromagnesian mineral is deep-green hornblende similar in every respect to that most commonly occurring as an original constituent of igneous rocks, though it is believed to have been produced from augite through contact metamorphism.

The metamorphic amphiboles comprise common hornblende, actinolite, and tremolite, apparently connected by complete gradations. Tremolite is developed chiefly in limestones and dolomites, particularly in the Madison limestone. Calcite is invariably the most abundant mineral associated with it; other minerals that commonly accompany it are diopside, quartz, muscovite, and scapolite. It has not been found with garnet. Green amphiboles are abundantly developed in calcareous shales and sandstones, and actinolite is formed in some rather pure limestones close to the granite contacts. The minerals commonly occurring with these amphiboles are quartz, calcite, diopside, epidote, scapolite, and garnet.

The amphiboles, like the pyroxenes, occur throughout a zone extending outward from the immediate contact for about half a mile. The amphibole in the metamorphic rocks is largely a fibrous variety derived from pyroxene.

Cordierite.—Cordierite is common as a contact mineral in shaly rocks of various formations ranging from Algonkian to Cretaceous. It is invariably accompanied by quartz, biotite, and muscovite and usually by andalusite or sillimanite or both. Tourmaline, magnetite, and zircon occur in most of the cordierite-bearing rocks, and spinel and garnet in some of them. Cordierite has not been observed in rocks containing amphibole and pyroxene.

The distribution of cordierite with respect to irruptive contacts is similar to that of andalusite, but the rocks that contain it have a narrower range of composition, so that strict comparison is difficult.

Garnet.—Garnet, mostly reddish brown but partly green or pale yellow, is abundantly formed in the contact metamorphism of calcareous shales and locally in that of limestones virtually free from silica. Its occurrence is confined to comparatively narrow zones, this mineral not being developed nearly so far from the contacts as amphibole, pyroxene, or scapolite. Some calcareous shales, such as those in the Silver Hill formation near Philipsburg, are metamorphosed to rocks composed almost wholly of garnet. As a rule, however, the garnet formed in calcareous rocks is accompanied by pyroxene, epidote, calcite, and quartz in considerable amount. Among its common associates are amphibole, vesuvianite, scapolite, magnetite, and feldspar. Garnet crystals associated with some of these minerals are shown in Plate IX, *A* (p. 60).

Pinkish garnets in small quantity occur in metamorphosed aluminous rocks, such as those of the Prichard formation, where their characteristic associates are quartz, mica, cordierite, spinel, and sillimanite.

Red garnets of small size are constituents of some pegmatites and aplites.

Olivine group.—Olivine as a constituent of igneous rock has not been found within the Philipsburg quadrangle. In many specimens of the metamorphic limestone, however, olivine minerals, probably near forsterite, have been identified.

The common associates of olivine are calcite, diopside, humites, spinel, phlogopite, and pale chlorite. These also occur in the bodies of magnetic iron ore formed by replacement of limestone near igneous contacts (Pl. IX, *B*). Very fresh grains of the mineral associated with magnetite and ludwigite in the Redemption mine near Philipsburg, have a water-white color and a relatively low refractive index that indicate a very low content of iron.[1]

Scapolite.—Scapolite has been developed very abundantly in the calcareous sedimentary rocks by contact metamorphism. It also occurs as a primary constituent of igneous rock.

The metamorphic scapolite is developed most abundantly in calcareous shales, rarely in relatively pure limestones. It may be accompanied by any of the minerals calcite, quartz, diopside, tremolite, actinolite, hornblende, epidote, garnet, feldspar, and titanite, as well as others of less importance.

The metamorphic scapolite of the Philipsburg district has been formed in immediate proximity to intrusive contacts, but in many places it occurs also fully a mile from any observed outcrop of igneous rock. As it is obvious that the contacts may be closer underground than at the surface, these observations do not make known the absolute range of the scapolite, but they show it to be much broader than that of garnet, vesuvianite, and the humites and comparable to that of the micas, amphiboles, and pyroxenes. Although these minerals are found in all the contact zones, scapolite occurs only in parts of certain ones. This is because chlorine, an essential constituent of scapolite supplied to it by the intrusive magmas, is given off only by certain masses of magma and more abundantly at some parts of their peripheries than at others.

Scapolite is an abundant and clearly original constituent of an aplitic dike rock rich in pyroxene described on page 122, and is probably also original in some dioritic rocks.

Vesuvianite.—Vesuvianite is one of the less common minerals of the metamorphosed limestones of the district. Its common associates are garnet, wollastonite, epidote, calcite, and tremolite. It occurs only very close to contacts.

Zircon.—Zircon can be identified in most thin sections of both igneous and sedimentary rocks. Small crystals of zircon have been identified in the black sands from gulches tributary to South Boulder Creek.

Epidote group.—Zoisite and clinozoisite occur as products of the decomposition of feldspar in the basic igneous rocks, also as metamorphic minerals in certain calcareous shales.

Pistacite, the common yellowish-green epidote, is a very common secondary constituent of the igneous rocks and in one rock appears to be original. It is also common in the metamorphic rocks, particularly those that contain abundant garnet. Other minerals with which it is commonly associated here are quartz, calcite, amphibole, pyroxene, and scapolite. In the calcareous metamorphic rocks it frequently appears to be essentially contemporaneous with these other minerals, but in many places it also forms veinlets, small or even microscopic in size, which are evidently of subsequent formation. Inasmuch as the associated minerals do not in general appear decomposed, however, it is probable that the epidote has not been formed at their expense, but is rather a product of a later stage in the metamorphic process.

Allanite is widely distributed in this quadrangle, both as a pyrogenic and as a metamorphic mineral. As a pyrogenic mineral it is an accessory in almost all the granular and porphyritic intrusives.

Andalusite.—Andalusite, one of the commoner metamorphic minerals of the district, is abundantly developed in shales that contain little or no calcium. It is invariably accompanied by quartz, biotite, and muscovite, and commonly by sillimanite, cordierite, feldspar, tourma-

[1] Schaller, W. T., Ludwigite from Montana: Am. Jour. Sci., 4th ser., vol. 30, 1910, p. 146.

line, and small quantities of other minerals. It is never intimately associated with pyroxene, amphibole, or scapolite, a fact probably explainable on chemical grounds, for where enough alumina to form andalusite is present, the feldspars and micas would be formed rather than the less aluminous minerals nearest them in composition.

Sillimanite.—Sillimanite is not uncommon as a constituent of aluminous rocks that have been intensely affected by contact metamorphism. It is particularly abundant in the Prichard rocks of the Anaconda Range and occurs there also as a minor constituent of the Neihart quartzite. It is invariably associated with quartz and the micas and is usually accompanied by andalusite and frequently by cordierite. Tourmaline, magnetite, rutile, and zircon are generally present as minor constituents in the rocks that contain sillimanite. Sillimanite occurs in the same kinds of rock as andalusite but is not developed so far from igneous contacts. Like andalusite this mineral does not occur in immediate association with silicates of lime.

Prehnite.—Prehnite has been found in only a single specimen, in which it forms microscopic veinlets in a contact rock composed chiefly of garnet.

Humite group.—Minerals of the humite group occur in metamorphosed magnesian limestones, particularly in the area between Warm Spring and Thornton creeks. These minerals depend for their formation upon emanations of fluorine, which seem to come only from certain masses of magma. The formation of humite is localized, therefore, like that of scapolite. It is usually associated with calcite, forsterite, spinel, phlogopite, and chlorite and occurs also with olivine and magnetite in the iron-ore bodies mentioned under those minerals. Although their characteristic twinning and their pleochroism and other optical properties clearly identify these minerals with the humite group, it was not possible in any specimen to determine the extinction angle, which affords the only optical means of discriminating between chondrodite, humite, and clinohumite.

Tourmaline.—Tourmaline is widely distributed in the metamorphosed rocks of the district and is a constituent of some of the igneous rocks but is abundant only in certain pegmatites and aplites. As a metamorphic mineral it is generally visible only under the microscope, though it forms crystals about 1 centimeter long in certain specimens. Its habitat is chiefly in the noncalcareous shales and impure sandstones and their derivatives. Wherever these rocks show any considerable evidence of alteration by igneous agency, amounting even to thorough cementation or the development of mica, it is rarely absent. It is less abundant in more highly siliceous rocks and is on the whole relatively scarce in metamorphosed calcareous rocks though locally abundant and conspicuous in limy shales.

In consequence of its general distribution, tourmaline is associated with most of the metamorphic minerals. The rocks in which it develops most abundantly are those in which quartz, mica, andalusite, sillimanite, and cordierite are abundant. It less frequently accompanies calcite, olivine, amphibole, and pyroxene and has not been noted in association with garnet in lime-rich rocks.

It is one of the metamorphic minerals which may form farthest from igneous contacts, and it does not appear to be most abundant in close proximity to igneous rocks. On the contrary, certain highly metamorphosed rocks of a composition favorable to its development, as, for example, some of the cordierite-bearing schists derived from the Prichard formation, are notably poor in tourmaline. It appears as if the gases upon whose presence the formation of this mineral depended were so volatile that they could find no rest in the places where metamorphic activity was greatest.

Tourmaline is abundant near Twin Peaks as a filling of minute joint fissures in quartzite, and native gold has been noted in association with tourmaline on Cable Mountain.

Dumortierite?—A specimen of metamorphosed argillaceous sediment consisting chiefly of quartz, mica, and andalusite, collected from the immediate contact with the granite 2 miles south of Fred Burr Lake, contains a few grains of a deep-blue mineral which, from its occurrence and such properties as could be determined, appears more likely to be dumortierite than any one of the few other minerals with intense blue color.

Zeolites.—Undetermined zeolites occur in the andesite on lower Willow Creek. Zeolites also occur in some of the intrusive rocks as products of the decomposition of scapolite and feldspar.

Micas.—Muscovite, with its finely divided variety sericite, is probably second only to quartz in the breadth of its distribution and the variety of its modes of occurrence. This mica is a primary constituent of many of the granular intrusives and replaces the feldspar to a greater or less degree in most of the igneous rocks. Clastic flakes of muscovite are common in the sediments and are developed often in the form of sericite by metamorphism in various kinds of sedimentary rocks. It also occurs as a vein-forming mineral. The vein quartz of some of the deposits in the northeastern corner of the quadrangle is cut by thin veinlets of muscovite, and this mica forms the marginal parts of many quartz veins in quartzite at the head of Barker Creek. In most of the fissure veins sericite was not deposited in open spaces, but it was formed extensively in the walls by vein-forming solutions through metasomatic processes.

A pale lithium-bearing mica occurs associated with fluorite in a metamorphosed shale at the head of Mill Creek.

Phlogopite, either pale brown or colorless, is a widespread though nowhere very abundant component of metamorphosed magnesian limestone.

Biotite is almost as common as muscovite, for it is present in even more varieties of igneous rock and in all the kinds of altered sediments excepting some of the relatively pure limestones, in which only phlogopite is developed.

Veinlets of a green mica are found locally, as in the Cable mine, at the contact between granite and limestone and in small fissures cutting magnetite. Some of the flakes are several inches in diameter. Like normal biotite, this mica is highly flexible and elastic and has an extremely small optic axial angle. Chemical tests of the mineral by W. T. Schaller indicate that it does not contain chromium.

Margarite.—Margarite is a minor constituent of a metamorphic sedimentary rock rich in fluorite collected at the head of Mill Creek. It is accompanied, as is common, by corundum. Its identity was determined by its characteristic optical properties and lamellar twinning parallel to the base.

A pale-green mineral occurring with olivine, diopside, spinel, etc., in a limestone inclusion of the diorite east of Storm Lake appears to be allied with the "brittle micas," although it has not been positively identified with any one of them. It has a micaceous cleavage, but its folia are brittle and do not exhibit between crossed nicols the mottled appearance characteristic of the true micas. The mean refractive index is about 1.6, and the double refraction about 0.014. The extinction is sensibly parallel, and cleavage flakes are normal to the bisectrix of a very acute optic axial angle. The optical character is negative. The pleochroism, though far weaker than for biotite, is distinct and highly characteristic. Rays vibrating parallel to the cleavage are pale reddish brown; those vibrating normal to the cleavage pale apple-green.

Chlorites.—The variety of chlorite most common in the quadrangle is pennine, which replaces biotite and to a less extent the other ferromagnesian minerals and the feldspars in the igneous rocks. In the granitic walls of some of the fissure veins it has been formed at the expense of the ferromagnesian minerals by the metasomatic action of the vein-depositing solutions. It similarly replaces biotite in some of the metamorphosed sediments, and in some of these it also occurs as a direct product of contact metamorphism.

Pale-green and colorless chlorites allied to leuchtenbergite are widely distributed in metamorphosed magnesian limestones associated with calcite, forsterite, spinel, and humites.

Serpentine.—Serpentine occurs in some of the metamorphosed magnesian limestones and in the replacement bodies of magnetite as an alteration product of olivine and humite minerals and rarely of diopside.

Talc.—Talc occurs in diorite as a decomposition product of rhombic pyroxene.

Kaolinite.—Kaolinite is formed by the weathering of feldspars, muscovite, and other aluminous minerals, and with sericite it enters into the composition of the gouge which occurs along movement planes in many of the mines.

**Chrysocolla.*—Chrysocolla, the hydrous silicate of copper, is not abundant in any of the deposits of this quadrangle, but it is present here and there in the upper levels of many of the mines. It is of secondary origin and does not occur at great depths in any of the deposits.

Titanite.—Titanite is widespread as a constituent of all the igneous rocks except the most acidic and most basic and occurs abundantly in the metamorphic diopside-bearing rocks derived from calcareous sediments.

Monazite.—A minute quantity of monazite was found in samples of black sand from Little Gold Creek sent to the testing laboratory of the Geological Survey at Portland, Oreg. The mineral has not been identified in the solid rocks of the quadrangle but occurs in a specimen of the granite of the Royal batholith (the principal country rock at the head of Little Gold Creek) collected on Rock Creek about 2 miles east of the quadrangle.

Apatite.—Apatite here, as elsewhere, is a constituent of virtually all the igneous rocks. It is also very generally distributed in the sedimentary rocks, but there is some doubt whether it is everywhere of clastic origin in these or whether it has been introduced locally by metamorphic agency. In many specimens, however, the apatite, in common with the other constituents of the rock, has evidently been thoroughly recrystallized and may well be considered a metamorphic mineral.

**Pyromorphite.*—This lead chlor-phosphate is widely distributed in the oxidized zones of the silver lodes, where it forms crusts on shattered quartz or occurs as a thin film of yellowish powder coating cavities. It probably carries considerable silver. Inasmuch as it does not occur in the lower levels of the mines or in massive uncrushed ore, it is presumably secondary.

**Pseudomalachite.*—Pseudomalachite, the hydrated phosphate of copper, has been identified by Richard Pearce in the ore of the Combination mine.

Ludwigite.—Ludwigite, a rare borate of magnesia and iron, occurs at the Redemption iron mine near Philipsburg, where it is intimately mingled with magnetite and a smaller amount of forsterite. It is a greenish-black, very finely fibrous mineral that forms felty or radiating aggregates which in general appearance resemble astrakhan fur. In thin section only slender isolated fibers are transparent. They show high refractive index, straight extinction, positive elongation, and marked pleochroism, the rays vibrating parallel to the elongation being brown and those perpendicular to it bottle-green.

Sulphates of iron and copper.—Iron and copper sulphates are formed in the galleries of mines by secondary processes.

Barite.—Barite, or heavy spar, is not an abundant gangue mineral of the deposits, though it occurs in small amounts in the ore of the Hope, Midnight, Modoc, and other mines.

Wolframite.—A small quantity of wolframite was found in samples of black sands from Little Gold Creek sent to the testing laboratory of the Geological Survey at Portland, Oreg.

Hübnerite.—Hübnerite, the tungstate of manganese, has been identified in the ore of the Combination vein, where it is a primary mineral intergrown with quartz and sulphides. According to Goodale and Akers [1] the 20 to 1 concentrates of the Combination ore assayed one-third of one per cent tungsten.

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[1] Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 248.

CHAPTER XI.

ORE DEPOSITS.

GENERAL FEATURES.

Silver and gold are the metals of chief commercial value in the Philipsburg quadrangle. Copper, however, is present in much of the ore and is a commercial asset in some deposits. The silver ores carry zinc and lead, but at present these metals are of no great economic importance. Magnetic iron ore and manganese oxide have been mined for flux, and the latter also to a less extent for its content of manganese. Of about 140 mines and prospects in the quadrangle, more than half have produced ore; six mines have produced more than $1,000,000 each, and as many others have produced more than $100,000. The Granite-Bimetallic lode, from which considerably more than half of the output for the quadrangle has been obtained, is by far the most important of the deposits, and the others are dwarfed by comparison with it.

The deposits are of three types and include fissure veins cutting both igneous and sedimentary rocks, contact-metamorphic replacement deposits in limestone near the granitic intrusives, and replacement deposits in the sedimentary rocks, in part conforming with their bedding planes.

The precious-metal ores may be divided into four classes, of which the most important is a silver ore carrying a considerable quantity of silica, with some antimony, arsenic, and copper. The ores of the Granite-Bimetallic mines are of this class. Some gold is always present, but its proportion to silver is generally less than 1 to 200 by weight. A second important class is a siliceous silver ore in which the amount of the metallic sulphides is much smaller and the percentage of silica still higher. Gold is practically absent from ores of this type, which come from the Hope, Cadgie Taylor, and other replacement deposits in limestone. A third class of ore is the gold-copper ore of the Cable district, which carries a large proportion of iron and copper sulphides with calcite and a relatively small proportion of quartz. Only a little silver is present. The fourth class of ore is composed almost entirely of quartz and pyrite, and in it there is practically no silver. Sulphides other than pyrite are locally present but not in large quantities. The ore from the Royal, Sunday, and Pyrenees veins belongs to this class, and the ore from some of the gold-bearing replacement veins in limestone is presumably the oxidation product of ore of a similar character. The occurrence of the minerals in the ore deposits is briefly discussed in Chapter X.

GENERAL DISTRIBUTION.

Metalliferous quartz veins are distributed over a large part of the quadrangle but are most numerous in the northern and northeastern portions. The paying deposits are in general limited to relatively small areas within the larger tract, the most productive group of deposits being that of the Flint Creek mining district, adjoining and east of Philipsburg. This district is about 3 miles square and includes the camps at Granite, Hasmark, and Tower. Its principal product is silver.

In the Georgetown district, 6 miles south of the Flint Creek district, the deposits are not closely restricted but extend northward to the head of Flint Creek. The principal metal is gold, but silver deposits occur here and there in an area that extends eastward almost to Anaconda.

On Boulder Creek and its tributaries gold and silver deposits are located at many places over a large area. Here the Royal is the only mine which has yielded any considerable quantity of ore. What may be regarded as a continuation of this area of mineralization is the country around Pikes Peak and Rose Mountain, where gold and silver have been discovered in a large number of prospects.

In the Black Pine district, 9 miles northwest of the Flint Creek district, are low-grade deposits which at one time produced considerable silver. The Combination mine has supplied nearly all of the ore from this district. At Henderson, 3 miles northeast of Combination, are several gold deposits, the largest of which is in the Queen mine. On Flint Creek, near Flint station, are a great many gold, silver, and copper prospects, some of which have yielded small amounts of these metals. The Mountain Ram, Carp, Gold Reef, and other mines are in comparatively isolated deposits.

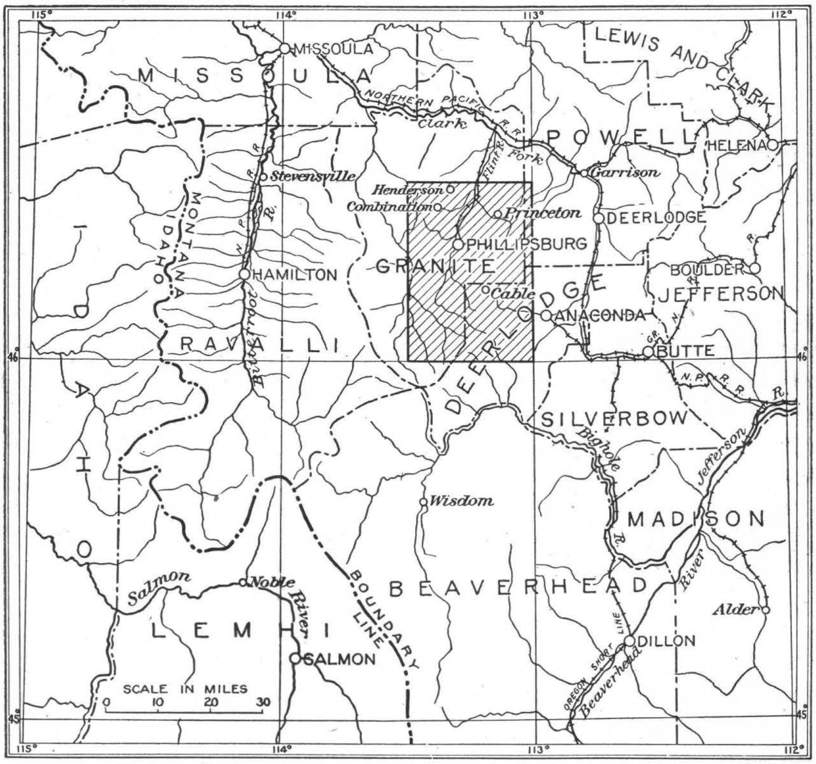

FIGURE 10.—Index map showing position of principal mining camps in the Philipsburg quadrangle.

The abundance of intrusive igneous rocks in the high and rugged range in the southeast portion of the quadrangle which forms part of the Continental Divide and the complex geologic structure of the region would seem to be favorable conditions for ore deposition. A few small quartz veins occur in this area, but no paying deposits have been discovered.

The location of the principal mining camps in the quadrangle is shown in figure 10.

GEOLOGIC RELATIONS.

The metalliferous deposits of the quadrangle occur both in igneous and in sedimentary rocks, but in the latter they are confined more or less closely to the vicinity of the contacts with igneous intrusions, and the most productive deposits are not more than a mile from such contacts.

The Philipsburg granitic[1] batholith, which is one of the largest bodies of intruding rock in the quadrangle, is bordered nearly everywhere by sedimentary rocks. At some places the sedimentary rocks are greatly changed by contact metamorphism, but no contact-metamorphic ore deposits, except some bodies of magnetic iron ore, are known to occur around this batholith. At Philipsburg the granite and the sedimentary rocks near it are cut by a large number of silver-gold fissure veins, and at the head of Flint Creek, in the Red Lion district, the limestone near its contact with the batholith is cut by gold-bearing veins.

The Cable batholith, which is closely similar in composition to the Philipsburg batholith, is a relatively small body of granite, which outcrops over an area of something less than 4 square miles. Several important gold deposits are situated in the sedimentary rocks near the contacts, part being of contact-metamorphic origin and the rest fissure veins. Gold-bearing veins occur also in the granite near the outer border of the batholith.

In the northeast corner of the quadrangle is another large body of granitic rock, which, with the sedimentary rocks near it, is cut by fissure veins carrying gold and silver. The Queen

[1] "Granite" in the chapters on economic geology is generally used in the broad popular sense, indicating a granular intrusive rock containing considerable quartz.

(Henderson) and Bunker Hill mines are in limestone near an intrusive granitic rock. The intrusive nearest the Combination lode is a granitic dike about a mile north of the Harrison shaft.

All the sedimentary rocks except the superficial Tertiary and Quaternary gravel beds were probably formed before any of the ores were deposited. Therefore none of the pre-Eocene consolidated rocks can be classed as barren on account of geologic age. The ore deposits are found in many of the formations, but some rocks, owing to their physical character or chemical composition, are more favorable for deposition than others, especially for particular classes or groups of deposits. The contact-metamorphic deposits, for example, are confined to calcareous rocks because such rocks are more easily dissolved and replaced by the mineralizing solutions. On the other hand, the simple fissure fillings, which carry both silver and gold, are best developed in granitic rocks and quartzites because, inasmuch as these rocks are more rigid than shales and limestones, they are more easily fractured, and spaces once opened are less likely to close.

Bedding-plane deposits of silver and of gold are numerous. These deposits, except in the Combination mine, occur in calcareous rocks, and in such rocks replacement is an important process of deposition. They are not confined to certain sedimentary horizons, though they are more likely to occur in some formations than in others, a condition due probably to differences in physical constitution rather than to differences in the chemical composition of the country rock.

The Newland formation, which is of Algonkian age, is composed of impure limestones and other calcareous beds. It has a considerable areal extent in the quadrangle but does not contain many important ore deposits. The Queen lode at Henderson, a bedding-plane replacement vein carrying gold and copper, is the most productive deposit in this formation.

The Spokane formation, which is the latest of the Algonkian formations, is composed of quartzites and red shales. It contains deposits of both silver and gold, the most extensive of which are those of the Combination mine. In the introduction of the deposits into the Spokane formation the most important process has not been replacement of the country rock but the filling of open spaces to form fissure veins, some of which follow the bedding planes and some of which cut across them. A number of the veins near the summit of Cable Mountain are examples of the latter variety. The Spokane formation over a considerable area in the quadrangle does not contain ore deposits, and in general the upper part, in which quartzite predominates over shale, appears to afford more favorable horizons than the lower, more shaly part.

The Flathead, which is at the base of the Cambrian, is a massive quartzite of fairly uniform medium grain. It does not contain any ore deposits known to be extensive, although it incloses some small rich veins on Cable Mountain between the Southern Cross and Red Lion mines. It forms the summit of Franklin Hill near Philipsburg, but no ore deposits have been discovered in this area, though other formations near by contain metalliferous veins. Near Flint station the Flathead is extensively fissured, and some of the fissures carry ore.

The Silver Hill, a shaly formation, which rests upon the Flathead quartzite, is about 400 feet thick. North of Franklin Hill, near Philipsburg, this formation is metamorphosed by intruding granite and forms extensive bodies of garnet rock. It is not so favorable a horizon for deposition by replacement or for fissure veins as are the limestones which overlie it.

The lower dolomite member of the overlying Hasmark formation, which is about 550 feet thick, is thick bedded and massive; physically it is relatively homogeneous. The gold deposits of the Cable, Red Lion, Hannah, Gold Coin, and other mines are in this member, as are some of the silver-bearing replacement veins near Philipsburg. These deposits do not as a rule conform to the bedding. The overlying shale member of the Hasmark formation is from 10 to 150 feet thick. It is not known to form the walls of bedding-plane deposits but is crossed by some fissure veins. The upper dolomite member of the Hasmark formation, which locally contains thin beds of shale, is about 350 feet thick. It is the country rock of the Southern Cross and other mines, and is traversed by many of the fissure veins of silver-gold ore near Philipsburg. It is readily replaced by the ore-bearing solutions, and like the lower dolomite member is regarded as a favorable horizon for ore deposition. The deposits that occur in this member include veins which conform with the bedding of the country rock and those which cut across it. In the cross-cutting fissure veins, ore shoots are formed in the purer beds of the member between the more or less argillaceous beds.

The Red Lion formation, which overlies the Hasmark formation, consists of a shale member at the base, overlain by a limestone member. The shale member, which is about 25 feet thick, is somewhat calcareous and is traversed by fissure veins, but these are not notably rich. Near Philipsburg it forms the hanging wall for some bedding-plane deposits, which, however, do not appear to be developed over wide areas. The limestone member, about 250 feet thick, characteristically carries thin siliceous laminæ, which are as a rule very closely spaced. Near Philipsburg the limestone member is the country rock of silver-bearing veins that cut across the bedding. The Silver Reef lode northeast of Silver Lake follows in part the bedding planes of this limestone.

The Maywood formation (Silurian?) which overlies the Red Lion formation, consists of calcareous shale and sandstone and flaggy magnesian limestone. Its average thickness is about 250 feet. The siliceous silver lode of the Okoreaka mine on Silver Hill, south of Silver Lake, is a bedding-plane deposit in this formation. The formation is also cut by metalliferous veins in the Headlight mine at Tower, east of Philipsburg, and in the War Eagle mine, southeast of Georgetown Lake.

Overlying the Maywood formation is the Jefferson limestone (Devonian), composed of massive medium-grained, more or less magnesian limestone. Near granite it is extensively marmarized, and locally it contains considerable tremolite. It is the country rock of the silver deposits of Hope Hill, near Philipsburg, which are among the most productive deposits in the quadrangle. Many of these deposits follow the bedding planes of the limestone, but some of them cut across the bedding. The deposits near Philipsburg are the only important mines in this formation within the quadrangle.

The Madison limestone (lower Mississippian) contains bodies of metalliferous quartz near Philipsburg, but, so far as known, it does not contain deposits in this area that could be worked with profit. It is the country rock at the Gold Hill mine near Princeton. This deposit is a gold-bearing fissure vein approximately parallel to the bedding of the limestone.

The Quadrant formation (Pennsylvanian) consists of shale and impure limestones at the base and quartzite above. It is not known to contain extensive metalliferous deposits. Some small irregular lodes appear in this formation in the country drained by Boulder Creek.[1]

The Jurassic and Cretaceous formations include shales, sandstones, and quartzites and form in all a series about 3,400 feet thick. Considerable areas of these rocks occur in the drainage of Boulder Creek, where they are cut by a large number of small metalliferous quartz veins.

It appears, therefore, that practically all the sedimentary rocks carry ore deposits, but that some formations because they are more readily fractured or more readily replaced, supply more favorable places for deposition. Of greater importance, however, is the relation to the igneous rocks, since the deposits almost without exception are in or near certain granitic rocks or related porphyries. Both granodiorite and granite contain ore deposits.

CHARACTER OF OUTCROPS.

In the course of erosion or degradation of a mineralized country the veins are removed with the rock that surrounds them.

If they are more resistant than the country rock, they wear away more slowly, and protrude in more or less conspicuous outcrops above the general plane of the surrounding rock. Such outcrops often lead to the discovery of the ore body. Some of the deposits near the summit of Hope Hill were of this character and were consequently among the first in this district to be located. If the vein is less resistant to erosion than the surrounding rock, a slight depression or shallow gully may be formed along its outcrop. In general the lodes of this

[1] Since the Philipsburg quadrangle was surveyed, H. S. Gale has found that the upper part of the Quadrant formation in this region contains a bed of phosphate. See Gale, H. S., Rock phosphate near Melrose, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 440-451.

quadrangle do not differ notably from the surrounding rock in capacity to resist erosion, except where they are extensively broken by postmineral fissuring. Such deposits may occur in the bottom of shallow depressions, where blocks of the hard vein quartz may be mixed with the débris of the country rock. In favorable places the removal of a thin layer of loose material will reveal the outcrop of the deposit. Some of the deposits of the quadrangle were found in this manner through excavations in quartzose débris near the surface.

Iron pyrite is present in large quantities in some of the ore, and the outcrop of such an ore body will be marked by the presence of limonite, an oxidation product of pyrite. The outcrops of the deposits of the Cable, Southern Cross, Red Lion, and other mines, for example, are conspicuously stained with iron oxide. Rocks so stained near the surface do not always represent the outcrops of ore bodies, for where the surrounding rocks contain iron minerals, the metal is dissolved and reprecipitated as iron oxide along streams or in small basins. Such deposits, however, are superficial, and the true character of the iron-stained area may be ascertained by a relatively shallow excavation.

The siliceous veins in granite and in quartzite weather at about the same rate as the country rock. The highly pyritic ore bodies in limestone likewise do not outcrop conspicuously because the pyrite ore weathers as rapidly as the limestone. The most conspicuous outcrops of ore bodies are those of the highly siliceous deposits in limestone.

With respect to the metals carried by the outcrops of veins, only broad generalizations may be made. If gold is present in relatively large particles, as at the Cable mines, the apex of the vein is likely to be rich and placers may be formed near the outcrop. If the gold is present in very small particles it is more likely to be carried away by the streams, and less opportunity is presented for placers to be formed.

The outcrops of auriferous deposits containing manganese oxides in general carry less gold than lodes free from manganese, because chloride solutions in the presence of acid and manganese oxides dissolve gold very readily, but in general such solutions do not carry gold far below the surface, for it is precipitated by ferrous sulphate produced by the oxidation of pyrite.

Outcrops of silver deposits are likely to lose much of their metal by solution of the silver minerals in the surface waters. Horn silver or silver chloride, however, is almost insoluble in water, and this rich silver mineral, which forms in the oxidized zone, may accordingly remain at the very surface. The outcrops of some of the Hope ore bodies were composed of spongy quartz carrying much horn silver, the selected ore assaying hundreds of ounces of silver to the ton.

FISSURES.

Most of the ore deposits of the quadrangle are related to well-defined fissures. For convenience in treatment the fissures may be divided into two groups, the first including those which were formed before the ore was deposited, and which therefore may contain veins, and the second those which were formed after the ores were deposited, and which may brecciate or cut across and displace veins, but which are not themselves mineralized. A large number of fissures are not mineralized, and among these are many faults of great throw. Four of the vein deposits fill fault fissures where the movement is known to be considerable, but none of these deposits appear from present development to be of great importance. Most of the ore-bearing fissures have no displacement that can be measured. Some of the faults that are not mineralized are probably as old as or older than the veins.

The faults along which displacement has been greatest do not cross the granite, nor is this rock involved in the movement that the faults show. These faults were formed, presumably, before the granite was intruded, or at least before it had completely solidified, and are for the most part barren. The mineralized fissures along which displacement has been relatively slight were formed partly after the granite had solidified, for many of them are in the granite. They may have been formed by compressive stresses incidental to minor earth movements consequent upon intrusion. If the solutions which deposited the ores were waters given off by the cooling granite, and if some of the fissures were formed by movements of the magmas, then the processes of fissuring and of vein deposition represent different effects of the same or closely related geologic processes. Fissures so formed would be open at the most opportune time to receive solutions from the rocks which were still crystallizing below the solid portion of the batholiths. The larger fissures, many of which are thrust faults, were presumably unfavorable to the passage of metalliferous solutions, owing to the finely crushed material developed by movement.

FISSURE SYSTEMS.

The mineralized fissures of the whole quadrangle strike toward every point of the compass and taken as a whole do not fall into well-defined groups, although in some smaller areas of

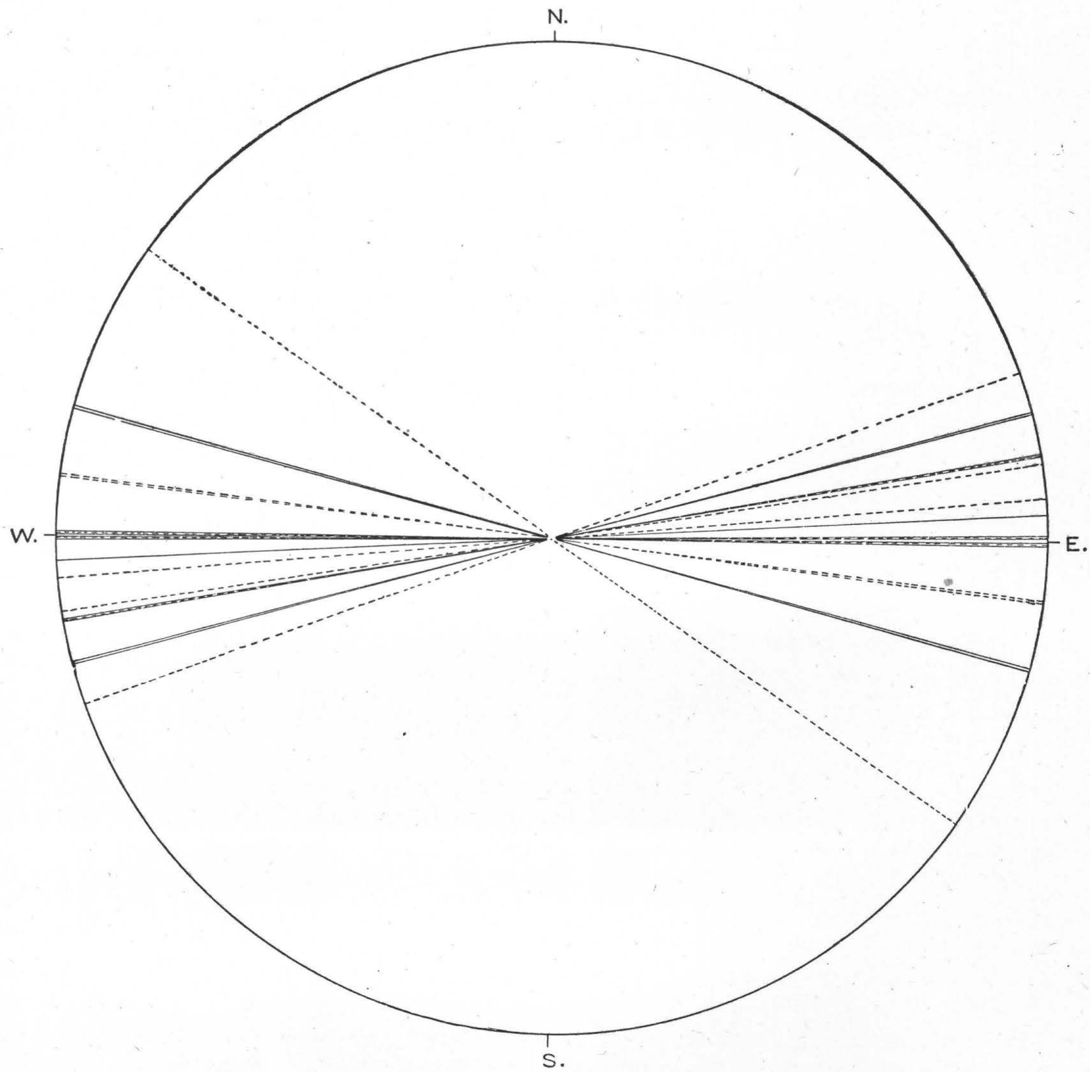

FIGURE 11.—Diagram showing variation in strike of 20 veins in a fissure system near Philipsburg.

mineralization parallelism of the ore-bearing fissures is close. For example, all the silver-bearing fissure veins near Philipsburg trend nearly east, and all but two of them dip southward. In figure 11 the strikes of 20 of the most important veins near Philipsburg are platted through a common center, the 11 solid lines indicating fissure veins in granite and the 9 dotted lines veins in sedimentary rocks near by. This figure shows clearly the close parallelism of these veins. The gold-bearing fissure veins in the drainage of Boulder Creek, near the Royal mine, have a greater range of strike, but they also strike eastward and dip toward the south.

The strikes of both of these groups of fissures are nearly normal to the contacts of the batholiths near which they are located. In a third group of fissures near Flint station a number of veins in quartzite strike toward the northwest and dip southwestward. Figure 12 shows the wide variations of the strikes of 52 veins in the quadrangle, excluding those shown in figure 11, similarly platted through a common center. These strike in many directions.

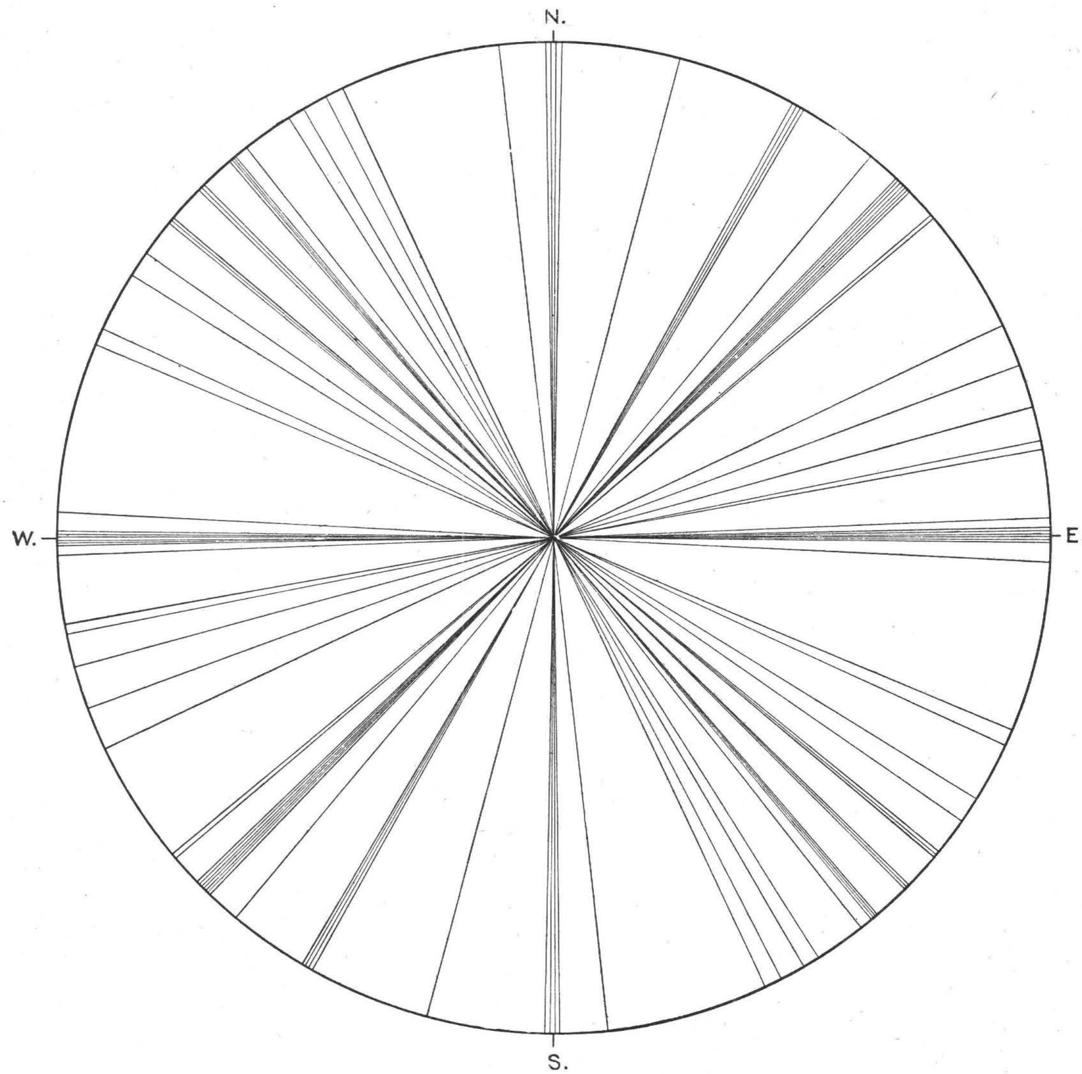

FIGURE 12.—Diagram showing the variations in strike of 52 veins in the Philipsburg quadrangle.

POSTMINERAL FAULTS.

Faults which involve the ore bodies in their movement are termed postmineral faults. Where these cut across an ore body and displace it the faulting movement is ordinarily easy to recognize, for the ore body may serve as a datum plane, but where the fault follows the strike of the lode it may not be possible to determine the character or the amount of the displacement. In such a condition the slickensided surface or the zone of crushed ore may show the plane of movement, but in the absence of a horizon marker in the country rock the amount of displacement along such a plane is not known. Faults which cut across the lodes are of great importance in the exploitation of ore deposits, because the ore may be lost through them. Such faults are numerous in this quadrangle, but in nearly all of them the throw is less than 50 feet. The faults of greatest throw do not appear to cut the ore bodies, and may have been formed before intrusion and mineralization. Many of these are reverse faults. More than 90 per cent of the faults that cut the ore bodies, however, are of the normal type, which implies a downward movement of the hanging wall. This condition is so general in the quadrangle that it is reasonable, in the absence of other evidence, for the miner to proceed on the assumption that the fault is normal. If a flat ore body is cut by a fault dipping away from it the continuation on the other side of the fault is most likely at a lower horizon, but if the fault dips toward the ore the continuation on the other side of the fault plane will probably be at a higher elevation (fig. 13). Ore bodies that are approximately vertical may best be represented in plan, as in figure 14. In diagram 1, figure 14, an east-west vein dipping south is cut by a fault that dips away from the ore. The continuation of the vein on this level should first be sought north of the point where it is faulted. If either the vein or the fault dips in the opposite direction

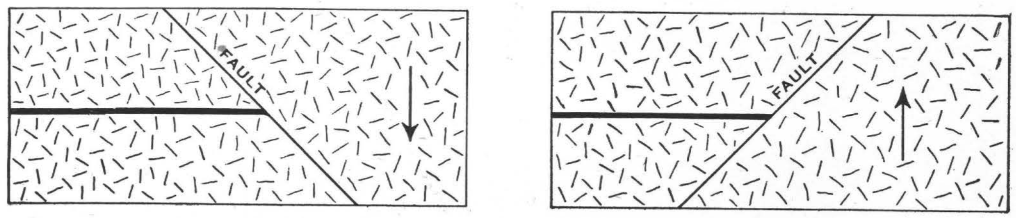

FIGURE 13.—Vertical sections of flat ore bodies faulted by normal faults. The large arrows indicate the direction in which the search for ore should be made first.

the offset also would be in the opposite direction, as is indicated in diagrams 2 and 3, figure 14. In all these diagrams the large arrows indicate the directions in which search should first be made.

In addition to the faults that cut across and displace the ore bodies are many fissures, approximately parallel to the lodes and following in the main the walls of the vein. The planes of such fissures are marked by slickensides, by gouge streaks composed of clay and crushed quartz, and by brecciation of the veins. In some of the deposits, notably the Granite vein, the processes of fissuring and of vein filling were to a certain extent synchronous. The vein was filled, reopened, and refilled, probably several times. Evidence of such reopening is afforded by the presence of many small angular fragments and parallel slabs of the country rock near

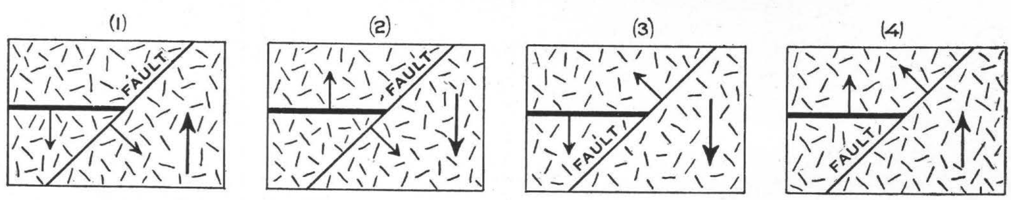

FIGURE 14.—Plans of nearly vertical ore bodies faulted by normal faults. The large arrows indicate the direction in which the search for ore should be made first.

the center of the vein, where they are completely surrounded by ore. In many places the ore itself is brecciated and completely recemented by ore of somewhat different character. The parallelism of the lodes and the postmineral fissures indicates that the contacts of the vein quartz and the country rock are planes of weakness and illustrates the tendency shown by fissures to follow planes along which movement has taken place before. Postmineral fissuring of veins is a process of great importance, for it favors secondary enrichment by descending waters. Some of this fissuring was accomplished during the period of mineralization and some of it afterward. It was probably caused by minor orogenic movements connected with declining volcanism.

Many of the ore deposits in the granitic rocks are not displaced by faulting. The Granite vein may be followed about a mile without encountering a single cross fault, and many other deposits are unbroken for considerable distances along the strike. The Tussle and the Bluebird veins, in the granite near the head of Little Gold Creek, are, however, displaced by cross faults.

RELATION OF FAULTS TO BEDDING PLANES.

Of the deposits in sedimentary rocks the Hope, Combination, Headlight, Queen, Douglas, and Homer mines are all displaced by faulting, some of them by a number of faults. As

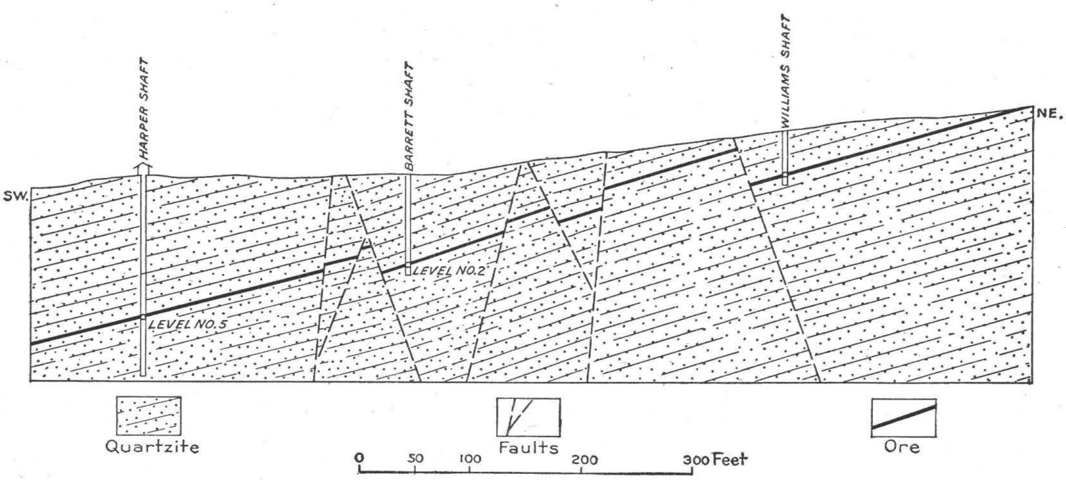

FIGURE 15.—Cross section of the Combination lode, a bedding-plane fissure vein in quartzite. It is cut by normal faults across the bedding.

a rule such faults cut across the bedding planes, but some of them follow the bedding. An instructive comparison may be made between the Combination and Headlight veins. The Combination is a large flat-lying deposit, which follows the bedding of the country rock and is displaced by numerous faults that cut across the bedding (fig. 15). The Headlight is a steeply dipping fissure vein, which cuts across the bedding of the country rock and is displaced by faults that follow the bedding of the country rock (fig. 16). In some of the faulted deposits in sedimentary rocks neither the veins nor the faults follow bedding planes.

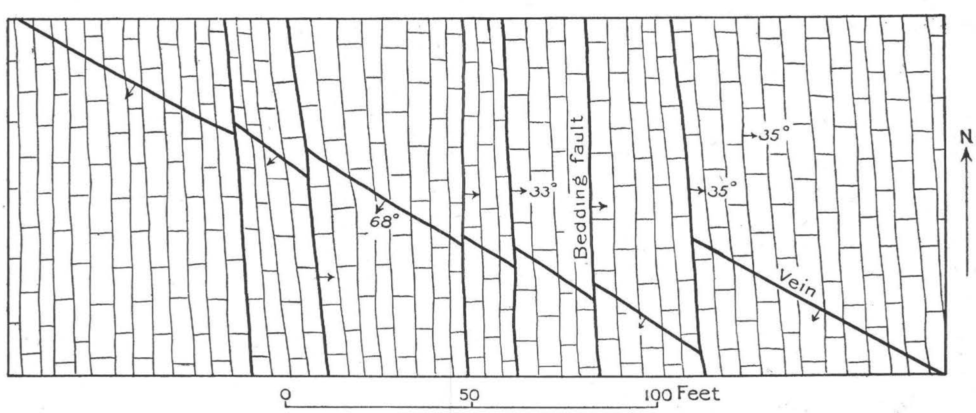

FIGURE 16.—Plan of Headlight vein on lower tunnel level. The vein cuts across the bedding of the country rock and is displaced by faults which follow the bedding planes.

CLASSIFICATION OF THE ORE DEPOSITS.

With the exception of the gold placers, which are discussed elsewhere, all the ore deposits of the Philipsburg quadrangle were precipitated from aqueous solutions. The character of such deposits depends, first, upon the physical condition and chemical composition of the metalliferous solutions, and, second, upon the physical condition and chemical and mineral composition of the country rock that they enter. A classification of the deposits should give proper weight to each set of conditions, but inasmuch as the deposits occur in many combinations, it is not always possible to form a single classification which is strictly consistent and which gives proper emphasis to the features of greatest importance or of clearest expression in each deposit or group of deposits. For example, in a classification which emphasizes differences in contained metals, the deposits may be divided into gold-bearing deposits and silver-bearing deposits, since these are the principal metals for which they are worked; but such a classification would be of little value, because both metals are found in single deposits, and because either metal may predominate in deposits otherwise closely similar. Moreover, a knowledge of the physical condition of the solutions by which the ores were deposited is important for a proper understanding of the genesis of the ore. A classification based upon the nature of the openings that were mineralized is helpful, because the form of the deposits in large measure depends upon this factor. The chemical composition of the wall rocks controls to a great extent the character and the details of form of many of the deposits. The following classification is probably the most useful for purposes of description and comparison:

Classification of ore deposits of the Philipsburg quadrangle, except placers.

A. Deposits filling fissures.

1. Silver-bearing veins in granitic rocks.
2. Gold-bearing veins in granitic rocks.
3. Silver-bearing veins in quartzites.
4. Gold-bearing veins and sheeted zones in quartzites.

B. Replacement deposits related to fissures or to bedding planes.

5. Silver-bearing replacement veins in sedimentary rocks.
6. Silver-bearing deposits in bedding planes of calcareous rocks.
7. Gold-bearing replacement veins in sedimentary rocks.

C. Replacement deposits of contact-metamorphic origin.

8. Gold-copper deposits.
9. Magnetite deposits.

DEPOSITS FILLING FISSURES.

GENERAL FEATURES.

As already stated, nearly all the ore deposits of the quadrangle are related to openings which have been formed by mechanical forces, but the group here considered includes only those deposits in which the deposition of workable ore was confined mainly to open spaces. The solutions that carried the metal to such spaces added certain elements to the wall rocks and subtracted other elements but generally did not replace the walls with payable ore.

These deposits are long, thin, tabular bodies conforming in shape to the openings that they fill. They are confined to igneous rocks and to quartzites, which rocks have greater strength than limestones and are for that reason better capable of holding the larger spaces open. They are not so soluble as the calcareous rocks and are therefore less readily replaced.

Inasmuch as the solutions were unable completely to dissolve the country rock, the walls show sharp contacts with the ore body, and for the same reason the corners and edges of fragments of the country rock which were broken off and lodged in the open space were not dissolved and rounded by the vein-forming waters.

The minerals of these deposits have a marked tendency to form in layers which are in the main parallel to the walls, but this feature, though common, is not everywhere apparent. The silver-bearing veins, which have a great variety of minerals, are more strikingly banded than are the gold-bearing veins, which are composed in the main of quartz and pyrite.

Locally the fissures are not completely filled by the solutions, and in consequence many small cavities are left in the veins. The last deposit in such a space is a layer of well-formed crystals, whose shape and crustified arrangement are generally sufficient to distinguish them from minerals replacing soluble rock. Few replacement deposits show crustification.

SILVER-BEARING VEINS IN GRANITIC ROCKS.

Nearly all the silver veins in granite that have been mined are within the granitic batholith east of Philipsburg. This group includes the deposits of the Granite, Bimetallic, Hobo, Silver Chief, Puritan, San Francisco, Mitchell, Three Metals, and other mines. These deposits differ greatly in point of production but are similar in the main features of form and structure and in the general character of the ore. They differ chiefly in the size of the ore bodies and in the richness of the ore. The fissure system in the area east of Philipsburg is shown by figure 17, where the most important veins are plotted at the surface. The strike of the group of veins varies less than 25° from east-west, and most of them strike north of east. In general they dip about 75° toward the south. Most of the fissures show evidence of movement, but in the absence of datum planes on opposite sides of the walls the amount of movement can not be ascertained. The displacement does not appear to have been great, however, for where these fissures are projected beyond the contact of granite and sedimentary rocks the beds at the points of crossing are not notably displaced. Postmineral movement in some of the veins is shown also by local brecciation of the vein material and by slickensided streaks of gouge along the walls. The fragments of the wall rock included in the veins are, as a rule, of flat tabular shape, and for the most part their orientation is with the veins. They are broken slabs which were scaled from the walls in part before the fissures was filled (fig. 18). One of the blocks shown in the figure is faulted by a small cross fracture which also faults the vein. The blocks are more abundant in the lower portions of this mine than in the upper levels and at some places lie haphazard, a condition which indicates that some of them may have fallen from great distances.

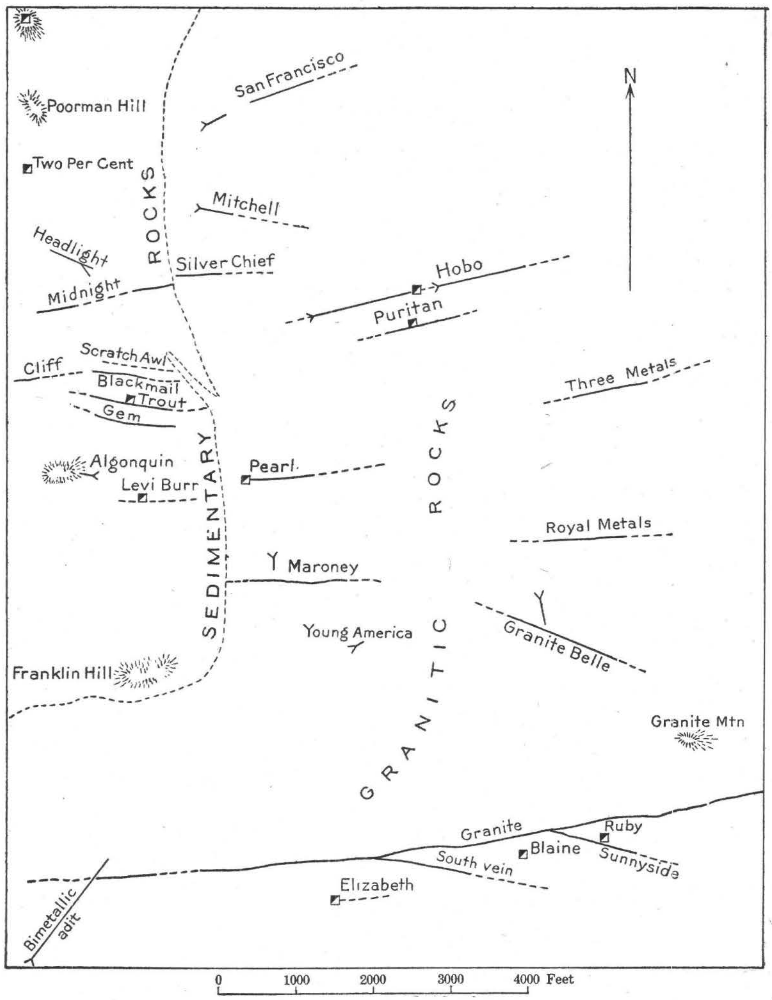

FIGURE 17.—Sketch map showing veins in the area east of Philipsburg. The dotted line is the contact between granitic and sedimentary rocks.

The veins are of fairly uniform width, and where the ore has been removed by mining the irregularities of the walls on the two sides commonly correspond in their general features with each other. Locally, however, the walls do not correspond, and at some places their lack of correspondence is conspicuous (fig. 19). Such conditions may be caused by vertical or lateral movement of the walls with respect to each other, or by blocks of the country rock falling from the walls. Evidence appears in some of the veins that the walls moved with respect to each other more than once, but such movement was probably small and was perhaps to a certain extent compensating, as is shown by the close agreement of the broader undulations of the walls. (See figs. 20 and 21, and upper part of Pl. XVII, p. 202.) No very great movement has taken place either in a horizontal or vertical direction since the fissure illustrated in these figures was formed, for such movement would have resulted in much wider spaces than is indicated by the width of the vein, unless the walls crushed in and narrowed the space before the fissure was filled—a theory highly improbable, because the clear-cut vein is in itself evidence that the fissure was filled at depths where the pressure did not exceed the crushing strength of the wall rock, and where narrow extended cavities could remain open long enough to be filled.

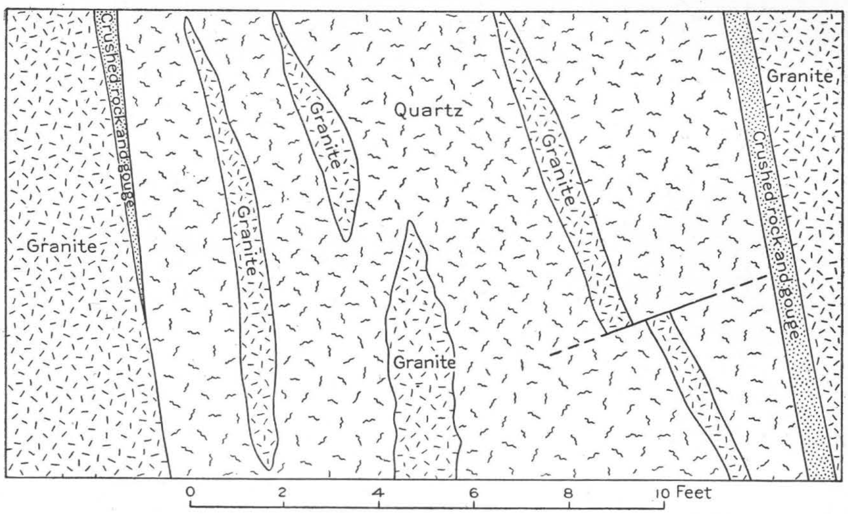

FIGURE 18.—Vertical section of the Granite vein, 600 feet west of the Ruby shaft, between levels 10 and 11, showing fragments of granite included in the vein. The cross fracture is later than the vein. The granite is technically a granodiorite.

The ore is composed of quartz, rhodochrosite, calcite, pyrite, arsenopyrite, stibnite, tetrahedrite, tennantite, galena, zinc blende, realgar, orpiment, pyrargyrite, proustite, cerargyrite, native silver, and pyromorphite, with iron and manganese oxides and copper and lead carbonates. (See also pp. 204–205.)

METASOMATIC PROCESSES.

The granite walls of the fissure fillings, though extensively altered by the vein-forming solution, are not commonly replaced by ore. These solutions have attacked nearly all of the

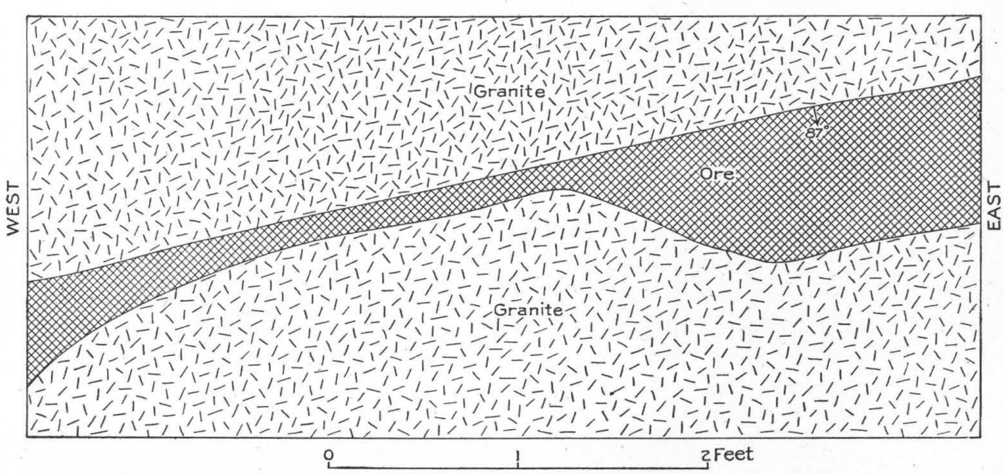

FIGURE 19.—Plan of Granite vein between levels 5 and 6, about 900 feet west of the Bimetallic shaft, showing lack of correspondence of opposite walls, a feature locally developed in this vein. The granite is technically a granodiorite.

minerals in the granite and have deposited large quantities of calcite and sericite with considerable pyrite. The alteration extends for considerable though not uniform distances from the deposits, but the greatest alteration is in the main confined to a zone usually less than 20 feet in width on each side of the vein. The alteration is not noticeably greater near the surface than a thousand feet or so in depth. The changes induced in the wall rocks by the solutions which deposited the gold-bearing fissure veins were of the same general character as the alterations along the silver-bearing fissure veins in granitic rocks.

Biotite and hornblende are most readily attacked and have at many places been completely replaced by pyrite, calcite, sericite, and chlorite. The feldspars are less easily altered but are replaced by calcite and sericite near the veins. Magnetite has either been removed altogether or replaced by pyrite. Quartz alters less readily than the feldspars, but some of it has been removed, and silica has to a certain extent been redeposited. Ilmenite is changed to rutile. Apatite has undergone little if any alteration. Calcite in considerable quantity replaces biotite, hornblende, plagioclase, and orthoclase. Sericite replaces orthoclase, plagioclase, and biotite, and to a less extent hornblende. Pyrite replaces all minerals, including quartz and biotite. It crystallizes as cubes and other forms or as anhedral masses scattered through the rocks with fairly even spacing. Pyrite has a strong tendency to assume the crystal form. A crystal of secondary pyrite in biotite is shown in figure 22. The mica foils are pushed aside and folded to completely inclose the idiomorphic pyrite grain, showing that the force of crystallization was sufficient to pry the mica foils apart.

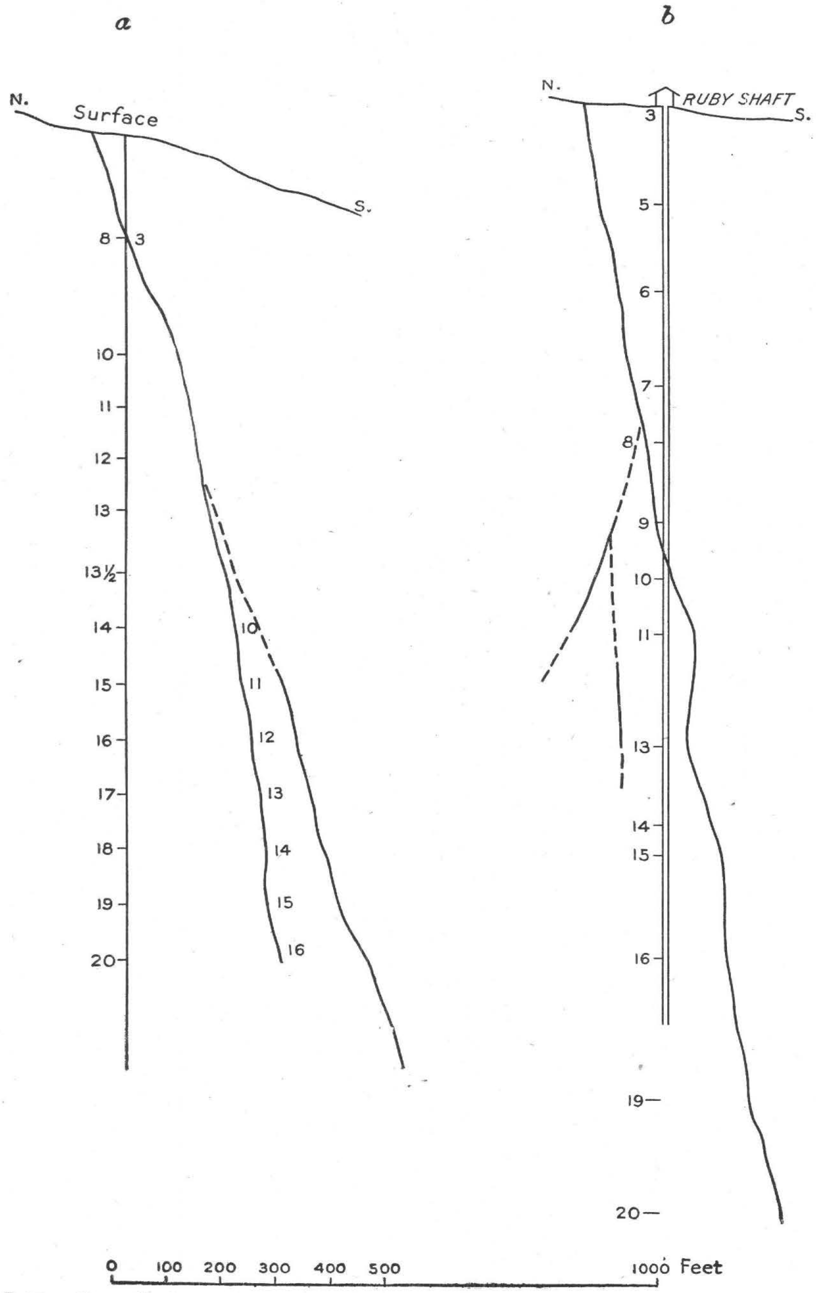

FIGURE 20.—*a*, Section of Granite vein and South vein 900 feet west of Blaine shaft. Levels on vertical line are corresponding levels in the Granite mine. *b*, Section of Granite-Bimetallic lode through Ruby shaft. Direction of sections, S. 15½° E.

Kaolinite has formed where the wall rocks are greatly altered, though it is not abundant where the minerals of the granite are only partly replaced. It was identified in the so-called talc from the walls but is probably a product of alteration resulting from the action of surface waters long after the veins were formed. Quartz replaces feldspars and ferromagnesian minerals but has not been added to granite wall rocks in very great quantities. The orthoclase crystals of the granite walls are not notably different from orthoclase in the normal granite, except through alteration, and no secondary orthoclase (or adularia) has been identified. Chlorite has formed at some places through the alteration of biotite and hornblende, but is absent where alteration is greatest.

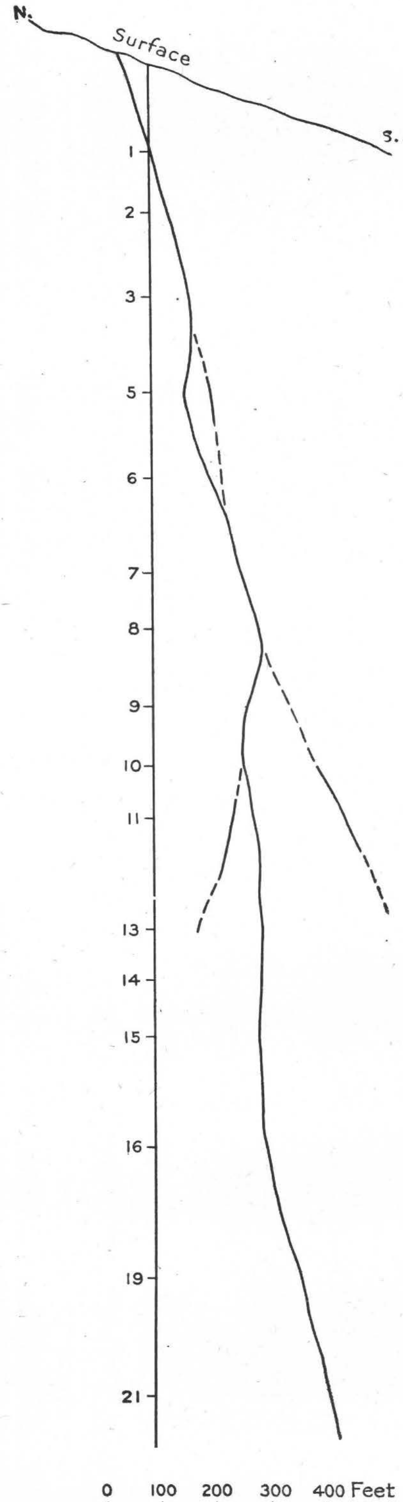

FIGURE 21.—Section of Granite-Bimetallic lode 900 feet east of Ruby shaft. Direction of section, S. 15½° E.

The vein-forming solutions added sulphur and carbon dioxide to the granite and probably also potash and some iron. Some silver and gold were added but generally not in sufficient quantity to convert the wall rock into ore. Soda, magnesia, and probably other elements were removed. It is noteworthy that in the wall rocks carbonates were deposited in greater amount than quartz, and that the reverse is true of the ore deposited in the open fissures. The veins classified with respect to alteration of the wall rocks are included in the group of sericite and calcite veins as described by Lindgren,[1] a group which includes many deposits in the western part of the United States.

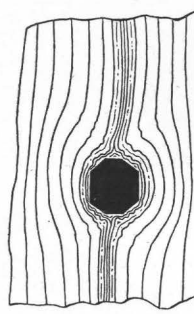

FIGURE 22.—Pyrite replacing biotite in granite near the Granite-Bimetallic lode. Biotite foils completely inclose pyrite and are crumpled at the contact. Figure greatly enlarged.

The hydrothermal alterations of the wall rock are closely similar to those observed in granodiorite in the Willow Creek district, Boise County, Idaho,[2] where the country rock is cut by fissure veins bearing gold and silver. At Philipsburg, however, the altered wall rock is richer in the carbonates.

After the formation of the veins the granite walls were sheeted in some places by fissures parallel to the veins, and oxidizing waters have had free access to the wall rock. The granite everywhere contains iron-bearing minerals, and iron is present in a more easily oxidized form where pyrite has been deposited in the walls by vein-forming solutions. Limonite is extensively formed near the veins by the oxidation of the iron minerals. The yellowish-brown zone is often much wider than the filled portion of the veins, and as it contrasts strikingly with the fresher country rock is sometimes regarded as the vein, but in most places paying ore is limited to the once-open fissures.

VEIN STRUCTURE.

Banding is in many places a conspicuous feature of the silver-bearing veins. The bands are of four classes and include layers of relatively pure quartz grading into the darker quartz sulphide ore; films or thin slabs of altered granite broken from the walls by reopening of the veins; tabular masses of rhodochrosite and quartz cutting through the earlier quartz-rich ore and in many places following

[1] Lindgren, Waldemar, Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 578.
[2] Lindgren, Waldemar, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 641.

planes approximately parallel to the walls; cracks filled with secondary minerals and planes along which drusy cavities lined with secondary minerals occur at short intervals.

At many places relatively pure light-colored quartz, carrying only a small proportion of the dark sulphides, forms bands of the first variety approximately parallel to the walls. It grades into the sulphide-rich quartz on both sides, but the difference in the proportion of dark minerals gives a color contrast at some places very marked. The quartz-rich bands were deposited early in the ordinary process of continued deposition.

Thin slabs of granite (forming the second class of bands) were broken from the walls by reopening of the veins during deposition. These are not conspicuous features of the internal structure of the veins, for, though of common occurrence, they are as a rule small. Many of these slabs are less than a quarter of an inch thick and not more than a foot square, and some of them are completely surrounded by ore. Apparently they were broken by movement which must have taken place while the veins were being filled, because the ores on the two sides of the slabs are similar. The small, thin slabs of country rock surrounded by ore and approximately parallel to the walls appear to have moved only a little way from their original positions, although other bodies of the granite, in haphazard orientation, have apparently fallen from the walls into the open fissures, perhaps to great depths.

At some places the deposits contain veinlets of rhodochrosite and quartz, which carry a subordinate amount of sulphides. The cracks that they fill are in the main parallel to the walls, and accordingly they give a streaked or banded appearance to the ore. The manganese-rich ore was introduced later than the dark sulphide-rich ore. The vein was opened after the first deposition, and some of the cracks were filled with the carbonates, which are as a rule of lighter color than the earlier ore.

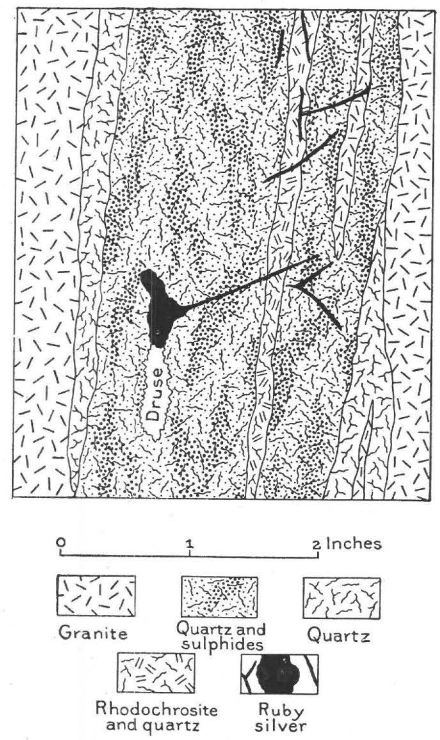

FIGURE 23.—Sketch of banded ore from the South vein of the Granite-Bimetallic lode. The granite is technically a granodiorite.

Small drusy cavities are not uncommon in the silver-bearing veins, and many of these appear to be related to planes approximately parallel to the walls. They are either solution cavities or unfilled portions of the veins. They are generally lined with quartz and carbonates, and in the richer deposits with ruby silver. Where they are closely spaced they give a banded appearance to the vein (fig. 23). In the South vein of the Granite-Bimetallic lode, veinlets of rhodochrosite and quartz cut the sulphide-rich ore, and paper-thin seams of ruby silver cut both ore and veinlets. A thin flake of the country rock is included in the vein.

PARAGENESIS.

The paragenesis indicated above suggests that the ore first deposited consisted mainly of quartz, rhodochrosite, calcite, pyrite, arsenopyrite, stibnite, tetrahedrite, tennantite, galena, and zinc blende. Pyrargyrite, proustite, realgar, and orpiment are present in this ore in smaller amount, and it is possible that they have formed at the same time. After the first deposition of ore the veins at some places were fractured and reopened. Some of these fractures were parallel to the walls and others cut across the veins and produced slight faults in the bands of vein quartz.

Solutions more highly carbonated, presumably introduced from below, deposited much rhodochrosite, some calcite, and quartz, with a minor quantity of the sulphides. At a still later period, after the deposition by waters rich in carbonates, some of the veins were again fractured, and descending sulphate waters, carrying in addition to considerable iron an important amount of silver, deposited ruby silver and other rich silver minerals in the cracks traversing the primary ore.

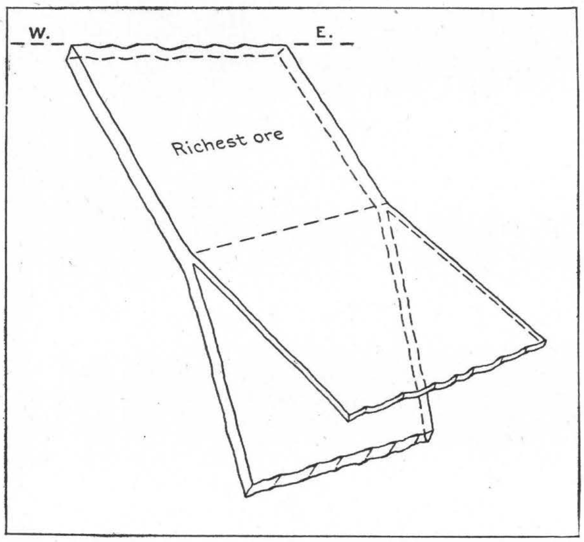

FIGURE 24.—Stereogram showing nearly horizontal intersection of two veins which unite to form the Granite vein above the ninth level, east of the Ruby shaft. The ore is richest above the intersection.

DEPTH TO RICHEST ORE.

The sulphate waters which deposited the rich silver minerals in the cracks of the primary ore obtained their burden higher in the same vein, and the leaching of silver from the vein is correlative with its deposition below. The depth to which such leaching extends is an important factor where veins are being prospected. In general, the rich ore extends upward to within about 200 feet of the surface, though locally it may be within a few feet of the apex, or exceptionally as much as 400 feet below the surface. If a vein has not been crushed and disturbed by movements since deposition it will not be so deeply leached, and on the other hand it will not be so much enriched below. In the Granite vein, where conditions for leaching and enrichment were exceptionally favorable, the leached zone had an average depth of about 200 feet. The greater part of the richer ore is at 200 feet to 800 feet below the surface.

ORE SHOOTS.

Aside from those parts of the veins enriched by descending surface waters, as indicated above, certain portions were doubtless originally much richer than others. In the Granite lode the richest ore occurred above the approximately horizontal junction of two veins below which the veins dipped away from each other in such a manner as to inclose a wedge-shaped mass of rock pointing upward. The ore above the junction was of much better grade than the ore of either of the veins below it. Possibly the mingling of the solutions from the two channels was favorable to the primary deposition at and above their junction.

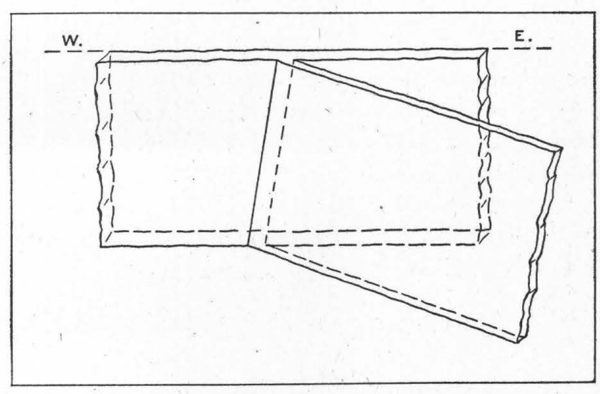

FIGURE 25.—Stereogram showing nearly vertical intersection of South vein and Granite vein in western part of Bimetallic mine. The ore is not richer near the intersection than elsewhere.

GENESIS OF PRIMARY ORE.

The mineralogic composition of the primary ore of the silver-bearing fissure veins does not afford conclusive evidence as to the source of the solutions which deposited it, but the great vertical extent of the Granite vein, its persistence horizontally, and its great width in the lower levels of the mine indicate that the primary ore was deposited by ascending waters. As already stated, the richest ore in this vein occurred above a junction of two veins forming a nearly horizontal line of intersection (fig. 24). Vertical junctions as illustrated by figure 25 were not enriched in this manner. If the enrichment is due to the mingling of solutions, the position of the enriched portion of the vein is further evidence that the waters were ascending. The silver-bearing veins in sedimentary rocks are of the same composition as those in granite, a fact which also suggests a deep source for the solutions and one independent of the rocks they entered.

GOLD-BEARING VEINS IN GRANITE.

The gold-bearing veins in granite are not so productive as the silver-bearing veins, and are practically limited to two small groups, of which the more important is on Boulder Creek and includes the Royal, Sunday, Bluebird, and neighboring deposits.

The second group is at Georgetown and includes the Pyrenees and Luxemburg lodes. Gold does not predominate in any of the fissure veins in the granite of the Philipsburg batholith.

In their larger structural features these veins resemble the silver-bearing veins in granite, but the banded vein structure is much less conspicuously developed. In general the veins are smaller and some of the gold-bearing lodes consist of several thin, closely spaced parallel veinlets, the whole forming a sheeted zone (fig. 26). The silver veins and the gold-bearing veins were presumably deposited by solutions of closely related genesis. The alterations of the wall rocks are of the same general character, but the mineralogy of the gold-bearing vein stuff is much more simple. This ore is composed in the main of quartz, iron pyrite, and native gold. Some of the ore contains a small amount of calcite, and in the Royal group galena is present. It is noteworthy that the Tussle vein, in which silver predominates, is situated among the gold veins of the Royal group.

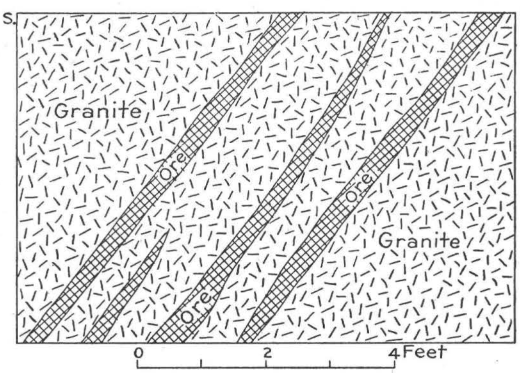

FIGURE 26.—Cross section of the Sunday lode near the intersection of the shaft and adit. At this place the lode is a sheeted zone in granite.

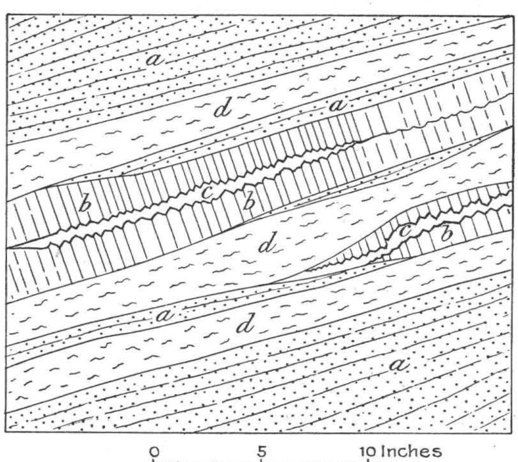

FIGURE 27.—Cross section of the Combination vein, a fissure filling in the bedding planes of quartzite. *a*, Country rock; *b*, crustified quartz; *c*, druses; *d*, quartz and sulphides.

SILVER-BEARING VEINS IN QUARTZITE.

The silver-bearing veins that fill fissures in quartzite have been less productive than the silver deposits in granite and in limestone. The quartzites include those of the Spokane, Flathead, Quadrant, and Mesozoic formations, all of which carry metalliferous deposits, but the Combination mine is the only deposit of this kind that has yielded any considerable amount of silver. This deposit fills a fissure in the Spokane formation and is oriented approximately with the bedding of the country rock. The silver veins near Flint, which are in the Flathead quartzite, were in the main deposited in open spaces, although there appears to have been some replacement of finely crushed quartz sand where the rock was extensively sheeted. The Albion and Powell veins, which cut across Mesozoic or Carboniferous quartzites, are also of this class. A cross section of the Combination vein (fig. 27) shows comb quartz, druses, and flakes of country rock in the vein, features which indicate that the lode was formed by repeated deposition in open spaces.

The country rock of the silver-bearing veins in quartzite is as a rule not greatly changed by the vein-forming solutions. Pyrite replaces the quartz grains and sericite is developed in the interstitial spaces, but metasomatism is not extensive. In mineral composition some of these deposits resemble more or less closely the silver-bearing veins in granite, and they may have been deposited by the same kinds of solutions, though under different conditions. Comparison of analyses of the ore of the Combination vein and of that of the Granite vein shows that the Combination ore contains less silver and much less gold but more copper and antimony than does that of the Granite vein.

GOLD-BEARING VEINS AND SHEETED ZONES IN QUARTZITE.

The gold-bearing veins which fill fissures in quartzites have a wide distribution. Deposits of the group are located on Cable Mountain, in the drainage basin of Warm Spring Creek, and in the drainage basin of South Boulder Creek. On most of these lodes only a small amount of work has been done, and none of them has produced more than a few thousand dollars worth of ore. The Yellow Metal and Montana lodes of the Red Lion district and the St. Thomas and other deposits belong to this group.

Most of the lodes are small, but locally, where several narrow veins are closely spaced to form a sheeted zone, fair-sized deposits of ore occur. The ore does not replace the walls to any considerable extent, but fills the open spaces and cements the angular fragments of broken rock. The sulphide ore is composed of quartz and pyrite, with chalcopyrite in subordinate amount. The oxidized ore near the surface is iron-stained quartz, with here and there small bunches of copper carbonate. The native gold is associated with both quartz and pyrite. The veins are not conspicuously banded, and few of them show comb structure.

An occurrence of gold ore on the Golden Eagle claim possibly belongs to this group of deposits. Tourmaline and free gold occur in very thin fissures of the quartzite, and tourmaline replaces both the grains of quartz sand and their siliceous matrix.

REPLACEMENT DEPOSITS.

GENERAL FEATURES.

Replacement deposits are formed by processes in the course of which the rock is removed simultaneously with the deposition of the ore. If the open space is simply filled with metalliferous material the form of the original opening is generally preserved, but if the country rock has been replaced by ore the original boundaries of the open spaces are usually obliterated. A small opening, such as a very thin fissure, may, therefore, after replacement, become a vein of considerable size, and the boundaries of the original open space may be lost. It is not always possible to distinguish sharply between the two classes of deposits, for in most replacements a part of the deposit represents filled space.

All kinds of igneous and sedimentary rocks are, under favorable conditions, replaced by metalliferous solutions, but in this quadrangle the replacement deposits are mainly in limestones and other calcareous rocks. These deposits may be divided into two groups, the first including replacement deposits related to fissures or bedding planes and the second comprising replacement deposits of contact-metamorphic origin. The first group includes deposits that are rudely tabular but less regular in detail than the fissure veins in granite and in quartzite. The ore is closely similar in composition to that of the fissure veins, and the solutions and the conditions of deposition were presumably similar. In the mineralized district near Philipsburg the same vein-forming waters which filled the fissures in granite formed replacement deposits in limestones.

Many of the deposits of this quadrangle follow closely the bedding planes of the rocks inclosing them. This agreement may be due either to the presence of a bed which, on account of its greater permeability, offered a favorable channel to circulating water, or to the presence of fractures along the bedding (bedding-plane fissures). Most of the bedding-plane deposits here discussed appear to be related to bedding-plane fissures rather than to horizons which were from primary causes more permeable.

To just what extent the contact-metamorphic deposits are controlled by openings in rocks is not fully understood. These deposits were formed in soluble rocks and presumably by very hot solutions given off by cooling igneous rocks. Such solutions under considerable pressure are capable of penetrating the small openings more easily than solutions under less intense conditions. The larger openings or fissures probably facilitate the replacement of the limestones by the contact-metamorphic solutions but do not seem to be necessary conditions for deposition by such solutions, for the latter appear to be capable of penetrating minute openings like the cleavage cracks of minerals and interstitial spaces between crystals or grains.

REPLACEMENT DEPOSITS RELATED TO FISSURES OR TO BEDDING PLANES.

This group of deposits includes replacement veins in sedimentary rocks which are closely related to the fissure veins in granite, together with a large number of thin tabular deposits which follow the bedding planes of calcareous rocks. So many of the latter deposits are probably related to planes of movement that they also may properly be called replacement veins.

In sedimentary rocks faulting movements that follow the bedding-planes are difficult to detect, for available horizons of reference by which the amount of throw may be determined are generally lacking. Such movements are probably much more common than they appear to be. In the Headlight (fig. 16, p. 171), Albion, and other mines, bedding plane faults are clearly recognizable, and probably many of the bedding-plane deposits were formed through replacement along fissures of this character. When the wall rock is replaced and the fissure filled with ore, the evidence of such movement is likely to be obscured or destroyed and is to be had only at fortunate exposures.

Replacement veins differ generally from contact-metamorphic replacement deposits by differences in the mineralogy of the ore. The replacement veins are much less uniform in width than the veins that fill open spaces, and though broadly tabular nearly all of them are nodular, having wide and narrow places along the dip and strike. The contacts with the wall rocks are not so sharp and definite as they are in fissure fillings and in some places they are clearly gradational. Small angular fragments of the country rock are not commonly found in replacement veins, for solutions capable of replacing the walls are also capable of dissolving or at least of rounding the sharp edges of such fragments. Few replacement veins show the crustified banding characteristic of some fissure fillings, and the small open spaces in replacement deposits are solution cavities rather than unfilled portions of the veins, so that the surrounding minerals show no regular arrangement.

Chambers and pipes of ore in limestone, such as are developed at many places in the western States, are probably also represented in this quadrangle. The deposit of the Blue-eyed Nellie mine is said to be of this character, as are other deposits now inaccessible, but those now exposed are believed to have been deposited in or along fissures, in bedding planes, or along bedding-plane fissures.

SILVER-BEARING REPLACEMENT VEINS IN SEDIMENTARY ROCKS.

The most important silver-bearing replacement veins in sedimentary rocks are in the Flint Creek district, near Philipsburg, and include, with others, the deposits of the Trout, Blackmail, Salmon, Headlight, Cliff, Midnight, True Fissure, and Gem mines. At present these mines are not actively exploited, and the majority of them are inaccessible. The veins strike nearly east and dip toward the south, cutting across the bedding of the sedimentary rocks at large angles, and are wider in the purer limestone than in shale. The ore is composed of quartz, rhodochrosite, calcite, dolomite, zinc blende, galena, stibnite, gray copper, pyrite, ruby silver, chalcopyrite, and realgar. Where this ore is oxidized it is stained black with manganese compounds, and locally it carries bunches of lead and copper carbonates. Horn silver and native silver are present in the higher-grade oxidized ore, which carries 50 to 200 ounces of silver and $2 to $5 gold to the ton. The sulphide ore, like that of the veins in granite near by, is much less siliceous than the ore of the bedding-plane deposits of Hope Hill. The richer silver ore, which is composed of quartz, carbonates, and sulphides, is locally fractured and brecciated. The spaces between fragments of this ore are filled almost entirely with manganese carbonate carrying too little silver to be worked for that metal. Near the surface this carbonate ore oxidizes to pyrolusite and other manganese oxides, and the ore has been mined to a small extent for manganese. A few veins of manganese ore, which have been only slightly developed, do not show the fragments of richer silver ore. Such veins probably occupy fissures formed at the time of the brecciation of the silver-rich veins, and were filled from below by the same manganese carbonate solutions that cemented the brecciated siliceous silver ore.

Near Philipsburg the silver-bearing replacement veins in sedimentary rocks and the silver-bearing fissure fillings in granite were deposited in the same set of fissures. The close parallelism of the lodes is graphically illustrated by figures 11, page 168, and 17, page 173. The composition of the ore of the two classes of deposits indicates that the depositing solutions contained essentially the same elements in about the same proportions; but the ore bodies are unlike because of differences in the method of deposition, and because the granite, being harder, stronger, and more nearly homogeneous than the limestones and shales, furnished better conditions for forming persistent fissures and held them open more efficiently. On the other hand, the limestone, being more soluble than granite, was replaced by ore, whereas the deposition of the payable ore in the granite was generally limited to open spaces. Veins of both groups were reopened and refilled by manganese-rich solutions, as shown in figures 23, 28, and 37. The limestone wall rock was, however, the more readily replaced by the manganese carbonate. When two compounds are in solution, the less soluble will be precipitated first. Under conditions of temperature and pressure which hold at the surface, one part of calcium carbonate is soluble in 1,428 parts of water saturated with carbon dioxide, and one part of manganese carbonate is soluble in 2,000 parts of water so saturated.[1] Presumably the solubilities are of the same order at higher temperatures and under the conditions which obtained when the veins were deposited, for calcium carbonate was extensively replaced by manganese carbonate.

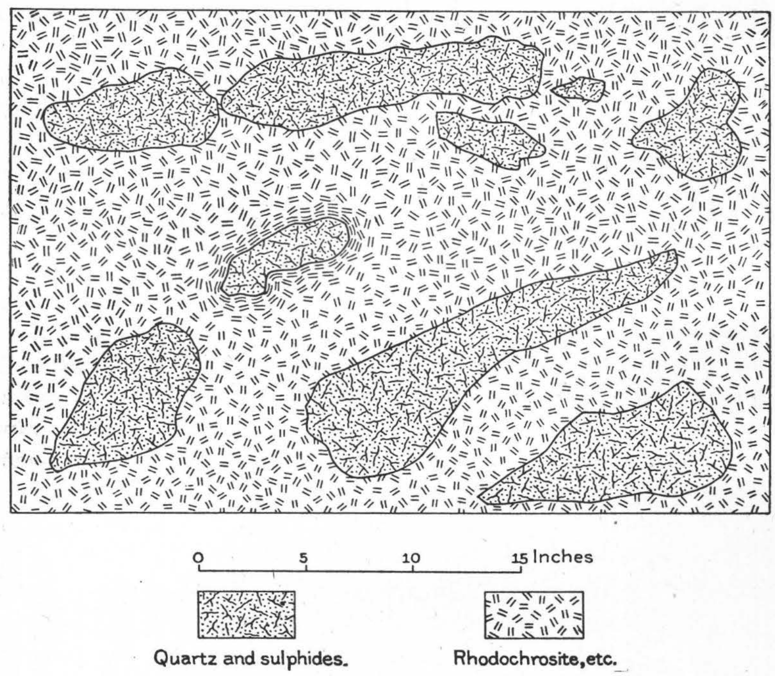

FIGURE 28.—Ore from Trout mine, level 1. Fragments of quartzose sulphide-rich ore are cemented by ore which is mainly rhodochrosite.

At present none of the silver-bearing replacement veins can be followed directly from the sedimentary rocks into the granite. The Midnight vein in the limestone and the Silver Chief vein in the granite appear to have been deposited along the same fissure, but if so, the Midnight vein at the contact is offset about 50 feet to the south of the Silver Chief vein. (See fig. 17.) According to report the San Francisco vein was followed from the granite into the limestone, but was also found to be shattered and broken at the contact and offset toward the south. The Scratch Awl vein was also found disturbed at the contact of the sedimentary rocks and granite. Such scanty observations as could be made in the field and reports of old workings now inaccessible indicate that the fault planes at the contact dip toward the granite. If so the movement of the southward-dipping veins in the hanging wall of the faults toward the north on the hanging-wall side indicates that the faults are normal, for depression of the hanging wall would cause a south-dipping vein to be offset to the north on the hanging-wall side.

[1] Lassaigne, Comey's dictionary of solubilities, pp. 83 and 88.

SILVER-BEARING DEPOSITS IN BEDDING PLANES OF CALCAREOUS ROCKS.

This group includes the ore bodies of Hope Hill, near Philipsburg, and several smaller deposits in the country tributary to Warm Spring Creek, among them the Okoreaka, Silver Moss, and Silver Reef. Several of these deposits have produced considerable ore, but the deposits of Hope Hill are by far the most important. The Hope ore is highly siliceous and in the lower levels of the mine is composed of quartz, calcite, barite, fluorite, argentite, galena, pyrite, chalcocite, and a little gray copper. In the best ore horn silver and silver glance occur with iron oxides and copper carbonates and oxides. Not enough deep exploration has been done to show whether the sulphide ore is primary or whether it has undergone subordinate chemical changes since it was first deposited. The siliceous silver ore differs strikingly from that of the silver veins in the granite near by and in the limestones near Hasmark and Tower. The greater abundance of

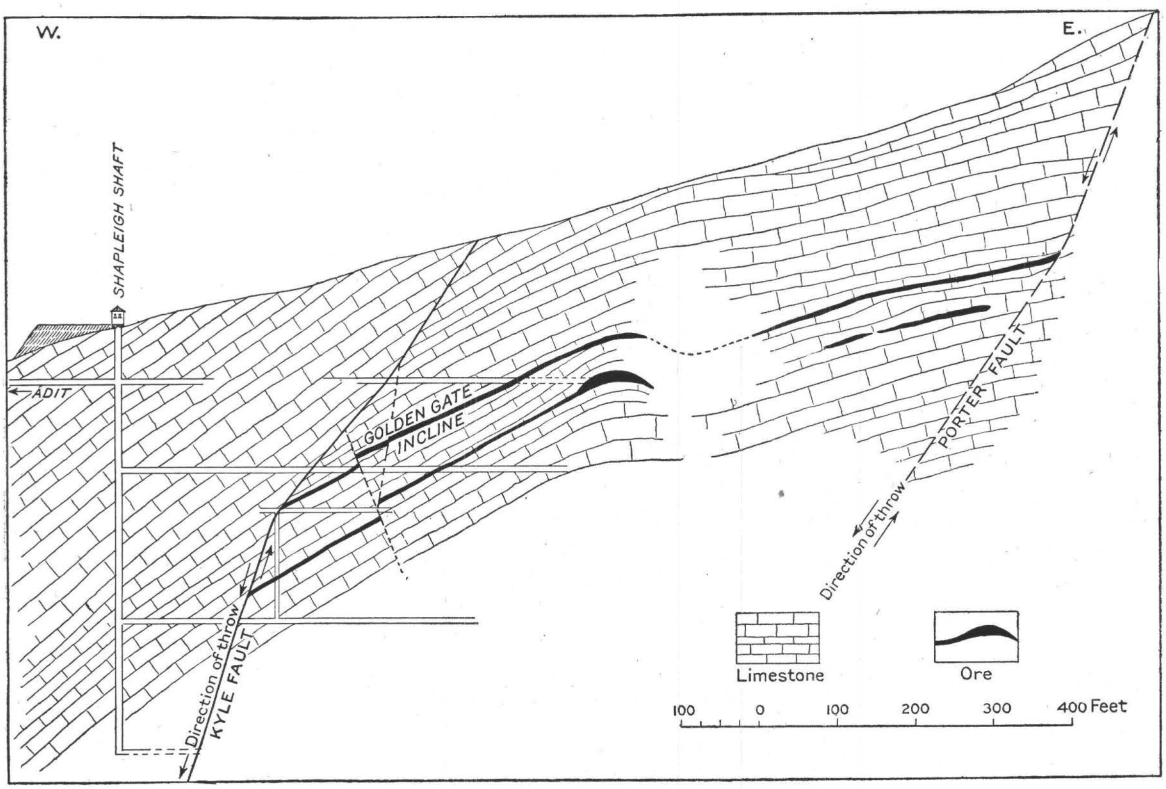

FIGURE 29.—Vertical section in Hope mine along Golden Gate incline, looking north. The direction of the section is east-west.

quartz and barite and the presence of fluorite in the silver deposits of this group, and the much greater abundance of pyrite, stibnite, blende, galena, and other sulphides in the ore of the silver veins in granitic rocks, are contrasts as marked as the differences in the structural features that distinguish the two groups of deposits.

STRUCTURAL FEATURES.

The structural features which have controlled or modified the deposition of the ore of this class are fissures, bedding planes, thin beds of intercalated shales, and saddles or minor anticlines.

Fissures.—At the Golden Gate incline, in the Jubilee workings of the Hope mine, and at the Two Per Cent mine and elsewhere the deposits which are in the main along the bedding planes are joined by nearly vertical fissure veins which cut across the bedding. Although these veins indicate that the fissures were small, they appear to have been the paths through which the solutions rose. Those reaching favorable horizons spread out laterally, forming deposits which extended outward far from the fissure.

Bedding planes.—Nearly all the ore bodies follow the bedding planes closely. The ore occurs at a number of horizons, several of which are extensively mineralized (fig. 29). In some places, for example in the Sweet Home mine, brecciated structures indicate that the shearing of beds one over the other has made the horizon of the movement more accessible to solutions, but such structures are not conspicuous in that mine or elsewhere. Movement of this character followed by replacement commonly does not leave a clear record.

Beds of shale.—The thin beds of calcareous shale intercalated between the massive limestone members of the Jefferson formation have influenced the course of the replacing solutions, in some places rather conspicuously, as, for example, in the Hope Discovery workings and at the Two Per Cent mine. The shale forms the hanging wall, and as it is comparatively impervious to solutions, their ascent was checked by it; in consequence of this ponding the purer limestone below the shale was replaced by ore. A shaly roof is not, however, a necessary condition for ore deposition, for at many places the hanging walls are not argillaceous but pure limestones closely resembling the footwalls in composition.

Saddles.—The deposits of Hope Hill are on the slopes of a great plunging anticline, the axis of which strikes northwestward from the top of Franklin Hill. The prevailing dip at Hope Hill is northwestward, but in the folding of the beds small anticlines or flexures were formed with local dips opposed to those prevailing. In the Jubilee workings of the Hope mine, near the top of the Golden Gate incline, at the Cadgie Taylor mine, and elsewhere, the ore zones are exposed at the anticlines, and their thickness is appreciably greater near the crests. When beds are folded the rocks along the anticlines may be more extensively brecciated than elsewhere, or spaces may be formed near the crest. Furthermore, the rising solutions were presumably held in check at the flexures, thus favoring more extensive deposition at such places.

GENESIS.

Many of the silver deposits in bedding planes of calcareous rocks are half a mile or more from known igneous rocks. The inclosing limestone shows little evidence of metamorphism except recrystallization, though small needles of tremolite are developed locally. The contact-metamorphic minerals are not intergrown with the ore minerals. The occurrence of the ore below rather than above the beds of intercalated shale and the thickening of the deposits near the crest of saddles strongly indicate that the solutions were rising when they deposited the ore. The solutions must have been somewhat different chemically from those which deposited the silver-bearing replacement veins, because there is a constant difference in the composition of the ore of the two classes of deposits. Both, however, are believed to have been deposited by ascending hot solutions.

GOLD-BEARING REPLACEMENT VEINS IN SEDIMENTARY ROCKS.

The gold-bearing replacement veins are confined to sedimentary rocks and in particular are developed in the magnesian limestones of the Hasmark formation. Although the veins cut the beds of shale associated with the limestones, the larger ore bodies are in the more calcareous members. All the deposits that have been extensively developed by mining, including those of the Southern Cross, Gold Coin, Twilight, Montana, Red Lion, Modoc, Queen, and Bunker Hill mines, are near the contacts of intrusive igneous rocks. The gold-bearing replacement veins are similar in their general features to the silver-bearing replacement veins, but the tabular form is not so well expressed in most of them. Some of the deposits, as, for example, the West vein at the Southern Cross mine, are oriented approximately with the bedding planes of the inclosing sedimentary rocks (fig. 30). A number of the richer ore bodies are at intersections of fissures, and such places are regarded as the most favorable for prospecting. Most of the ore bodies have been greatly disturbed and fissured since they were deposited, and surface waters have had free access to them. The ore is consequently highly oxidized throughout the workings, which in 1907 were nowhere more than 250 feet deep. Small bodies of auriferous pyrite and other sulphides, with numerous pseudomorphs of limonite after pyrite in the oxidized zone, show that the primary ore is chiefly auriferous pyrite. The weathering of pyrite is illustrated by figure

31. The drawing on the left represents a nodular mass of partly oxidized pyrite from the Southern Cross mine. The drawing on the right is of a piece of ore from the Red Lion lode and shows a tabular mass of pyrite partly altered to iron oxide.

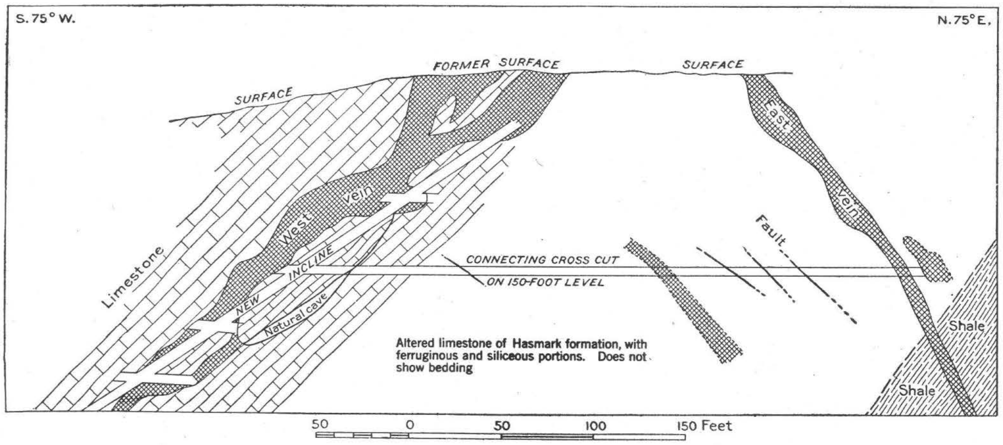

FIGURE 30.—Vertical section through Southern Cross mine, along a crosscut on the 150-foot level connecting old and new workings.

Quartz, calcite, siderite, pyrrhotite, magnetite, and specularite are present in some of these veins and indicate that the solutions which deposited the ore were hot and under considerable pressure, for several of these minerals do not commonly form under the conditions which ordinarily hold at moderate depth in open fissures extending to the surface. The wall rock is everywhere marmarized and at some places contains tremolite and diopside, but these minerals are not noticeably more abundant near the veins than a short distance away. The replacement veins contain more quartz and more silver than the ore of the contact-metamorphic zone of the Cable mine, and their gold content is more evenly distributed. Calcite, pyrrhotite, magnetite, and specularite are much more abundant in the Cable ores.

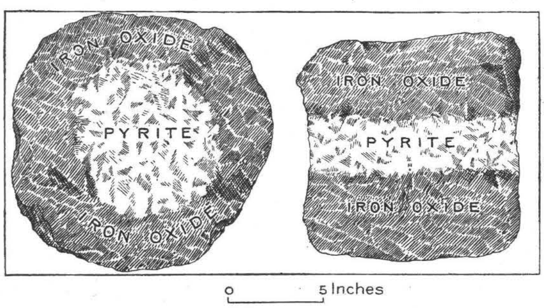

FIGURE 31.—Lumps of ore from Southern Cross and Red Lion mines, showing alteration of pyrite to iron oxide.

REPLACEMENT DEPOSITS OF CONTACT-METAMORPHIC ORIGIN.

The replacement deposits of contact-metamorphic origin are in calcareous rocks near their contacts with intrusive igneous rocks. These deposits do not approach the tabular form so closely as the replacement veins, and they do not follow the bedding planes of the sedimentary rocks, but they resemble replacement veins in that their contacts with the country rock are usually gradational. The country rock near the deposit is highly metamorphosed, and the ore contains a considerable quantity of minerals known to be formed under conditions of high temperature and great pressure. Under such conditions solutions are very active, and are probably able to penetrate very small openings. In consequence of this fact such deposits are not conditioned by the larger structural features, such as fissures or exceptionally permeable strata, and are very irregular in shape. The replacement deposits of contact-metamorphic origin include gold-copper deposits and deposits of magnetic iron ore. The mineralizing solutions originated in the cooling igneous rock near by and mainly in connection with granodiorite intrusives.[1]

[1] The granodiorites have also been called granite, this term being used in the popular sense to include several kinds of granitic rocks.

CONTACT-METAMORPHIC GOLD-COPPER DEPOSITS.

Deposits of this group occur in highly metamorphosed calcareous rocks near their contact with the granite of the Cable batholith. The ore is composed largely of calcite, quartz, pyrite, chalcopyrite, magnetite, and pyrrhotite, with which free gold is intimately associated. Garnet and other heavy silicates are present. During or immediately after the metamorphism of the country rock, the gold was presumably deposited by the aqueous solutions given off from the igneous rock. The ore bodies of the Cable mine, which are discussed in detail on pages 221–234, are the only deposits in the quadrangle known to belong to this group.

CONTACT-METAMORPHIC DEPOSITS OF MAGNETIC IRON ORE.

At a number of places where granite cuts through sedimentary rocks, large masses of magnetite have been deposited in limestones near the contact. Bodies of magnetitic iron ore have been mined for flux at several places on the west slope of Franklin Hill and in Olson Gulch, above Anaconda. Outcrops of magnetite occur also near the Southern Cross mine, and large masses have been exposed in the Cable mine in the course of exploration for gold. In carload lots the ore runs from 30 to 65 per cent iron. Owing to the low price of the product and the irregularity of the high-grade portions of the deposits, the industry has never been important, but the production could be increased if the demand justified it.

In most places the deposits do not conform to the bedding of the rocks but are, like the contact-metamorphic gold-copper deposits, very irregular in shape. Though magnetite occurs abundantly in the argillaceous beds of the Silver Hill formation and is nearly always present where calcareous rocks have been metamorphosed near the granite intrusives, the larger bodies of magnetite are best developed in the purer limestones and dolomites. Some of the rocks surrounding the magnetite bodies are almost pure marble, though others contain garnet, tremolite, actinolite, forsterite, white mica, green mica, diopside, and scapolite. At the Redemption iron mine ludwigite, a magnesium borate rich in iron, is closely associated with magnetite, and apparently the two were deposited together. None of the larger masses of magnetite are more than 1,000 feet and most of them are less than 100 feet from the granite (granodiorite) contacts.

The magnetite bodies are clearly of contact-metamorphic origin, and were introduced into the limestones by solutions given off by the cooling intrusive. The magnetite is itself a primary ore, and exploratory work done in the hope that the magnetite bodies will change to sulphide ores in depth is likely to prove disappointing.

SUMMARY OF GENESIS AND AGE OF DEPOSITS.

The genesis of the various groups of ore deposits has been stated or implied in preceding sections of this report, but it is desirable to summarize briefly the conclusions indicated. The geological relations of the various rocks show clearly that in this region a long period of sedimentation began in Algonkian time and extended through the Mesozoic. This period was interrupted by relatively short intervals of erosion, but no profound earth movements, such as those indicated by a great angular unconformity between beds of different ages, and no igneous activity are recorded after Cambrian time. After the deposition of Mesozoic sedimentary rocks, probably in early Tertiary time, extensive thrust faulting took place. Subsequently great igneous intrusives broke through the sedimentary rocks and on solidifying formed the batholiths of granitic rocks, of which the most important are the granodiorites near Philipsburg and Cable. The sedimentary rocks were greatly metamorphosed by the intruding igneous rocks and at some places garnet, epidote, magnetite, and other minerals of contact-metamorphic origin were extensively developed. At about this time the gold-copper contact-metamorphic ores of the Cable mine and the large bodies of magnetic iron on Franklin Hill and elsewhere were deposited by solutions emanating from the cooling granite, as were also probably some of the gold-bearing replacement veins formed under closely similar conditions.

After the granitic batholiths had solidified, fissures formed in them and in the sedimentary rocks near by were filled by metalliferous solutions carrying excess of silica, alkali carbonates, and sulphides. In certain groups of fissures silver ore with only a little gold was deposited, and in other groups gold ore with relatively little silver was introduced. The solutions were hot, for they produced changes in the wall rock characteristic of hydrothermal metamorphism.[1] They were probably ascending; because, first, the deposits they formed were very extensive vertically; second, where the country rock was limestone and was gently flexed, the anticlinal folds were the more extensively replaced by ore; and third, where shale beds were interstratified with limestones the ore was in places deposited below the bed of shale but not above it. In the Granite vein the richest ore shoot appears to be related to a junction of two fissures, and presumably the mingling of solutions was a favorable factor. The junction most enriched is above an approximately horizontal line, and other junctions, which are approximately vertical, do not seem to be related in any way to enrichments. The position of such enrichment strongly suggests ascending waters and gives additional weight to the evidence afforded by the relation of ore shoots to other structural features.

As already stated, the ore deposits are more numerous in the intruding igneous rocks and in the sedimentary rocks near intrusive igneous rocks than at a distance from their contacts, and the profitable ore so far as known is limited to such positions. This distribution indicates that the ore deposits are conditioned upon the presence of the igneous rock, especially of the granodiorite intrusives, and suggests the probability that the ascending waters were solutions given off from the intrusives exposed or from deeper unexposed igneous rocks.

It has been shown also that the silver-bearing veins in granite and the silver-bearing replacement veins in sedimentary rocks near Philipsburg fill the same group of fissures. Before they were faulted some of these veins extended from one rock into the other, but certain other veins of the same group are inclosed entirely in granite and still others are entirely in sedimentary rocks. Although the ore in sedimentary rocks contains more carbonate than that in granite, the metallic minerals are practically the same and are present in approximately the same proportions. They were undoubtedly deposited by solutions of the same general composition and of similar origin. Inasmuch as their composition was similar regardless of the rocks traversed, the solutions were probably related to a single deep-seated source. The general relations of each group of deposits point to waters of magmatic origin closely related to the granitic batholiths.

During the period of deposition some of the veins were fractured and brecciated, and ore genetically similar to the first deposit was introduced into the open spaces thus formed. At a still later period the country rock was at many places disturbed by small normal faults, which cut across the ore bodies and displaced them. These faults are not themselves mineralized. Other fissures following the veins or parallel to them were formed presumably at the same time, and this fissuring provided a condition for secondary enrichment of some of the deposits by descending sulphate waters.

Most of the deposits in the sedimentary rocks are in the Paleozoic formations. The geologic section of sedimentary rocks from the Cambrian through the Mesozoic is, as represented in this quadrangle, about 7,000 feet thick, and as nothing indicates that appreciable angular unconformities were developed between the Cambrian and the close of the Mesozoic, it is reasonable to assume that most of the deposition took place at a depth not much less than the entire thickness of the section, or 7,000 feet. Thrust faulting, which would thicken the sedimentary column, and probably some erosion, which would decrease it, took place between the deposition of beds and the deposition of ores, but these two processes may have nearly compensated each other in modifying the thickness of the sedimentary shell.

Inasmuch as the various types of ore bodies in the sedimentary rocks occur in formations at approximately the same geologic horizons, and inasmuch as all the deposits are regarded as of approximately the same age, it can not be assumed that very great differences in depth existed

[1] Lindgren, Waldemar, Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 578. Steidtmann, Edward, A graphic comparison of the alteration of rocks by weathering with their alteration by hot solutions: Econ. Geology, vol. 3, 1908, p. 381.

at the time of deposition. The contact-metamorphic deposits and some of the gold-bearing replacement veins deposited under somewhat similar conditions are in Cambrian limestones. The silver-bearing replacement veins occur elsewhere in these same limestones at approximately the same elevations, and some of the silver-bearing fissure veins in quartzites occur in Algonkian rocks, which were presumably buried as deeply at the time these veins were formed as were the limestones that were metamorphosed at contacts with igneous rocks. The minerals of the two groups of deposits indicate that the contact-metamorphic deposits and related veins were formed under great pressures,[1] and that the silver-bearing fissure fillings were formed under less intense conditions. It is almost certain that the silver-bearing veins were formed at about the same depths as the contact-metamorphic deposits and the gold-bearing replacement veins, but there is reason to believe that the silver-bearing veins were deposited in open fissures connected freely with the surface and probably under conditions of simple hydrostatic pressure. That the contact-metamorphic deposits and related pyrrhotitic replacement veins were probably formed where no such free communication with the surface existed is indicated by the presence of the minerals known to be formed under great pressures. The escape of the solutions that deposited these minerals was presumably through a large number of very small openings in which friction was too great for conditions approximating those of hydrostatic pressure to be maintained, and for that reason greater pressures were possible than those of hydrostatic head.

It has been shown elsewhere in this report that some of the granitic rocks cut late Cretaceous sedimentary rocks and that there is no evidence that any of these intrusives are pre-Cretaceous. The ore deposits, therefore, are probably not older than the late Cretaceous. Inasmuch as 6,000 or 7,000 feet of rock was eroded after the granites were intruded and after the ores were deposited, a considerable interval of time must have elapsed since these events took place. The Miocene beds, which are generally flat-lying, are later than the period of profound fissuring and eruptive activity and later, therefore, than the ore deposits. Furthermore, an interval of erosion must have intervened between the intrusion of the granite and the deposition of the Miocene beds. It may be stated with some degree of confidence, therefore, that the deposits were formed after late Cretaceous time or very early in the Tertiary, probably in the early Eocene.

SECONDARY ENRICHMENT OF DEPOSITS.

GOLD DEPOSITS.

Secondary enrichment is a process by which the amount of the valuable metals in deposits is increased locally by the removal of valueless constituents in the primary ore, or by solution and reprecipitation of the valuable contents by descending surface waters.

Practically all the deposits, both of gold and of silver, contain when first deposited iron pyrite in considerable amount, and this mineral or other iron-bearing sulphides, when oxidized at the surface in presence of air and water, forms solutions of ferric sulphate and sulphuric acid. Such sulphate solutions are known to dissolve silver, but gold is not nearly so readily dissolved as silver, and consequently the processes for enrichment of the two metals generally differ. Gold occurs presumably as the native metal, for the most part intimately associated with pyrite, arsenopyrite, and quartz. When such ore is attacked by surface waters the sulphur is removed as sulphate, and this process carries away iron and some silica in solution. Under some conditions, if chlorides are present, gold may be dissolved, but in a proportion generally less than that of the other elements removed. The remaining oxidized ore is consequently relatively richer than the original sulphide ore, for it has lost less of its gold than it has of its valueless constituents, and it has a further advantage in being more easily treated than the refractory sulphide ore. In the presence of chlorides and manganese oxides, however, gold is readily dissolved by the mineral waters and may be carried away in the general circulation or, in the presence of ferrous sulphate or other reducing agent, it may be reprecipitated as native gold in the vein. Many of the gold deposits of this quadrangle have been enriched presumably through

[1] Graton, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians: Bull. U. S. Geol. Survey No. 293, 1906, p. 72.

the removal of valueless minerals, and the Granite vein is apparently enriched in gold even below the oxidized zone, but this enrichment is slight as compared with the enrichment in silver.

SILVER DEPOSITS.

Silver dissolves in mine waters more readily than gold,[1] and for this reason the upper portion of a silver deposit is likely to be leached of some of its silver. According to Kohlrausch 0.55 gram of anhydrous Ag_2SO_4 will dissolve in 100 cubic centimeters of water at 18° C. Under favorable conditions such silver will be again deposited by descending waters as rich silver minerals in a lower zone of the vein. These conditions [2] are as follows:

1. The presence of sufficient pyrite or other iron sulphides in the ore. The oxidation products of pyrite (FeS_2), as pointed out by Weed, are more efficient solvents for silver than the products of galena (PbS) or of zinc blende (ZnS), because the pyrite carries more sulphur than is necessary to satisfy the iron when ferric sulphate ($Fe_2(SO_4)_3$) or ferrous sulphate ($FeSO_4$) are formed. The remaining sulphur yields sulphuric acid, and this is increased by the deposition of limonite by ferric sulphate, for this reaction also sets free H_2SO_4. When zinc blende and galena oxidize to sulphates free acid is not necessarily formed.
2. The formation of extensive fractures through the primary ore body. If after the deposition of the primary ore the country is disturbed by movements, the brittle quartz ore is generally fractured. In many places these minute fractures appear to be confined to the vein, and such conditions are peculiarly favorable because the more active circulation is consequently confined rather closely to the deposit. If the fractures extend far into the country rock the dissolved metals may be scattered. A great number of small fractures are more favorable to concentrated secondary enrichment than a small number of large fractures.
3. An efficient downward circulation of water. This condition, which depends on topography as well as on postmineral fracturing, is best supplied in moist areas of considerable relief in warm or temperate climates.

All these conditions have been supplied in the Granite vein, where the primary ore was highly fractured after it was deposited. The highest point of this vein as now exposed is about 2,500 feet above the valley of Flint Creek. The difference in elevation of different parts of the vein gives ample head for an active downward circulation wherever it is provided for by suitable channels. The mine is now drained by a long adit driven eastward nearly along the strike of the vein. This adit intersects the Ruby shaft about 1,300 feet below the surface, and farther east is about 1,800 feet below the surface. According to measurements made July 14, 1906, 540,000 gallons of water passes through this adit every day. The basin above the adit, if bounded by the watersheds shown on the map (Pl. II, in pocket) and by a north-south line 1,500 feet east of the portal of the adit, would present a flat surface 2.066 square miles in area. Assuming that the figures given for July 14 represent the average daily discharge, the annual discharge at the portal of the adit is equivalent to a sheet of water 5.5 inches deep covering the catchment basin. This water represents an important part of the total precipitation in the basin.

An analysis of the water by E. E. Blumenthal, chemist of the Granite-Bimetallic Mining Co., shows that it contains 147 parts SO_4 and 160 parts iron in a million, with traces of silver and gold. These figures indicate that about 0.6 ton of iron sulphate, sulphuric acid, and similar compounds are carried out of the mine every 24 hours. At some places the solutions are much more concentrated, and the mine rails are so vigorously attacked that within a few months they are unfit for use. The circulation in the vein before the mine was opened was probably less active, and the waters were probably less highly oxygenated, but otherwise it was much the same as it is to-day.

The silver which has been dissolved by sulphuric acid and ferric sulphate is precipitated by the action of ferrous sulphate and the sulphides. The arsenic and antimony compounds, especially stibnite, enter into these reactions, and silver-rich minerals, chiefly ruby silver, have been deposited in considerable quantity in secondary fissures and in solution cavities. In the Granite vein, described on page 202, the effects of such precipitation are important in some places 1,000 feet below the surface, and the processes were operative at still greater depths.

[1] Smith, Alex., General inorganic chemistry, p. 544.

[2] Emmons, S. F., The secondary enrichment of ore deposits: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 177. Weed, W. H., The enrichment of gold and silver deposits: Idem, p. 424.

The change of character of the ore in depth is further discussed on page 178. The great extent of the secondary zone in this vein was favored by a relief that furnished an ample head for circulating waters, by fracturing of the vein subsequent to the deposition of the primary ore, by the abundance of argentiferous sulphides and of pyrite and stibnite present, and by the great size of the primary ore body. In the other silver lodes near Philipsburg the second and third conditions were less favorable.

CHAPTER XII.

HISTORY OF MINING DEVELOPMENT AND PRODUCTION.

The period of rapid settlement and active development of Montana began with the discovery of its rich placer deposits. The first discovery of gold in Montana is accredited [1] to François Finlay, a half-breed Indian, who in 1852 found colors in the gravels near the mouth of Gold Creek, a small stream which rises in the northeast corner of the Philipsburg quadrangle. The presence of gold at this place was noted later by John Evans, a geologist and engineer attached to a Government party, which was exploring a route from the headwaters of Missouri River to the Pacific coast. The first workable placers discovered in Montana were found on this creek by James and Granville Stuart, who with others in the summer of 1862 built sluice boxes and took out a small amount of gold near the present site of Pioneer. The following summer placer deposits were discovered 100 miles southeast of Philipsburg on Alder Gulch, a tributary of Madison River, and these led to the founding of Virginia City.

The Alder Gulch placers were extensive and very rich and are credited with a production of $30,000,000 for the three years following their discovery. The impetus given the mining industry in Montana by the successes at Alder Gulch resulted in rapid development of the territory. A large number of prospectors and miners from Idaho, Utah, and the southwestern States were attracted to Virginia City, where many exploring parties were organized. As a result of this activity much prospecting was done throughout the western parts of the State, and many important deposits were discovered between 1863 and 1868.

The Hope mine was discovered in December, 1864, by a prospector named Horton, and the deposits came into prominence through Charles Frost, who exhibited ores from this district at Helena in 1866. In the following year Philipsburg was founded on Camp Creek, a small tributary of Flint Creek, just south of this mine. The town was named for Philip Diedesheimer, of Comstock fame, who came from San Francisco in 1867 to erect the James Stuart mill, afterward called the Hope mill, the machinery for which was freighted in by wagon from Utah. In 1865 Joe Henderson discovered the placers in the gulch that received his name, and Emmettsburg, a short distance below the present site of Henderson, was settled. This was a very lively camp in the late sixties, when it produced about $300,000. The Georgetown placers were also worked at this time, and produced $40,000. In 1866 very rich deposits were discovered at Pioneer, near the early discoveries on Gold Creek and only a few miles north of the Philipsburg quadrangle. The Atlantic Cable mine was discovered in 1866, and in the following year the Nowlan mill was built to treat the ore. By 1870 two mills had been built at Cable and two at Georgetown.[2]

The mining operations were carried on with difficulty and at great expense, owing to the remoteness of supply points. Three routes communicated with outside markets. One was by way of Fort Benton, which for a few weeks in favorable seasons was the head of navigation of the Missouri River, and thence by wagon road through Helena to Philipsburg or Cable. A second route, by wagon road from Salt Lake, is now approximately the route of the Oregon Short Line Railroad between Salt Lake and Montana points. This route necessitated a wagon haul of 500 miles. A third route was the Mullan wagon road constructed by the Federal Government from Fort Benton to Walla Walla, Wash., connecting with points on Columbia River. The milling costs were especially high for the treatment of silver ores, for salt, which was used in great quantity in silver mills, had to be transported from Utah and in 1871 brought $120 a

[1] Bancroft, H. H., History of Montana: Bancroft's Works, vol. 31, p. 613.

[2] Raymond, R. W., Statistics of mines and mining west of the Rocky Mountains, 1870, pp. 276-278.

ton at Philipsburg. The Hope mill was at first not altogether successful, for a large part of the metals was carried away with the tailings, and it was not until several years after the erection of the mill that, under the management of Charles Clark and C. D. McLure, the Hope deposits were profitably exploited.

The Poorman's Joy, the Trout, the Algonquin, and other mines were located soon after the Hope deposits, and various attempts were made to treat the ores. The freight rates were almost prohibitive, but several shipments of refractory rich silver ore were hauled by wagon to railway points, to be thence forwarded to Reno and San Francisco, and to smelters in Germany and Wales. An attempt was made by Cole Saunders, who organized the Cole Saunders Silver Concentrating Co., to smelt the ores from the Poorman's Joy and other mines, and two furnaces were erected near Philipsburg. The attempt at smelting was soon abandoned, however, owing to the scarcity of suitable fluxes, and the company, which was experiencing financial difficulties, leased its mines and works to the Imperial Silver Mining Co., which in 1871 erected a 5-stamp dry-crushing mill and installed a reverberatory roasting furnace. This treatment proved to be efficient, but it was expensive, for the milling costs were as high as $28.33 a ton.

The mining industry in Montana languished somewhat during the seventies, owing to the exhaustion of the most profitable placers. At Philipsburg, the Hope mill was in operation much of the time, and two very complete silver reduction works were built near Tower, about 1½ miles east of Philipsburg. At Tower, the Northwest Co., which was controlled by Charlemagne Tower, A. B. Nettleton, and other Philadelphia capitalists, built the Northwest mill to treat the ore from the Trout and other mines. Shortly afterward the Algonquin mill was built near the Algonquin mine at Hasmark, a small mining camp half a mile south of Tower. Both of these mills were dry-crushing plants, in which the silver ore was treated by the Reese River chloridizing roast and by the pan-amalgamation process. The two plants were complete in all their details, and each is said to have cost more than $150,000. Operations were suspended by the Northwest Co. in 1879, and the Algonquin mill was permanently shut down four years later.

The Atlantic Cable and Georgetown deposits were worked with more or less success in the seventies. Salton Cameron & Co., who obtained a lease of the Cable, ran a considerable quantity of ore through the Hanauer mill. In 1877, J. C. Savery obtained possession of the Cable mine and milled a large quantity of rich ore, and six years later he built the 30-stamp mill still in use. He is said to have recovered nearly $3,000,000 from the Cable mine between 1877 and 1891.

In 1884 the Pyrenees mill at Georgetown was in successful operation. That year Salton Cameron built another mill at the present site of Glenn's mill, to treat the ores of the Southern Cross mine. In the following year the Blue-eyed Nellie mine, situated on the north side of Warm Spring Creek between Cable and Anaconda, became an important producer of silver, and for several years it yielded ore at the rate of more than $100,000 annually. In 1885 important discoveries were made on Boulder Creek and its tributaries above Princeton.

The period of greatest prosperity for the camps of the Philipsburg quadrangle was from 1881 to 1893, during which time the Granite Mountain mine, which had passed into the hands of C. D. McLure and associates, was most productive, and the largest ore bodies of the Bimetallic, Hope, Combination, Pyrenees, and Cable mines were uncovered. Philipsburg became one of the most important silver-producing camps in the United States.

The Northern Pacific Railroad was completed in 1883 and afforded a transcontinental route accessible at Drummond, only 30 miles from Philipsburg. A railroad from Drummond to Philipsburg was completed in 1887 and was later extended to Rumsey.

The town of Granite, which was laid out on the steep slopes of Granite Mountain, near the mine of the same name, had at the zenith of its prosperity a population of more than 2,000 people. Extensive dry-crushing roasting plants were built there and at Rumsey, 2 miles south of the mine. The production rose steadily until 1890, when it was 3,930,329 ounces silver and 8,583 ounces gold. During this year $2,500,000 in dividends were paid to the stockholders of the company. Meanwhile the Bimetallic Co., controlled largely by the same interests and operating on the extension of the Granite vein, had erected hoisting and reduction plants which were counterparts of those of the Granite Mountain mine. The production of the two mines was maintained at high figures for several years, while various other companies, encouraged by the success of these mines, vigorously but unsuccessfully prospected veins in the granite near by to find a similar ore body. In 1893, when the price of silver dropped so low that it could not be recovered at a profit, the mining industry at Granite and Rumsey became dormant, though the Hope mine near Philipsburg still continued operations. In 1898 the Granite and Bimetallic companies consolidated, and shortly afterward these mines were reopened. They produced steadily until August, 1905, when the pumps were pulled and the levels below the drain adit were allowed to fill with water. Since that time the company has used the leasing system, and the operations have been confined to the upper levels.

The rise in silver in 1906 made it possible to market a large tonnage of ore from the dumps of the Granite, Trout, Frisco, Salmon, Hobo, Algonquin, and other properties, which had formerly been regarded as too low grade to be of value. In the autumn of 1907 the Bimetallic mill was remodeled to work the dumps and waste of the Granite-Bimetallic Co.

The total production of the mines of the Philipsburg quadrangle can not be stated accurately, because for a portion of the period of their productiveness their records were not kept, but it is provisionally given as $50,000,000, which is probably a very close estimate. Approximately one-fifth of this amount is gold and the remainder silver. The production of copper, lead, iron, and manganese altogether is probably less than $250,000.

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CHAPTER XIII.

TREATMENT OF ORES.

SILVER ORES.

At present much of the ore is shipped to smelters at Helena and Anaconda, but when the deposits were first discovered smelting was not feasible, because suitable fluxes could not be obtained near by, and outside works were so remote and transportation so expensive that it was not profitable to ship ores except those of the very highest grade, which were not of great quantity. Pan amalgamation was best adapted to the conditions and is still used where smelting is impracticable. The following is a list of the silver amalgamating mills situated in the Philipsburg quadrangle:

Silver amalgamating mills in the Philipsburg quadrangle.

Name of mill.	Location.	Process.	Number of stamps.	Present condition.
Algonquin	Hasmark	Reese River	20	Ruins.
Bimetallic	Bimetallic	do	100	Good order.
Combination	Combination	Combination	20	Do.
Granite (A and B)	Granite	Reese River	80	Dismantled.
Hope	Philipsburg	Washoe	10	Good order.
Northwest	Tower	Reese River	20	Ruins.
Patten	Philipsburg	Washoe	5	Good order.
Rumsey	Rumsey	Reese River	100	Dismantled.

The processes used, which are illustrated in figure 32, are:

1. Simple pan amalgamation (Washoe process).
2. Chloridizing roasting and pan amalgamation (Reese River process).
3. Concentration with pan amalgamation of tailings (Combination process).

PAN AMALGAMATION.

Methods.—Pan amalgamation, which was developed in the Washoe district, Nevada, to treat the silver ores of the Comstock lode, is well adapted to the ores of Hope and Poorman hills. The ore minerals are chiefly argentite (silver glance) and cerargyrite (horn silver). Pyrite, galena, and chalcocite are present in but very small amounts. Antimony and arsenic compounds are at most places practically absent. The gangue minerals are quartz, barite, calcite, and fluorite. The striking feature of the ore is the small amount of the sulphides, particularly near the surface.

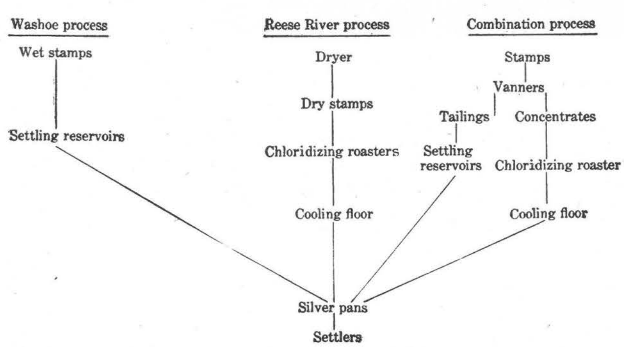


FIGURE 32.—Diagram to illustrate methods of treating silver ores.

Pan amalgamation depends upon certain chemical reactions which are not perfectly understood. The silver pan is an upright cylindrical vat about 5 feet in diameter and 2 feet deep, made of iron or of wood, with the bottom shod with iron. An iron disk, the muller, is a little smaller than the bottom of the vat, and moves against it with a rotary motion, mixing and grinding the ore, which goes from the settling reservoirs to the pans as a pasty mud. Salt, mercury, and copper sulphate are charged into the silver pans, and react upon the silver sulphide and silver chloride. Mercury, in the presence of iron, frees the silver from sulphide and chloride compounds and forms amalgam. The mercuric chloride formed is reduced to mercury by the iron. Copper sulphate reacts on common salt and in the presence of iron forms cuprous chloride, which reacts on silver sulphide and to a certain extent on sulpharsenates and sulphantimonates of silver. The reactions are facilitated by heat, which is supplied to the pans in the form of steam. After about eight hours grinding in the pans the pulp passes to the settlers, where it is agitated with cold water to facilitate the separation of mercury and amalgam.

Hope mill.—In the Hope mill, which is today essentially as it was first designed, the crushed ore is shoveled into two batteries of five stamps each, whence it passes through 40-mesh screens into settling reservoirs below the batteries. From these the thickened pulp is shoveled to the mixing floor, where salt, mercury, and copper sulphate are added. It is then shoveled into the pans, and after grinding and amalgamation passes into the settlers. The saving is from 70 to 85 per cent, according to the character of the ore treated.

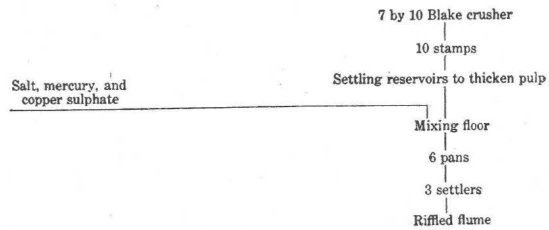


FIGURE 33.—Plan of treatment in Hope mill.

The general plan of treatment in the Hope mill is shown graphically in figure 33.

Patten mill.—The Patten mill, which is situated about 1 mile north of Philipsburg, was built to treat the ore from the Sweet Home, Cadgie Taylor, and other mines of Hope Hill. It is equipped with a 7 by 10 jaw-crusher, five gravity stamps, two silver pans, and one settling tank. The arrangement of the mill and the process of treatment is similar to that of the Hope mill.

CHLORIDIZING ROASTING AND PAN AMALGAMATION.

Methods.—The chloridizing roasting and pan amalgamation, or the Reese River process, was developed in the Reese River district at Austin, Nev. By it the ore is dried before stamping, stamped dry, and roasted with salt before being treated in the pans. The silver minerals are converted to chlorides, which amalgamate readily. The process is said to recover 85 to 95 per cent of the silver in the ore, and the mercury loss is low compared with that of the Washoe process. A large part of the gold is recovered in the bullion. The ores best adapted to the chloridizing roast are those which carry considerable pyrite and other sulphides, but not enough of such minerals to form a matte when roasted. Arsenic and antimony compounds are not so objectionable as for the Washoe process, because they are more readily converted into chlorides. The ores of the Philipsburg quadrangle which fall in this class are from the silver-bearing veins near Philipsburg. The Granite, Bimetallic, Rumsey, Northwest, and Algonquin mills used this process, and practically the entire production of the Granite-Bimetallic lode was recovered by it.

Treatment of ore from Granite-Bimetallic lode.—The ore of the Granite-Bimetallic lode consists essentially of a gangue of quartz, rhodochrosite, rhodonite, barite, and calcite, carrying pyrite, arsenopyrite, stibnite, tetrahedrite, tennantite, galena, sphalerite, ruby silver, realgar, orpiment, and other minerals. The gangue minerals as a rule constitute from one-half to four-fifths of the vein. In the upper levels ruby silver, argentite, native silver, and cerargyrite were present, locally in great abundance. The first attempt to treat the ore was in the Hope mill, where wet crushing by stamps and pan amalgamation without roasting was found unsatisfactory. The Algonquin mill, a dry-stamp salt-roasting pan-amalgamation plant, gave a good extraction, and several hundred thousand dollars worth of ore was treated at this plant in the early eighties. Mills A and B at Granite were in principle similar to the Algonquin mill and had in all 80 stamps. Water was supplied to these mills by a ditch from a reservoir at Fred Burr Lake, 3 miles east of Granite. The third mill, with 100 stamps, was built at Rumsey by the Granite Mountain Co., and one of equal size was built at Bimetallic. In the early nineties 280 stamps were dropping on the ore of the Granite-Bimetallic lode, the treatment in all the plants being practically the same. A concentrator designed to treat the low-grade ores was built at Granite in 1900. The richest of the concentrates, running up to 73 ounces silver and 0.76 ounce gold, were shipped to the smelter, while those of lower grade were worked in the mill. Concentration was only partly successful and was practiced only on ore obtained incidental to the mining of the high-grade ore. A run of 20,222.4 tons of ore concentrated from May 1 to August 15, 1903, at a cost of $2.40 a ton, yielded 114,644.7 ounces of silver and 672.26 ounces of gold, from which the net returns were $55,946.54. The tailings from the concentrate ran 4.2 ounces of silver and 0.028 ounce gold. The complete treatment of the ore when the concentrator was used is shown in figure 34. It was adopted only after the very rich secondary ores had been exhausted. The treatment of the rich ores would be represented by the lower portion of this diagram, beginning with the point where the ore from the mine passes into the cylindrical dryers. This part of the diagram, which also illustrates the Reese River process in some detail, represents the Bimetallic mill at its highest state of efficiency. The method of amalgamation was essentially the same in the three other mills.

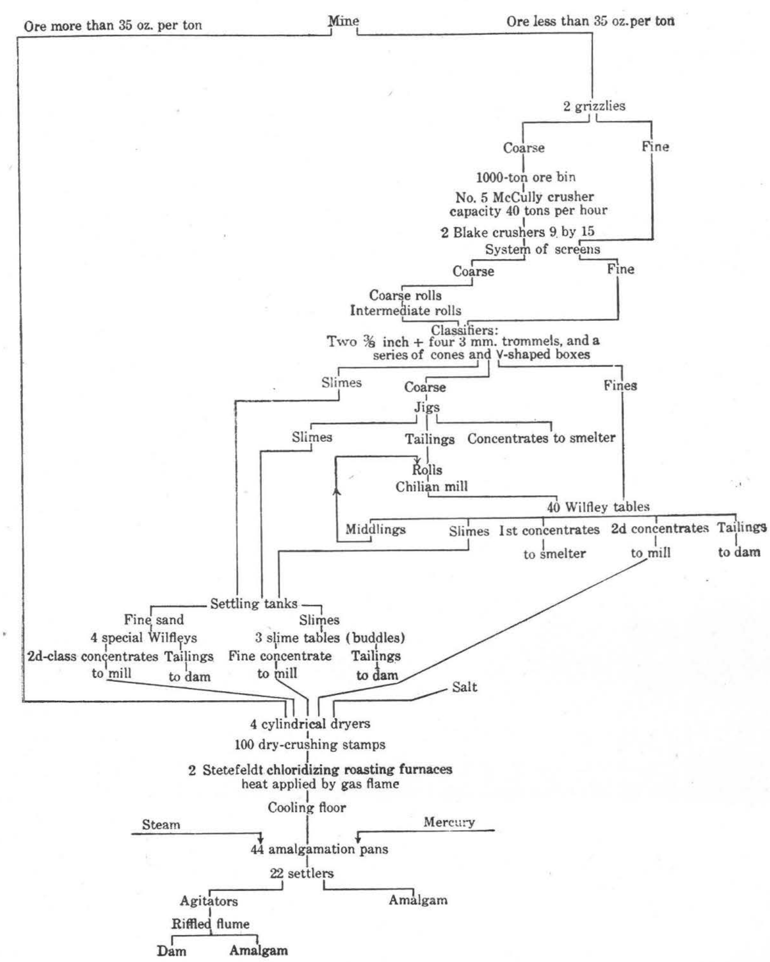


FIGURE 34.—Flow sheet showing concentrating and milling of ore from Granite-Bimetallic mine.

In 1893 a sulphite leaching plant was installed at the Bimetallic mill and a portion of the tailings was worked at a profit. By this method about 65 per cent of the silver was recovered from the tailings, but little or no gold was extracted. During the summer of 1906 an experimental cyanide plant, equipped with a tube mill and a filter press, was installed with a view to ascertaining the best method of treatment for the large accumulations of tailings that have been preserved at Granite, Bimetallic, and Rumsey.

Bimetallic mill.—The ore, which is crushed at the mine in three 9 by 15 Blake crushers, is forwarded with concentrates over a Bleichert wire tramway, about 1½ miles long, to the mill, where it passes into large ore bins. After the addition of from 10 to 12 per cent of salt it passes through four Howell-White rotary dryers using producer gas for fuel. From the dryers it is fed automatically to stamps which are arranged in 20 batteries of five stamps each. It is crushed dry in the batteries and passes through screens of 20 meshes to the inch. From the batteries a screw conveyor delivers the ore to bucket elevators which lift it to the tops of two Stetefeldt roasting furnaces. Impact screens are placed at the tops of the furnaces so that any coarse material which may have passed over a broken battery screen is returned to the ore bins. The Stetefeldt furnace is a shaft through which the powdered ore falls. Heat is supplied by a gas flame kindled at the bottom of the shaft. The chloridizing reactions take place in the shaft, in the dust chambers where the finer portion of the powdered ore is collected, and on the cooling floor where the roasted ore is afterwards spread. The roasted pulp is amalgamated in pans for six hours and then it passes to the settlers, where the amalgam and tailings are separated. (See fig. 34.)

A feature of the Bimetallic mill was the arrangement to catch the dust at the batteries. This device, designed at the Bimetallic mill by Louis Bailey, is a large V-shaped trough closed at the top and running above the batteries the length of the mill. Sheet-iron pipes about 1 foot in diameter connect the trough with the chamber which incloses the stamps at the top of each battery. A gentle current of air is supplied by rotary exhaust fans, and the finer dust which would otherwise escape from the batteries is drawn into the trough. A portion settles at once and is drawn into hoppers at the bottom of the trough, and the remainder is blown into dust chambers connected with the roaster stack. The device not only decreases losses but also improves the air in the mill.

CONCENTRATION WITH PAN AMALGAMATION OF TAILINGS.

Methods.—The method of treatment known as the Combination process differs from the Reese River process in that the ore is concentrated and a large part of the sulphides removed. The lighter material or tailings is treated in the pans without roasting. The method is used if the ore is not rich enough to pay for roasting the whole amount as in the Reese River process and if a satisfactory saving can not be made by the Washoe process. The concentrates may be roasted and treated in pans or shipped to smelters. The only deposits in the Philipsburg quadrangle for which this method has been used are those of the Combination mine.

Combination mill.—The ore of the Combination mine contains a considerable quantity of sulphides, of which tetrahedrite and pyrite are the most abundant. Chalcopyrite, galena, zinc blende, and bornite are also present. The gangue is essentially quartz, and in the upper levels the silica content is greater than 80 per cent. An analysis of this ore is given on page 254. The partly oxidized ore carries a notable amount of copper carbonate, iron oxide, a yellow amorphous powder, which is probably a mixture of silver and lead chlorides, and a sooty black substance, which is probably a mixture of chalcocite and argentite. The average content of the rock is about 20 ounces of silver to the ton. The gold content is very small, and no attempt was made to save the copper. The principal ore minerals are silver-bearing tetrahedrite, from which only a small amount of the silver could be obtained without roasting; the copper carbonate mixed with silver-lead chlorides, which could be won by pan amalgamation without roasting; and the black sooty powder, composed of silver and copper sulphides, which slimed badly and could not easily be recovered in the settling tanks.

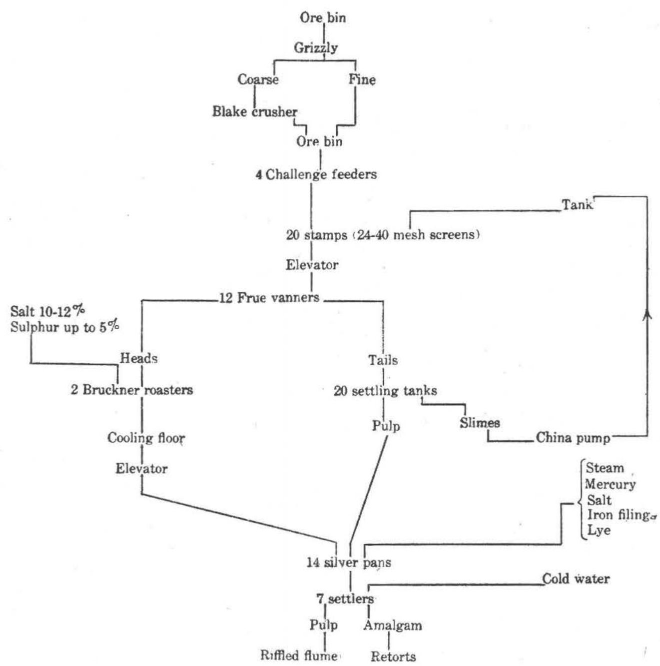


FIGURE 35.—Plan of treatment in the Combination mill.

The Combination mill as first constructed was a 10-stamp, wet-crushing, amalgamation mill, practically a duplication of the Hope mill, with a space left for Frue vanners, to be added later. Without the vanners the treatment was not successful, for it effected a saving of only 46 per cent. Much experimenting was done before the final method of treatment as illustrated in figure 35 was adopted.

The ore was dumped from four-horse wagons into a storage bin, whence it passed into small cars and was dumped on grizzlies at the head of the mill. The ore passing over the grizzlies was sent through a Blake crusher, from which it passed into a bin below the grizzlies. From this bin it was fed by Challenge feeders to four batteries of five stamps each. Brass screens from 24 to 40 mesh were used in the mortars. The pulp was elevated and passed over twelve Frue vanners. The tailings were settled in square settling tanks built below the vanners, and the pulp was treated in silver pans and settlers. The wet concentrates from the vanners went to the two Bruckner roasters, which were revolved until the concentrates were dry. Salt equivalent to 10 or 12 per cent of the concentrates was charged into the roasters, and sulphur was added to bring the content of the ore up to 5 per cent. The sulphur is said to combine with the antimony, thus preventing the formation of refractory antimony-silver compounds. The roasted ore went to the cooling floor and was thence elevated to the pans. Above the pans was a storage box for the roasted concentrates, and a desirable mixture for a pan charge was made with the raw and roasted pulp.

By this method only the sulphide concentrates were subjected to the expensive salt roast, the tailings going directly to the pans after being settled in the tanks. A considerable loss resulted from silver contained in the slimes, which could not be fixed in the settling tanks, for very often these slimes assayed twice as much as the raw ore. The loss was decreased by pumping the slimes from the settling tanks back into the stamp batteries. They were also mixed with steam and used to thin down the pulp in the silver pans.

TREATMENT OF GOLD ORES.

CONSTRUCTION OF MILLS.

In the early history of the district the gold ores were treated by crushing with wet stamps followed by plate amalgamation. The stamps are of the California type, weighing as a rule about 1,000 pounds and dropping from 5 to 9 inches at a speed of 60 to 100 strokes a minute. In some of the gold mills concentrating devices were used, but the production of concentrates was not great. In the four years 1903–1907 six cyanide plants were built. Four of these are very simple mechanically and are without devices for the treatment of the slimes. Two of them are experimental plants. The Southern Cross mill as lately rebuilt has the largest capacity and is the most thorough in its method of treatment. The following list includes all the gold mills of the quadrangle.

Mills working gold ores in the Philipsburg quadrangle.

Name of mill.	Location.	Process.	Number of stamps.	Concentrating devices.	Present condition.
Bloomington	Mine	Amalgamation and concentration.	10	3 vanners	Ruins.
Cable (new)	do	Amalgamation	30	2 vanners	Good order.
Cable (old)	Cable Creek	do	20		Dismantled.
Douglas	Mine	Amalgamation and cyaniding	2 (steam)		Good order.
Dougherty	Near Montana mine	Amalgamation	3		Do.
Glenn	Near Georgetown	Amalgamation and cyaniding	10		Do.
Gold Coin	Mine	Amalgamation	30	1 slime table	Do.
Gold Hill	Near Princeton	do	Huntington mill.		Dismantled.
Gold Reef	Near mine	Amalgamation and cyaniding	6		Good order.
Hannah	do	do	Rolls, etc.		Do.
Henderson	do	Amalgamation and concentration.	20	5 Wilfleys	Do.
Pyrenees	Mine	Amalgamation	10		Dismantled.
Red Lion	Near mine	do	10		Do.
Royal	Mine	Amalgamation and concentration.	10	4 vanners	Good order.
Southern Cross	do	Amalgamation and cyaniding	Rolls, etc.		Do.
Stuart	South of Georgetown Lake	Amalgamation	5		Do.
Sunday	Mine	do	Huntington mill.		Do.
Twilight	do	do	10		Ruins.

DESCRIPTIONS OF MILLS.

Southern Cross mill.—The Southern Cross mill as first designed was a dry-crushing cyanide plant and is said to have saved from 70 to 85 per cent of the gold and silver in the cellular oxidized ores. In the summer of 1907 the mill was remodeled and a thoroughly modern plant installed, in which the crushed ore is sent through wet rolls and ground in a Chilian mill. The ore is sized in Dorr classifiers, from which the sands go to the 250-ton cyanide tanks, and the slimes are treated by the Moore filter process.

Cable mill.—The Cable mill, situated at the mine, is equipped with two Blake crushers, 30 stamps, and amalgamation plates. A fair saving is made by simple amalgamation even with the sulphide ores. In the autumn of 1906 experiments were made with a view to adding concentrating machinery to the plant. The concentrates, though low in gold, carried sufficient copper and iron to make them a valuable asset.

Hannah mill.—The Hannah mill is situated on Flint Creek, below the Hannah mine, with which it is connected by a 3,800-foot gravity tramway. The ore, after it is broken in a 7 by 10 Blake crusher, passes through wet-crushing rolls and thence through a Chilian mill. From this it goes over a 40-mesh impact screen, the oversize being returned to the mill. The material which passes through the screen goes over amalgamation plates and thence to 4 cones, from which the coarse material passes through a sand pump to the cyanide tanks. The fine material is classified, and the coarse part of it is passed over additional plates, from which it goes with the slimes to the tailings dam. About five days is required for leaching, and the process is said to save 85 per cent of the metals. The saving could probably be increased by some process of slime treatment.

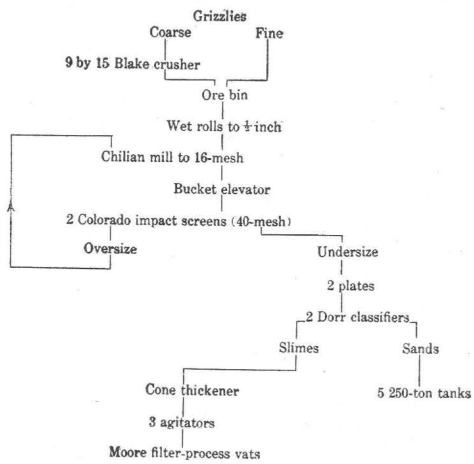


FIGURE 36.—Plan of treatment at the Southern Cross mill.

Gold Coin mill.—The Gold Coin mill, located at the mine, is a 30-stamp amalgamating plant. The saving is said to be about 85 per cent, of which 60 per cent is caught in the mortars.

Henderson mill.—The Henderson mill is situated in Henderson Gulch just below the Queen mine. The crushed ore at this mill passes to four batteries of five stamps each, the stamps weighing 980 pounds and dropping 5 to 6 inches 90 times a minute. The pulp passes over amalgamation plates and thence to an elevator which delivers it to classifiers at the top of the mill. The sized ore passes to five Wilfley tables, from which the middlings are sent through a Bryan mill back to the tables. The finer light material goes to a double-decked Buddle or slime table, from which slimes are shipped and fine sands passed to the tailings dam. The method was not successful for treating the low-grade ore, because the sands carried off several dollars to the ton in gold. It is said that the tailings may be satisfactorily treated by the cyanide process.

Douglas mill.—The Douglas mill, which is situated at the Douglas mine, is equipped with a Gates rock crusher, two steam stamps, amalgamating plates, and cyanide tanks. A small amount of ore was run through this mill with poor saving, owing to lack of facilities for catching slimes, which carried away a large part of the metals.

Glenn mill.—The Glenn mill, which is situated about midway between Georgetown and the Southern Cross mine, is equipped with a rock crusher, 10 stamps, amalgamating plates, and cyanide tanks. It was originally built by Salton Cameron to treat the ore of the Southern Cross mine but was purchased by the owners of the Orphan Boy and equipped with cyanide tanks to treat the ore from that mine. Only a small amount of ore has been put through.

Pyrenees mill.—The Pyrenees mill, situated near the mine, was equipped with 10 stamps and amalgamating plates. It produced a considerable quantity of gold in the eighties but is now dismantled.

Twilight mill.—A 10-stamp amalgamating mill, built near Flint Creek below the Twilight mine, is now in ruins.

Red Lion mill.—The Red Lion mill, situated on Flint Creek below the mine, is a 10-stamp amalgamating mill operated in the late eighties but now dismantled.

Dougherty mill.—The Dougherty mill, about one-half mile south of the Montana mine, in the Red Lion district, is a log structure equipped with three small gravity stamps and amalgamating plates. A few tons of ore have been treated.

Royal mill.—The Royal mill, near the Royal mine, is equipped with a Blake crusher, 10 stamps, amalgamating plates, and four Frue vanners. A fair proportion of the metals is said to have been saved by amalgamation and concentration. The tailings were not impounded by dams, but were turned into the gulch below, and a large quantity settled in a flat a mile or so below the mine. These tailings were located by parties other than the owners of the mine, and in the summer of 1905 a plant with six 50-ton cyanide tanks was installed to work them. The tailings ran about $2.80 to the ton, and about 70 per cent of the content is said to have been extracted.

Gold Reef mill.—The Gold Reef mill, on South Boulder Creek, below the Gold Reef mine, is equipped with six Hendy quadruple-discharge stamps and amalgamation plates. A saving of 50 per cent was made on the plates, and about 800 tons of ore were put through. In the summer of 1906 a 20-ton cyanide plant was added to treat the tailings, and a saving of 70 per cent of their contents is said to have been made.

Sunday mill.—The Sunday mill, which is situated at the mine, is equipped with a rock crusher, Huntington mill, and amalgamation plates. The saving effected was presumably unsatisfactory, for the tailings are said to carry several dollars in gold to the ton.

Stuart mill.—The Stuart mill, at the south end of Georgetown Lake, is equipped with five gravity stamps and amalgamation plates. An overshot water wheel supplied power.

Bloomington mill.—The Bloomington mill, which was situated at the mine, was a 10-stamp plant equipped with amalgamation plates and vanners. It was built in 1896 but was shut down after a run of about three months and is now in ruins.

Gold Hill mill.—The Gold Hill mill, which is situated on Swamp Gulch Creek above Princeton, was equipped with a Huntington mill and amalgamation plates. A few hundred tons of ore from the Gold Hill mine were put through this mill, but the saving was not satisfactory. The tailings are said to carry high values in gold.

CHAPTER XIV.

MINES NEAR PHILIPSBURG, GRANITE, AND TOWER.

GENERAL FEATURES.

The mines near Philipsburg, Granite, and Tower lie east of Philipsburg in an area 3 miles square. They are on the west slope of the ridge forming the divide between Flint Creek and South Boulder Creek. The summit of this ridge is more than 8,000 feet above sea level, and the elevation of Flint Creek valley near Philipsburg is about 5,300 feet. The area is drained by several small streams, which flow westward and join Flint Creek a short distance below Philipsburg. In the country on the north, east, and south, bordering the area here outlined, small quartz veins occur locally, but no workable deposits have been discovered.

The ore is shipped to smelters at Helena, Anaconda, and Great Falls, or is treated in silver mills near the mines by the processes described in the chapter on the treatment of ores. The total production of this group is about $39,000,000, nearly all of which came from the Granite, Bimetallic, Hope, and Trout mines. Of this amount more than 90 per cent is silver and most of the remainder is gold. Some lead has been produced as a by-product of silver mining. A few thousand tons of magnetite has been mined for flux, and several carloads of manganese ore have been shipped to steel manufacturers.

The sedimentary rocks, which outcrop in the mineralized area east of Philipsburg, are chiefly Paleozoic, but comprise a little of the upper part of the Spokane formation (Algonkian). The section from the Flathead quartzite (basal Cambrian) to the Quadrant formation (upper Carboniferous) is typically exposed. The great granite batholith which cuts through the sedimentary rocks is Cretaceous or later, and the granite porphyry exposed on Red Hill is probably of the same age. Although local variation in dip and strike is considerable, the structure of the sedimentary beds is relatively simple and nearly everywhere they lie one above the other in the regular sequence. The quartzite of the Spokane formation, which outcrops on the summit of Franklin Hill, forms at this place the crest of an anticline, the axis of which strikes west of north and plunges steeply in the same direction. Accordingly the formations which occur above the Flathead are exposed successively toward the north.

Faults are common, but most of them are small and can not be easily followed on the surface. Although recognition of these faults is of great importance for rational exploitation of the ore bodies, their throw is not great and they do not notably modify the broad structural features of this area.

The calcareous sedimentary rocks in the mineralized area have undergone notable contact metamorphism. Nearly everywhere they are recrystallized to marble, and considerable tremolite is developed at many places. Locally they are changed to rocks composed of garnet, epidote, diopside, quartz, hornblende, scapolite, and other minerals.

Subsequent to the intrusion of the granite, and presumably after the folding of the sedimentary rocks, a system of east-west fissures was superimposed upon the structure. These fissures are extensively mineralized and traverse both sedimentary and igneous rocks. (See fig. 17, p. 173.)

The deposits belong to four groups, each of which has been discussed in the chapter on ore deposits. They comprise silver-bearing veins in granite, silver-bearing replacement veins in sedimentary rocks, silver-bearing deposits in bedding planes of calcareous rock, and magnetite deposits of contact metamorphic origin.

SILVER-BEARING VEINS IN GRANITE.

GRANITE-BIMETALLIC MINE.

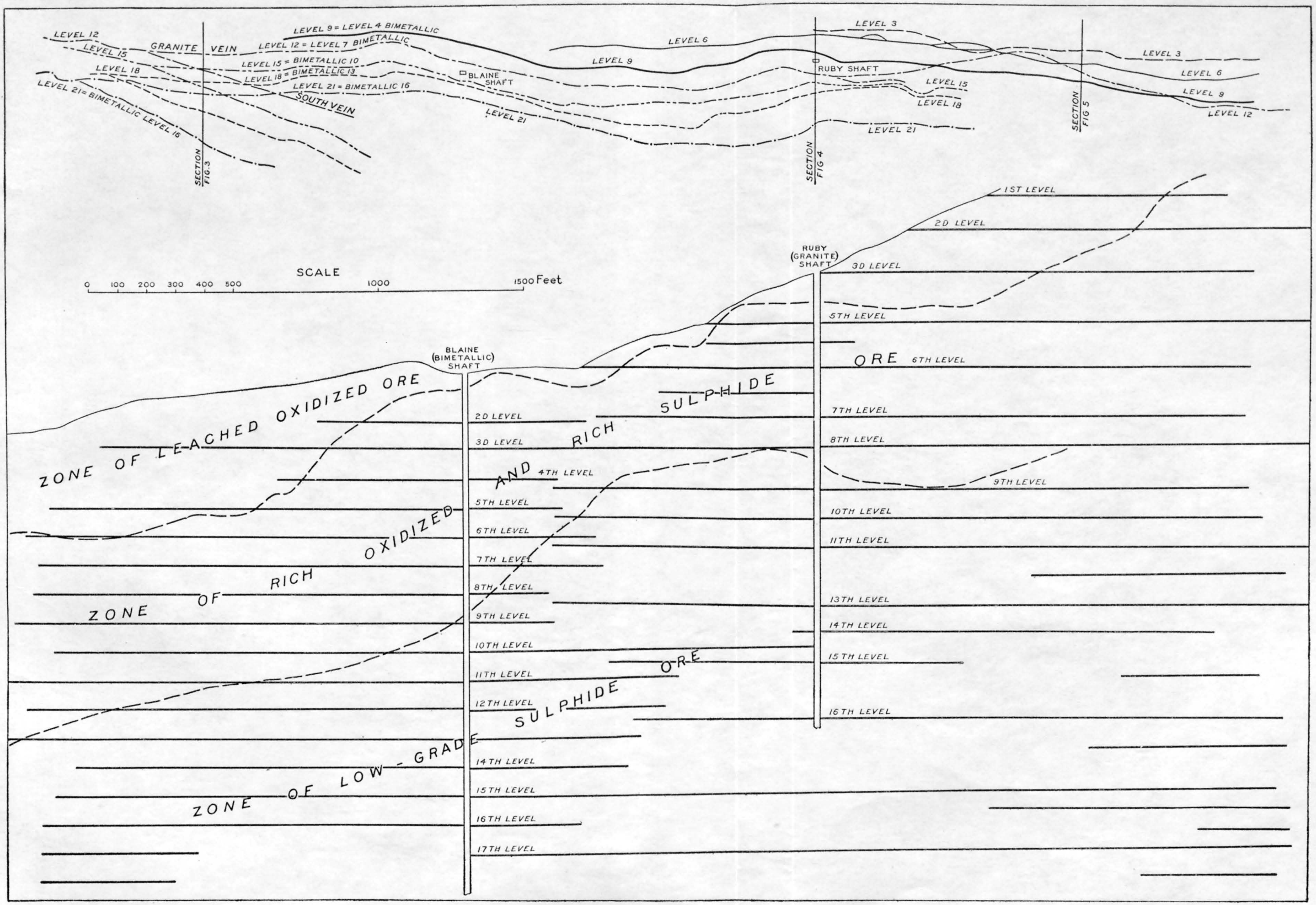
HISTORY AND DEVELOPMENT.

The Granite Mountain and Bimetallic mines are about 2½ miles southeast of Philipsburg, on the steep western slope of Granite Mountain. Although they were located on the same ore shoot and controlled from the first by practically the same interests, they were worked separately, each with its own reduction plants, until a consolidation was effected in 1898, since when the mines have been operated as one. (See Pl. VII, *B*, p. 50.)

The Granite Mountain mine was located in 1872, but the location was allowed to lapse and it was relocated in 1875. In 1880 Charles D. McLure, then superintendent of the Hope mill, encouraged by an assay of a specimen picked up from the dump, obtained a bond on the property for $40,000. After several thousand dollars had been spent in developing the block of ground between what are now levels 1 and 2 he succeeded in organizing a syndicate of St. Louis investors, chiefly from the Hope directorate, who advanced him altogether $132,000. The mine was examined in April, 1881, by Prof. J. E. Clayton, who reported $75,000 worth of ore in sight, the vein being from 4 to 6 feet wide and carrying on the average 44 ounces of silver to the ton. At this time tunnel No. 1 (level 1) had been driven 186 feet and No. 2, which tapped the ore shoot 300 feet from the portal, had been extended 443 feet. The rock was iron-stained quartz carrying a small amount of low-grade silver chloride ore. Development work was continued steadily, and in 1882 and 1883 about 1,400 tons from levels 1 and 2 were milled at the Algonquin mill at Hasmark, 1¼ miles northwest of the mine, a fair saving being made by dry crushing, roasting, and pan amalgamation. As exploration reached greater depth the oxidized ores became higher in grade, and sulphide ores extremely rich in silver were found about 200 feet below the surface. Assured of sufficient reserves, the company built at the mine a dry-crushing stamp mill (mill A) with a chloridizing roasting furnace. Soon afterward a larger mill was built, providing a total of 80 stamps. At this time the ore milled was of very high grade, as is shown by the fact that on level 6 an 11-foot face running 150 ounces in silver was left untouched for a long period, the mills being occupied with ore of still higher grade. From 1885 to 1892 the company was extremely prosperous, taking out about $20,000,000 in silver and gold and paying dividends amounting to more than $11,000,000. A third mill with 100 stamps was built at Rumsey, 1½ miles south of the mine, and connected with it by a wire tramway, and the railroad to Philipsburg was extended to the mill, a distance of 7.7 miles. During the same period a tunnel was driven from Rumsey 8,500 feet toward the mine. For some time during these years the Granite Mountain was the most productive silver mine in the United States. Among the larger owners were Messrs. McLure, Rumsey, Fusz, Clark, Ewing, Filley, Lionberger, Shapleigh, and Taussig, all of St. Louis.

The Bimetallic Mining Co. was organized in 1882, Charles D. McLure, Charles Clark, and J. M. Merrill owning practically all the stock. Its plant was similar to that of the Granite Mountain Co. A 100-stamp chloridizing mill was built at Bimetallic, on Douglas Creek, about 1¼ miles above Philipsburg. This was connected by rail with the railroad from Philipsburg to Drummond, and by a wire tramway with the ore bins at the hoist house. The mine had a large part of the same ore shoot that was exploited in the Granite Mountain mine, but the ore was in general not so rich. The production of the mine from 1883 to 1893 aggregated about $6,000,000, of which sum nearly $2,000,000 was paid in dividends. Owing to the fall in the price of silver the mine was shut down in 1893. Consolidation with the Granite was effected in 1898 under the name of the Granite-Bimetallic Consolidated Mining Co.

Extensive improvements were made after the consolidation with a view to working the lower-grade ores, of which a large tonnage still remained. An 8,850-foot tunnel from the canyon of Douglas Creek to the mine was completed, draining the Bimetallic mine at a depth of 1,000 feet and the Granite at a depth of 1,450 feet, and greatly reducing the the cost of pump-



PLAN AND ELEVATION OF LEVELS IN GRANITE-BIMETALLIC MINE.

Upper drawing shows position of Granite vein and South vein from level 3 to level 21 of the Granite mine. Approximately corresponding levels of the Bimetallic mine are indicated. Lower drawing is a projection on a vertical plane of Granite vein.

ing. A subsidiary organization, the Montana Water, Electric Power & Mining Co., built a reservoir covering several square miles on Georgetown Flat, near the head of Flint Creek, and installed an electric plant which supplied the mines and mills with 1,100 horsepower. This plant was subsequently sold to a company identified with the Amalgamated Copper Co., of Butte, and the power is now utilized at Anaconda. A 300-ton concentrator, built below the collar of the Bimetallic shaft, was the last notable improvement. From 1898 to 1904 the mines produced about $1,000,000 a year, but in August, 1905, they were shut down on account of the low price of silver and the decreasing value of the ore. Subsequently they have been reopened above the drain tunnel, and the company has adopted the leasing system. In the summer of 1906 about 100 men were engaged in the mines and in sorting the old Granite dumps and waste.

The total production of the two mines has been more than $32,000,000 in silver and gold, and nearly $15,000,000 has been paid in dividends. The Granite produced more than three-fourths of the total, and its dividends have been about $13,000,000. This represents net profits, because the original purchase price and other funds advanced by the syndicate were returned with interest, and the extensive hoisting and reduction plants were built from the proceeds of the mine.

The mine was worked from five drift tunnels, two deep shafts, and a long adit which drains the Granite mine between levels 14 and 15 and the Bimetallic mine at level 10. The Granite (Ruby) shaft is about 1,550 feet deep, and the Bimetallic (Blaine) shaft is about 1,800 feet deep. The vein has been stoped as far as 2,600 feet below the surface, and the drifts and crosscuts have a total length of more than 20 miles. At present the mine is under water below the adit level.

ORE DEPOSITS.

GENERAL CHARACTER OF THE LODE.

The Granite-Bimetallic lode is composed of several intersecting veins, which traverse the granodiorite and join at small angles. The Granite vein is much the largest and the richest. This vein outcrops at two or three places but is for the most part concealed by soil and talus. It has an average strike about N. 78° E., and the dip is in general about 75° S., but in places it is vertical, and locally it dips steeply northward. Its average width is between 4 and 8 feet, but in many places it is much wider, and it has a maximum width of about 20 feet. It has been stoped for 4,500 feet along the strike, and in places 2,600 feet below the surface. Of the fissures which join the Granite vein the South vein is the most productive, and though it is much narrower than the Granite vein, a considerable portion is of working grade. The minor veins do not cross the main fissure, but join it at angles generally less than 25°. As expressed on a horizontal plan, their junctions commonly point westward, and as expressed in a vertical section across the vein, the junctions as a rule point upward.

The upper figure of Plate XVII is a composite level map showing the positions of the Granite vein and of the South vein at intervals about 300 feet apart vertically. Many of the drifts are omitted for the sake of clearness. This map shows the vein to be fairly uniform in strike and of simple structure, though in places it splits to include horses of the country rock. A vertical cross section of the Granite vein and of the South vein in the western part of the Bimetallic workings, showing the relatively simple structure of these two veins, is illustrated in figure 20, *a*, page 175. Figure 20, *b*, is a vertical cross section at the Ruby shaft, and figure 21, page 176, a vertical cross section 900 feet east of the same shaft. The latter figure shows the greater complexity of the fissuring below level 8 in the Granite mine, where several fissures unite to form the Granite vein.

The walls of the vein are well defined, and as a rule regular. The wall rock is generally not workable. The width of the vein is fairly uniform and, where the vein between them has been removed by mining, the larger irregularities of the two walls correspond closely one with the other. Locally, however, the walls on opposite sides of the vein have boundaries which do not correspond (fig. 19, p. 174), and at some places their divergence is conspicuous.

CHARACTER OF ORES.

Primary ore.—The primary ore, which is found in the lower portions of the mine, has a gangue of quartz, rhodochrosite, and calcite, inclosing a large quantity of pyrite, arsenopyrite, stibnite, tetrahedrite, tennantite, galena, and zinc blende. Sparingly scattered through this ore are small specks of pyrargyrite, proustite, realgar, and orpiment. This ore carries 20 to 30 ounces of silver and from $1.50 to $3 in gold. In many places sulphides, chiefly pyrite and arsenopyrite, constitute half the volume of the vein, though they are as a rule less abundant than quartz. Much of this ore is fractured by movements since it was deposited, and many of these fractures are filled with low-grade quartz and rhodochrosite.

In the lower portion of the mine, about 2,600 feet below the surface, the vein was as strong and persistent as in the upper levels, according to authentic records of the company, and there was no indication that it was decreasing in width. The upper limit of the zone of low-grade primary sulphide ore is shown in the vertical section along the strike of the Granite vein. (See Pl. XVII.)

Enriched sulphide ore.—Where the primary sulphide ore is fractured the secondary cracks are often filled with ruby silver, argentite, and gray copper. Of these ruby silver (pyrargyrite) is by far the most important. Locally zinc blende and chalcopyrite fill cracks and appear to be secondary. The secondary ore carries from 50 to 1,000 ounces of silver and from $4 to $8 gold. This zone of secondary enrichment extends nearly to the surface in one place, but by far the greater portion occurs from 300 to 800 feet below the surface. In much of this ore the ribbon-like bands of primary ore are faulted by minute fissures, both normal and reversed, which are as a rule included entirely within the vein. This fracturing appears to have been produced along movement planes that follow the vein very closely. Probably more than half the silver of this ore is contained in dark ruby silver, or pyrargyrite, though light ruby silver, or proustite, is present, as are also tetrahedrite, and argentite. By far the greater portion of the ruby silver occurs in the minute veinlets or seams filling cracks in the vein, as films on the outside of crushed vein material, or as crystals nearly an inch in diameter partially filling cavities in the vein. Such cavities are in general rudely ellipsoidal in shape, and though they are not connected, their longer axes lie approximately in the same plane, a condition which suggests that they are parts of a larger cavity that has been almost completely refilled. Clear quartz and calcite of later age than that of the remainder of the vein occur at some places as well-defined crystals pointing to the center of a druse. Possibly they also have been deposited by cold sulphate waters. Most of the dividends the mine has paid came from exploitation of the secondary sulphide ore. An analysis of mixed primary and secondary ores is given below.

Analysis of mill run, Bimetallic mill, Jan. 29, 1905.

[E. E. Blumenthal, analyst.]

SiO_2	75.70
Fe	4.30
S	4.40
Mn	1.71
Pb	1.20
Zn	.85
Cu	.14
MgO	.5
As	.21
Sb	.13
Na	.11
K	.06
CaO	.1
Au and Ag	.12
Silver ounces	36.12
Gold	$1.60

Enriched oxidized ore.—Above the zone of enriched sulphides is a zone of enriched oxidized ore, for the most part between the 100-foot and 400-foot levels but in a few places extending nearly to the surface. The enriched oxidized ore is usually composed of quartz stained with iron and manganese oxides, and less commonly with copper carbonates. Cerargyrite, pyromorphite, and native silver occur as thin seams cutting through the quartz, or as films plastered on the outside of crushed quartz fragments. A little argentite is associated with this ore, and galena, zinc blende, pyrite, and chalcopyrite are sometimes present. Some of this ore runs from 300 to 400 ounces silver, and in places carries from $5 to $16 in gold. The value of this oxidized ore is in general less than that of the enriched sulphides. The upper limit of the zone of enriched oxide ore is shown in Plate XVII.

Poor oxidized ore.—From the surface to depths locally as great as 300 feet or more is a zone of oxidized ore consisting for the most part of quartz broken and stained with iron and manganese oxides. It contains some lead carbonate, malachite, azurite, chrysocolla, pyromorphite, and a little horn silver, and in places pyrite and galena. It carries less than 30 ounces of silver and only a little gold and is of too low grade to work. This portion of the vein was so unpromising that at one time, before the richer ores were discovered, the claims were abandoned by prospectors.

The apex of this zone, which is the apex of the vein, has been leached of the greater part of its value in some places to depths of more than 300 feet. Small masses of galena, with which a little argentite is probably associated, occur here and there as unoxidized remnants. Some massive low-grade pyrite which shows no sign of postmineral crushing is of similar occurrence at this horizon and may be a remnant of primary ore not involved in movement subsequent to veining and therefore in a position unfavorable to enrichment. It is believed that the zone of poor oxides was once the zone of rich secondary sulphides, and that from the latter valuable minerals were carried downward by sulphate solutions.

PARAGENESIS.

Veinlets of rhodochrosite and quartz cut the earlier primary ore, but these are regarded as having been deposited by ascending solutions from the same source as those which deposited the primary ore. Their introduction followed a reopening of the veins.

The very rich ore is, as already stated, crossed by small veinlets which contain a considerable quantity of pyrargyrite. These rich veinlets are later than the primary ore and later than the ore which is high in rhodochrosite, and since they do not occur in the lower levels of the mine it is assumed that they were deposited by descending waters on the sulphides of the primary ore. The cerargyrite and native silver which form similar veinlets in the upper part of the rich zone are presumably oxidation products of the silver-rich minerals.

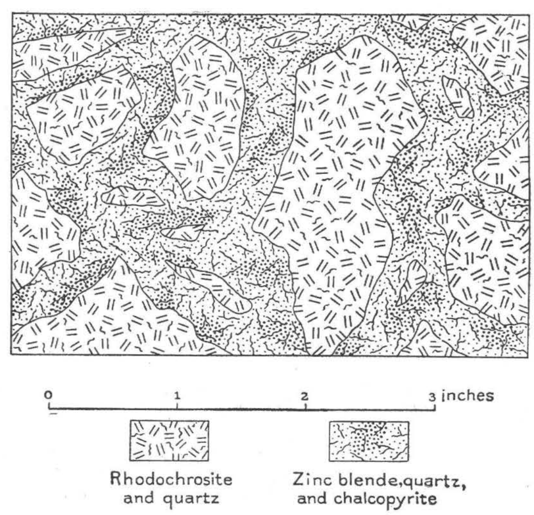


FIGURE 37.—Ore from Granite vein level 8, about midway between Ruby and Blaine shafts. Fragments of rhodochrosite and quartz are cemented by an ore composed of zinc blende, quartz, and chalcopyrite.

Between levels 6 and 8, about midway between the Ruby and Blaine shafts, the vein carried high-grade secondary silver ore, whereas on level 8, just below this ore, it was composed of rhodochrosite and quartz cut by a large number of veinlets of zinc blende, chalcopyrite, and quartz. The rhodochrosite and early quartz is here distinctly older than the zinc blende and chalcopyrite, for the vein was opened and locally brecciated in the interval between the deposition of these minerals. The zinc blende and the chalcopyrite at this place are related to the earlier minerals in the same way that ruby silver is at the levels above. It can not be shown positively that the zinc blende was deposited by secondary descending waters on the primary ore, but the presence of considerable chalcopyrite, which is rare in the primary ore, suggests the possibility that the ore is secondary. Such zinc blende is not abundant compared with that of earlier deposition. These veinlets of zinc blende are shown in figure 37.

DISTRIBUTION OF ORE.

The principal ore body is a tabular mass, in the main from 2 to 10 feet wide and about 4,500 feet long. The surface slopes to the west, and consequently the greatest depth is obtained in the eastern portion of the mine, where the ore extends downward more than 2,600 feet. The west end of the ore body has been explored to a depth of about 1,600 feet. Between the eastern and western boundaries the ore is continuous in the upper levels, but in the lower levels a large part of the vein near the central portion of the mine is narrow or of too low grade to work. The form of the shoot of the workable ore is therefore something like that of a flat arch, the ore pitching in both directions away from the keystone, which is assumed to be about 300 feet west of the Ruby shaft. The rich ore, however, is closely related to the topography of the country, and therefore descends toward the west. It occurs for the most part between 300 and 800 feet below the apex of the vein. The zone containing each type of ore in the vein is cut by zones above it, and the upper zones descended deepest where the brecciation of the vein favored the downward circulation of water. The high-grade ore is practically limited to the enriched oxide and the enriched sulphide zones, but a considerable amount of the low-grade primary ore has been mined.

Where other veins unite with the Granite vein along a nearly vertical line effects of enrichment are not marked. The line of junction of the South vein with the Granite vein is on level 14, about 1,200 feet west of the Blaine shaft. (See fig. 25, p. 178.) The ore is approximately of equal tenor in the South vein and in the Granite vein on both sides of the junction. Several unimportant veins join the Granite vein east of this junction, but nowhere do they appear to have enriched the ore.

Between levels 7 and 9 in the Granite mine several veins join the Granite vein. The line of junction is approximately horizontal, as is shown in figure 24, page 178. Some of these veins also join below level 9, but others diverge in depth. At the upper junction the angle formed by the two veins is everywhere small. The richest ore in this mine occurred above this junction, and the stopes at this place have supplied many thousand tons of ore, which on the average ran about 175 ounces per ton. It is probable that the primary ore at this place was above the average.

FORMER VERTICAL EXTENT OF THE VEIN.

The average of the low-grade ore in the lower levels of the mine was only about 25 ounces silver. The average in the bonanza east of the Ruby shaft, as shown by annual mill runs, was about 175 ounces. This rich zone has an average vertical extent of about 400 feet, and if we assume that it has resulted from the enrichment of a primary ore carrying 25 ounces of silver in a vein of constant width, 150 ounces of silver must have been added to each ton of the enriched ore. Thus 6 times 400 feet, or 2,400 feet of 25-ounce vein material would be required to produce this bonanza, provided all the silver went into solution and was reprecipitated in the ore of the bonanza. If the leached oxidized ore now carries 25 ounces of silver (p. 205), there must have been 2,400 feet of 25-ounce ore eroded and accordingly the vein now developed 2,600 feet below the surface would have had before denudation a vertical extent of at least 5,000 feet. Near the Blaine shaft, between levels 3 and 7, the ore averaged about 100 ounces for a vertical distance of about 350 feet. If this ore has resulted from the enrichment of 25-ounce rock, again assuming that the leached oxides carry approximately 25 ounces, it would require the erosion of 1,050 feet of the vein from above its present apex, provided all of the values were dissolved and redeposited. Here the vein is developed 1,800 feet in depth and this would give a minimum vertical extent of about 2,850 feet for the original vein here before denudation. It is believed, therefore, that the former vertical extent of the vein was between 2,850 feet and 5,000 feet or more. Considerably more than 2,400 feet have been eroded since the granite was intruded into the sedimentary rocks, for the Flathead quartzite, the earliest Cambrian formation, now outcrops at the contact with the intrusive. The entire Paleozoic and Mesozoic section above the Flathead, comprising about 7,000 feet, has probably been eroded from the quartzite since the intrusion. If the vein was formed soon after the solidification of the granite, erosion can amply account for any probable amount of enrichment.

Even if the vertical extent of the vein which has been eroded from above the rich ore shoot east of the Ruby shaft, is no greater than that indicated by the grade of the ore west of the Blaine shaft (1,050 feet), the vertical extent of the vein before denudation must have been about 3,650 feet, for it is known to extend 2,600 feet below the present surface.

HOBO MINE.

The Hobo mine, situated south of Camp Creek, about 1½ miles east of Philipsburg, was discovered in 1884, and in the early nineties Hines & Lynch, the owners, took out a considerable quantity of rich oxidized ore. Subsequently it was bonded to Charles McLeod, who drove a tunnel 2,000 feet along the vein giving a depth of about 500 feet at the breast. Three tunnels are driven on the vein at higher elevations, and altogether about 3,500 feet of drifting has been done. The total production is said to be about $100,000.

The country rock is granite. The vein, which is a simple fissure filling, strikes about N. 80° E. and dips about 75° S. It is joined by several narrow stringers which make small angles pointing westward, and at one or two places it splits to inclose small horses of granite. The maximum width of the vein is about 1½ feet. In the lower tunnel the ore is composed of quartz, rhodochrosite, galena, zinc blende, pyrite, arsenopyrite, stibnite, gray copper, realgar, and a little ruby silver. The ore is too low grade to be worked with much profit. The oxidized ore is said to have carried a notable amount of lead carbonate with some pyromorphite and wire silver. The better-grade sulphide ore occurs from 200 to 300 feet below the surface and is said to carry 100 ounces of silver and about $3 in gold.

PURITAN MINE.

The Puritan mine is located just south of the Hobo mine and about half a mile southeast of Tower. A shaft inclined southward is sunk to a depth reported to be about 500 feet, and levels are turned at hundred-foot intervals. The first level is an adit intersecting the shaft and driven eastward from it about 495 feet on the vein. The country rock is granite, and the vein is a narrow fissure filling that strikes N. 80° E. and dips 71° to 85° S. It consists of quartz, rhodochrosite, galena, gray copper, zinc blende, and pyrite. The better ore is reported to carry about 100 ounces of silver. A little stoping has been done in places. On level 2 the ore plays out 100 feet west of the shaft, and below this level the mine is under water. The vein where developed is not wide enough to warrant profitable stoping, and the production reported is small.

SILVER CHIEF MINE.

The Silver Chief mine is in Tower, just east of the True Fissure mine, which is on the Midnight vein. It was worked by the Hope Co. from 1888 to 1890 and according to Mr. George Weaver has produced about $62,000 worth of ore. The country rock is granite, which is sheeted and characteristically oxidized. The vein strikes east and dips 84° S. and is said to be about 1½ feet wide. A deep shaft is sunk on the vein, and a long tunnel is driven eastward from a point near the collar of the shaft. In 1906 the shaft was inaccessible, and a few hundred feet east of the portal the tunnel was under water.

MITCHELL MINE.

The Mitchell mine is in Tower between the Silver Chief and San Francisco mines. According to the owner, Mr. Larry Donlan, its total production has been about $11,000. It is exploited through a tunnel driven eastward on the vein about 600 feet. The country rock is granite. The vein strikes about N. 74° E. and dips 66° S. It is a fissure filling about a foot wide and carries 15 to 20 per cent lead, about 35 ounces of silver, and $3 to $4 gold. The minerals of the ore are quartz, rhodochrosite, pyrite, galena, zinc blende, and ruby silver. Near the surface this ore is oxidized and contains some native and horn silver, which occur in veinlets through the quartz. The principal ore shoot is encountered 30 feet from the portal of the tunnel and extends eastward for about 170 feet. Beyond this point the fissure narrows to a streak of gouge about 6 inches wide, but still farther east it becomes wider and incloses ore which carries a large proportion of zinc blende.

SAN FRANCISCO MINE.

The San Francisco mine is a few rods north of Tower and about 1¾ miles northeast of Philipsburg. According to Mr. Donlan it has produced about $30,000, including $8,000 which he has mined and sorted from the dump. A shaft is sunk to a depth of 550 feet, and from this levels are turned at intervals of about 100 feet. About 3,600 feet of drifts have been run on the levels. In the autumn of 1906 the part of the mine below 300 feet was under water.

The vein is a fissure filling in granite, strikes N. 75° E., and dips from 80° S. to 90°. The ore is composed of rhodochrosite, quartz, calcite, galena, gray copper, zinc blende, and pyrite. Ruby silver is said to be present in small amount. The better ore carries about 45 ounces of silver and $3 or $4 in gold to the ton. In some of the ore the brecciated sulphides and quartz are cemented by rhodochrosite and calcite, clearly of later age, and the granite near the vein is sheeted by movement apparently later than the ore. The vein has been followed westward into limestones on level 4, which was under water when the mine was visited in the autumn of 1906. According to Mr. Donlan the ground is much disturbed at the contact and the vein is offset about 25 feet to the south. A second vein is said to have been encountered in a crosscut on the fifth level, 400 feet north of the main lode.

GRANITE BELLE CLAIM.

The Granite Belle claim is about half a mile north of the Bimetallic mine. The country rock is granite. The vein is intersected by a crosscut tunnel driven 417 feet S. 15° E., and is followed about 600 feet along the strike. Altogether some 1,500 feet of development has been done. The vein strikes about S. 75° E. and dips from 60° to 75° N. It carries a few inches of ore composed of quartz, pyrite, arsenopyrite, and galena and is stained with iron oxides and copper carbonate. In some places there is a pronounced sheeting of the granite parallel to the vein. So far as developed the vein is not of stoping width or grade.

ROYAL METALS TUNNEL.

The Royal Metals tunnel is about 1,000 feet north of the Granite Belle tunnel. It is a crosscut driven southeastward for about 750 feet and intersects three veins. The country rock is granite. The first vein is crossed 168 feet from the portal and has been followed eastward along its strike for about 500 feet. This vein dips from 80° to 85° S. It is only a few inches wide, and is composed mainly of quartz and pyrite. A second vein of similar character is intersected 500 feet from the portal, and a third near the breast of the crosscut. These veins are of small size and have not been explored.

THREE METALS AND SALT HILL TUNNELS.

These tunnels, which were driven to explore a group of claims about three-fourths mile east of Hasmark, were inaccessible in 1906. The Three Metals tunnel, as shown by mine maps, cuts a vein 234 feet from the portal and follows it for 1,200 feet along the strike. The vein dips 80° S. According to Mr. Hector McDonald the ore is composed of quartz, pyrite, galena, and a little ruby silver. A few hundred dollars worth of ore has been shipped from this vein. The Salt Hill tunnel is 260 feet above the Three Metals tunnel and is driven southeastward across it.

PEARL MINE.

The Pearl mine is located in the valley of Frost Creek, a few rods east of Hasmark. A shaft 300 feet deep has been sunk on the lode, and this is holed with an adit about 100 feet below the collar of the shaft. Below the adit the mine is under water. The lode outcrops on the surface above the hoist house, where it strikes N. 87° E. and dips about 75° S. There is a pronounced sheeting of the granite walls, and oxidation extends from the vein into the country rock on either side. The vein is narrow and is composed of blue quartz and carbonates stained with oxides. The metals are said to occur as lead carbonate and ruby silver. A few carloads of ore have been shipped.

ANNIE MARONY CLAIM.

The Annie Marony claim is located southeast of Hasmark and about 1,000 feet south of the Pearl mine. A crosscut tunnel 270 feet long is driven southward to a vein in granodiorite, which strikes east and dips about 80° S., and the tunnel follows this vein for 700 feet. The vein is composed of several inches of clay gouge and crushed quartz and locally carries small bunches of galena. Other workings above the level of the lower tunnel are caved.

YOUNG AMERICA CLAIM.

The Young America claim is half a mile east of the summit of Franklin Hill. The vein, where exposed in an open cut, strikes eastward, and dips about 66° S. The face shows 2 or 3 feet of partly oxidized granite, carrying thin sheets of quartz and sulphides. A tunnel driven on the vein was inaccessible in 1906.

SILVER-BEARING REPLACEMENT VEINS IN SEDIMENTARY ROCKS.

TROUT MINE.

The Trout mine, formerly called the Speckled Trout, is on the crest of the divide between Camp and Frost creeks, about midway between Hasmark and Tower. It was located in the late sixties and for a number of years supplied considerable ore, a large part of which was milled in the Northwest mill at Tower. According to Mr. James Patten, of Philipsburg, its total production has been about $500,000. In the summer of 1906 it had long been idle, and the workings were inaccessible. During that year Mr. Patten obtained a lease on the property and shipped considerable ore from the old dump. Hoisting machinery was installed and a part of the shaft retimbered. Some very good ore was found and the mine was worked successfully in a small way.

The shipping ore carries from 20 to 150 ounces of silver and $3 or $4 gold. The gangue is composed of quartz, rhodochrosite, calcite, and dolomite. The metallic minerals are galena, zinc blende, pyrite, ruby silver, and gray copper. Where the ore is oxidized the quartz is stained black by manganese compounds, which are present in considerable quantity. Such ore contains masses of porous spongy quartz containing wire and leaf silver. Galena alters to lead carbonate ore, which carries also considerable silver.

The shaft is about 200 yards west of the contact of the Philipsburg batholith with the sedimentary rocks. In the mine the limestones and shales dip about 40° E., toward the granite contact and away from the crest of the anticline of Franklin Hill. As shown by the geologic map, the Hasmark and Red Lion formations strike northward on the ridge near the Trout shaft, and owing to their steep dip they outcrop as relatively narrow bands. The ore deposits are replacement veins of irregular width which cut steeply across the bedding. The sedimentary rocks are somewhat metamorphosed, and owing to further alteration near the veins and subsequent oxidation it is not possible, in the accessible portion of the mine, to identify the various formations with certainty.

The principal vein outcrops on the surface near the shaft, and has been stoped to the grass roots. On the 150-foot level it strikes about east and dips approximately 85° S. It is more than 10 feet wide 25 feet east of the shaft, and carries a large amount of rhodochrosite as a matrix surrounding angular fragments of quartz. In such brecciated ore the quartz fragments carry small specks of dark minerals, which, according to Mr. Patten, contain nearly all the silver. The rhodochrosite matrix is said to carry about 6 ounces of silver to the ton. Figure 28, page 182, illustrates the general appearance of this ore, and shows the angular fragments of quartz surrounded by massive rhodochrosite and by spherical shells of the same mineral. Much of the ore is less brecciated and carries a smaller proportion of rhodochrosite.

A second vein is situated about 30 feet south of the shaft on the 150-foot level. This vein, which strikes N. 55° W. and dips about 62° S., is accessible for about 100 feet along the strike. It is narrow but of good grade. Where the wall rock is shale the veins are narrower than in limestone. At one place where the wall rock is limestone the width of the vein increases just below beds of shale, and there is some evidence that the ore shoots pitch eastward with the dip of the beds, but the accessible workings were not sufficient to permit observations which might verify this generalization.

GEM MINE.

The Gem mine is a few rods north of Hasmark, and the Gem claim side-lines the Trout claim on the south. Though one of the first claims located in the district, it has never been worked extensively. The vein strikes eastward and dips about 80° S. It has been exploited through a number of shallow shafts and pits and is said to have produced altogether about $10,000 worth of silver. The ore resembles that of the Trout mine and the deposits are of the same character, but the vein, so far as it has been explored, is much narrower.

BLACKMAIL MINE.

The Blackmail vein is about 300 feet north of the Trout vein. Years ago it was worked through the Sharktown tunnel, and considerable ore is said to have been mined. The deep workings were inaccessible in 1906. A vertical shaft is sunk a few feet north of the vein, which is reached by a short crosscut about 50 feet below the surface. The vein strikes N. 83° W. and dips 76° S., across the bedding planes of limestones and shales. It is followed by a drift 190 feet long. The ore carries 20 to 40 ounces of silver and 15 to 40 per cent of zinc. At the west breast the vein is 2 or 3 feet wide and consists chiefly of rhodochrosite, quartz, and zinc blende, with some galena and other dark sulphides. Locally the ore is shattered, crushed, and recemented with rhodochrosite, which, as in the Trout vein, appears to have been introduced after the more highly metalliferous ore was deposited. The calcareous walls are partly replaced by ore. The quartz and carbonate appear to have been deposited farther from the center of the vein than the sulphides.

SALMON MINE.

The Salmon mine is about 300 feet north of the Trout shaft. It was formerly worked through a shaft, now caved, and through the Sharktown tunnel, which was driven southward from the flat just above Tower. In 1906 all the workings were inaccessible. The vein is said to be the same as that exposed in the Blackmail shaft to the west.

SCRATCH AWL VEIN.

The Scratch Awl vein lies north of the Salmon vein and approximately parallel to it. This vein also was exploited through the Sharktown tunnel and was followed eastward to the granite contact. According to Mr. N. B. Ringling, the vein continued eastward beyond the contact into the granite but was offset at the contact by a fault of small displacement. This vein was inaccessible in 1907.

HEADLIGHT MINE.

The Headlight mine is at Tower, about 1½ miles east of Philipsburg. It has been worked from time to time since 1878, but mainly in 1905 and 1906. According to the owners, Messrs. W. J. and Charles Sprague, it has produced about $8,000, chiefly silver. It is exploited through two drift tunnels, comprising altogether about 700 feet of workings. The limestone country rock strikes nearly north, and dips about 35° E. The deposit is a fissure vein from 1 to 16 inches wide, and the sorted ore is said to carry up to 200 ounces of silver, 6 per cent copper, and about 7 per cent of lead. The minerals are quartz, gray copper, galena, pyrite, zinc blende, chalcopyrite, and realgar. These have oxidized to form limonite, copper and lead carbonates, and pyromorphite. Where the vein is encountered in the lower tunnel it strikes about N. 70° W. and dips 68° W.

The Jefferson limestone, which is exposed in the workings near the portal of the tunnel, is a medium-grained, rather pure limestone. In this rock the walls are not clearly defined, and the vein is of the replacement type. Farther in the vein traverses the argillaceous Maywood formation, in which the vein is narrower and the walls more regular. The vein is dislocated by six nearly parallel faults that follow the bedding planes of the country rock. These are shown in figure 16 (p. 171), which is the plan in the lower tunnel sketched from a pace and compass survey. Along all these faults the hanging wall appears to have fallen.

MIDNIGHT, IMPERIAL, AND TRUE FISSURE MINES.

The Midnight mine is on Camp Creek, a few rods below Tower. A shaft is sunk north of the vein, which is reached by a short crosscut 50 feet below the surface. The vein strikes about N. 85° E. and dips about 65° S. It is followed by drifts for 100 feet. The country rock near the shaft is dolomite of the Hasmark formation, which dips steeply northeastward. The deposit is a replacement vein 2 or 3 feet wide and is composed of quartz, calcite, and barite stained with manganese and iron oxides and with copper carbonates. The quartz is as a rule dark gray, due to the presence of many small specks of silver-bearing sulphides. Several thousand dollars' worth of silver ore is said to have been taken from lower workings, which were inaccessible when the mine was visited.

To the east the Midnight vein passes through the Imperial mill site. Two shallow shafts have been sunk in this ground, and one of them was being retimbered in 1906 to explore the vein in depth. This vein can not be traced on the surface into the True Fissure claim, but the deposits of the True Fissure mine are either on the same vein or one nearly parallel to it and not far from it.

The portal of the True Fissure tunnel is about 800 feet N. 80° E. of the Midnight shaft, and the tunnel is driven to the east about 800 feet. The country rock is the limestone of the Red Lion formation and the Jefferson limestone, and the latter, near the eastern border of the claim, is in contact with granite. The vein strikes a few degrees south of east, and small stopes have been carried upward from the tunnel level. At some places siliceous ore makes out from the fissure in the bedding of the country rocks, and at the surface above the tunnel large knobs of quartz outcrop at several places. At the contact with granite the sedimentary rocks strike north and dip 57° E. The contact plane has approximately the same strike and dips rather more steeply toward the granite. The True Fissure vein ends abruptly at the contact, which is disturbed by movement, and the Chief vein, which occurs about 50 feet to the north, is probably an extension of the same fissure.

LEVI BURR MINE.

The Levi Burr mine is near Frost Creek, a few rods southwest of Hasmark. It was worked through a shaft and a tunnel, both of which were caved in 1906. The vein, which is possibly a faulted extension of the Pearl vein, outcrops on the surface, where it has been stoped to grass roots, and strikes about S. 83° W. across the bedding planes of limestones and shales. It is a replacement deposit composed of quartz, manganese oxide, silver-bearing sulphides, and zinc blende. According to Mr. Peter Coyle, the mine has produced about $10,000 worth of silver.

TERRID MINE.

The Terrid mine is situated about 600 feet S. 33° E. of the Levi Burr shaft and is owned by Peter Coyle, of Hasmark, who has worked the property in a small way for several years. A shaft inclined steeply southward is sunk on an outcrop of siliceous ore to a depth of about 100 feet, where a short level is turned. The ore body is a replacement of limestone and is composed of quartz, manganese oxide, pyromorphite, and silver-bearing sulphides. The workings accessible in 1906 were insufficient to show the strike or width of the vein. An adit driven S. 75° E. at an elevation about 300 feet below the collar of the shaft encounters a large irregular body of sooty, amorphous, manganiferous ore about 525 feet from the portal. About

160 tons of this ore was shipped to South Chicago and is said to have yielded 47 per cent manganese. A raise, now filled, is located 50 feet south of the manganese deposit and is said to connect with the silver ore encountered in the shaft above.

ALGONQUIN MINE.

The Algonquin mine, in the valley of Frost Creek a few rods west of Hasmark, is owned by the Hope Mining Co. It was among the first locations in the district and was sold shortly after it was located to Philadelphia capitalists, who built a substantial silver mill on the claim to work the roasted ore by the pan-amalgamation process. This mill is credited with a production of $493,000 for 1881 and 1882 in the report of R. W. Raymond on the precious metals of the United States, but it is probable that much of this ore came from the Granite mine. The Algonquin lode was never very productive. The mine has long been idle and in the summer of 1906 was inaccessible.

On the surface the lode outcrops above the portal of the tunnel, where it strikes N. 81° E. and dips southward. The country rock is the limestone of the Hasmark formation, and the lode cuts across the bedding planes. The ore on the dump resembles that of the Trout mine and consists of quartz stained with iron and manganese oxides carrying lead carbonate, pyromorphite, galena, and other minerals.

CLIFF MINE.

The Cliff mine, which is about 1,000 feet west of the Blackmail shaft, is the property of the Hope Mining Co. The workings are apparently extensive, but they have long been idle and in the summer of 1906 were inaccessible. The country rock is composed of the Silver Hill, Hasmark, and Red Lion formations, which dip about N. 25° E. On the surface east of the shaft the vein is exposed in several pits and short tunnels. It strikes N. 80° E. and is approximately vertical. Judging from the strike and position it is probably the same as the Blackmail vein.

SANDERS MINE.

The Sanders mine is on the southeast slope of Poorman Hill, about 200 feet above Tower. The country rock is Jefferson limestone, which dips about 45° E. The deposit is a replacement vein of irregular width and strikes across the bedding. The ore is composed of quartz, galena, pyromorphite, and other minerals. According to the owner, Mr. Larry Donlan, the mine has produced 100 tons of ore, which was 25 per cent lead and yielded 53 ounces silver and $3 gold per ton.

MYSTERY TUNNEL.

The portal of the Mystery tunnel is on Camp Creek about halfway between Philipsburg and Tower. It is driven northward 900 feet to explore some veins that outcrop on the south slope of Poorman Hill. The crosscuts and drifts include some 1,500 feet of workings. From the portal to the breast five small veins are crosscut, and each of these is followed a short distance along the strike. The country rock is the limestone of the Hasmark formation, which dips about 30° NW. The veins strike nearly east and dip from 63° to 83° S. They are at most places less than a foot wide and of relatively low grade. The oxidized ore is composed of quartz stained with iron and manganese oxides and with copper carbonates. The unoxidized ore carries pyrite and galena, and pyrite has also been deposited in the limestone walls. Here and there small stopes have been carried below and above the tunnel, but only a small amount of ore has been removed.

BASIN MINE.

The Basin mine is a short distance above Philipsburg on Camp Creek, where the lode outcrops a few feet north of the stream. It has been explored on the surface at several places by shallow pits and by a tunnel driven northward 365 feet. The country rock is limestone and shale of the Red Lion formation. Although the nearest large outcrop of igneous rocks is

4,500 feet away, the sedimentary rocks have been notably metamorphosed, and a considerable amount of scapolite and other contact-metamorphic minerals have been developed. The ore occurs as veinlets in the bedding planes and is composed of quartz, gray copper, pyrite, malachite, and limonite.

SILVER-BEARING DEPOSITS IN BEDDING PLANES OF CALCAREOUS ROCKS.

HOPE MINE.

HISTORY.

The Hope Mining Co. owns, among others, the Hope, Comanche, Little Emma, Potosi, Porter, Take All, Field, and Prince Imperial claims on Hope Hill, which have been exploited through a large number of connected openings and which may best be treated as a unit. These claims are clustered around the summit of the hill and extend more than half a mile southwestward down its slope.

The original Hope claim and some of those adjoining it were located in 1865, and these were acquired in the following year by the St. Louis Mining Co., which was then operating a small smelter at Argenta, Mont. This company erected a 10-stamp mill with silver pans to work the ore by the Washoe process. This was the first silver mill built in Montana and is still in operation. A reorganization was effected in 1867, and the new company was known as the Hope Mining Co. The Hope claim was the first exploited and was worked with moderate success until 1881, when a large body of rich ore was discovered. In that year the mine produced about $361,000, and it continued to yield from $100,000 to $200,000 a year until 1887, when $354,000 was taken out, mainly from stopes in the Porter workings. After this ore body was exhausted the production fell to a moderate figure and remained so until 1892 when, through the discovery of the Whitewash ore body, it was greatly increased. For the 40 years during which the mine has been worked the average production has been approximately $100,000 a year, giving a total of nearly $4,000,000. The Hope Mining Co., which is now exploiting the mines, is subsidiary to the Granite-Bimetallic Mining Co.

DEVELOPMENT.

Hope Hill is honeycombed with miles of intersecting workings. Access to the ore bodies at present exploited is through the Jubilee tunnel and Shapleigh shaft. The Jubilee tunnel enters the west slope of Hope Hill at an elevation of about 5,500 feet and is driven to the Shapleigh shaft, which it intersects about 540 feet from the portal of the tunnel. On the tunnel level about 6,000 feet of drifts and crosscuts have been driven. The Shapleigh shaft, which is 570 feet deep, is vertical, and levels are turned at depths of 100, 300, and 470 feet below the tunnel level. These levels are connected with the tunnel by winzes, stopes, and inclines. In the autumn of 1906 the workings below the 300-foot station were under water. Eastward the Jubilee tunnel connects with the base of the Porter incline and through it with the Porter workings above. To the southeast the Jubilee workings are connected with the Field and Cuno shafts and also through tortuous raises, drifts, and crosscuts with the original Hope Discovery workings.

GEOLOGY.

All the ore bodies of Hope Hill are in the Jefferson limestone (Devonian), which is about 1,000 feet thick. It is composed of white, gray, or black beds of medium-grained limestones, generally more or less magnesian, intercalated with calcareous shales. The limestone is almost universally marmarized and a little tremolite is developed locally, but otherwise it is not extensively metamorphosed by igneous agencies. No garnet was noted in the mine. The strike of the limestone is variable, but as a rule is from N. 10° E. to N. 60° E. The dip is generally about 30° NW. but is not uniform. The Jefferson limestone is overlain by the Madison limestone, the contact on the tunnel level passing near the Shapleigh shaft. Several faults which strike a few degrees east of north cross the mineralized area and displace the ore bodies. No igneous rocks have been encountered in the mine, and the nearest exposure is in Red Hill, half a mile north of the Shapleigh shaft, where a small area of granite porphyry is exposed. The border of the Philipsburg batholith is a mile east of this shaft and about half a mile east of the summit of Hope Hill.

ORE DEPOSITS.

Description.—The ore bodies are siliceous argentiferous replacement deposits, very irregular in detail but for the most part following the bedding planes of limestone. Some of them are connected below with narrow vertical stringers, and others appear to follow planes of faulting or jointing in the country rock. The general relations to bedding are shown by figures 29, 38, and 39.

The gangue minerals are quartz, calcite, fluorite, barite, and rhodochrosite, and scattered through the ore are small flakes of argentite and chalcocite, and locally ribbons of argentiferous gray copper. Pyrite and galena are not abundant, and zinc blende was not noted. The rich oxidized ore in the upper levels was composed of cerargyrite, malachite, azurite, and chrysocolla, which occurred in a siliceous gangue stained with iron and manganese oxides. The most important of the ore minerals are argentite, cerargyrite, and gray copper. In the deeper

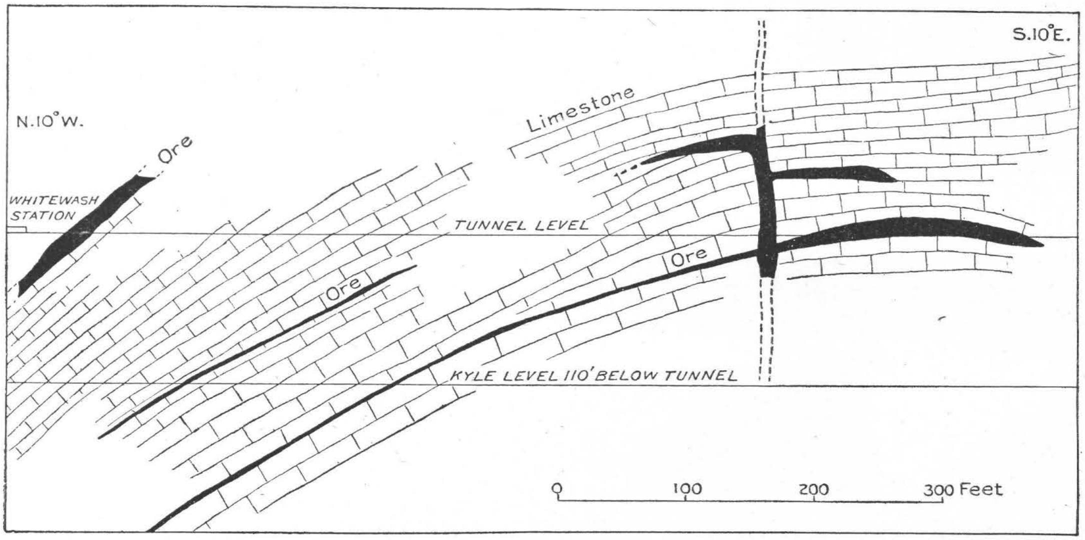


FIGURE 38.—Vertical section through Whitewash station, Hope mine; direction of section N. 10° W. Thickness of ore body is approximate.

workings some of the ore carries 3 or 4 per cent copper, which is considerably more than the copper content near the surface.

Structural relations.—The Jefferson limestone is unfavorable for detailed stratigraphic study. Except in color it is rather monotonous, and the color differences are not uniform. At many places where the ore occurs in bedding planes the footwall is a dark bluish-gray or black limestone and the hanging wall is a brown speckled limestone called "turkey-egg lime" by the miners. This color difference, though it is conspicuous in many places, can not be relied upon as a horizon marker, for it is not an original or sedimentary characteristic but has been produced by oxidizing waters after the limestones had formed. Locally, for example in the stope near the original Hope discovery shaft, the dark limestone may be seen grading into the "turkey-egg lime" along contacts following joint planes that cut steeply across the original bedding planes. The "turkey-egg" effect seems to have resulted from oxidation of iron and manganese compounds probably deposited by ore-bearing solutions. At a few places the hanging wall is an impure shaly limestone.

The beds in which the ore occurs are on the west slope of the anticline, the crest of which extends northeast from Franklin Hill. The northwest dip is not uniform, and at several places minor folds with local dip toward the southeast form gentle anticlines or saddles, the axes of which trend a little east of north and make large angles with the prevailing strike of the beds. Some of the larger ore bodies are in these small anticlines or saddles. The ore bodies in the bedding planes occur at several horizons, and three of these are extensively mineralized. The mineralized portions of such beds are not as a rule very wide, but they appear to have had a great linear extent before faulting, the ore forming long and relatively narrow ribbons in the beds.

The most important deposits, if charted on a horizontal plane, fall into two groups, each of which is composed of a number of disconnected ore bodies separated by faulting from other bodies in the same group. The longest axis of each group projected on such a plane trends about N. 80° E., and the two groups are about 300 feet apart. The north group includes the ore bodies at the Whitewash station, those in the Porter workings, and probably some inaccessible ore bodies in the Little Emma workings. The south group includes the ore bodies near the Golden Gate incline and those in the eastern part of the Hope discovery workings, including those of the long stopes between the Hope discovery and Golden Gate workings, the total length of the ore bodies of this group being about 2,000 feet. On account of faulting, and in the absence of datum planes in the beds, it is not possible to show that the ribbon of ore replaces the same horizon throughout its length, although it can be shown to do so for con-

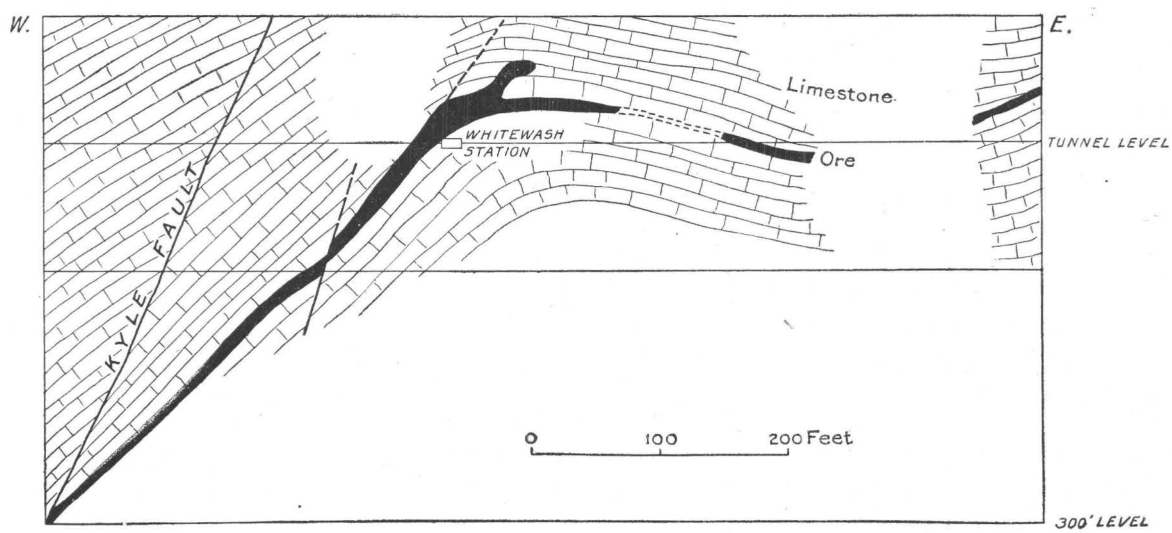


FIGURE 39.—Vertical east-west section through Whitewash station, Hope mine. Thickness of ore body (shown in black) is approximate.

siderable distances. Some of the ore bodies are joined by narrow vertical veins which cut steeply across the bedding planes, and at some places pipe-like chambers of ore extend outward from the tabular deposits.

Faulting.—The ore bodies are displaced by several faults which cut across them at large angles. Of these the Kyle fault is farthest west and is the first one encountered in the Jubilee tunnel. On the tunnel level it is 480 feet N. 73° E. of the Shapleigh shaft, and at this point it strikes N. 28° E. and dips 65° NW. It is fairly uniform in dip and strike and is exposed in several places on the lower levels. All the known ore bodies are to the east of it, and consequently the throw can not be measured. On the surface above the mine workings the fault is not clearly expressed, because the Jefferson limestone forms the country rock on both sides of it. Toward the north, a jog in the contact between the Jefferson limestone and the overlying Madison limestone indicates that the fault is normal and that the vertical throw is probably not much more than 100 feet, but the exposure is not of such a character that a close calculation can be made. It is well established, however, that the fault is normal, and therefore the beds which occur east of the fault will be found at lower elevations west of it. This fault is shown in figures 29 and 39. Two smaller faults appear to intersect it, but these have very small throw. Toward the east is the Porter fault, which is exposed 80 feet above the tunnel level at the extreme eastern point of the Jubilee workings and also in the Garnet tunnel. It strikes N. 15° E. and dips 47° W. It displaces the ore body in the Porter workings and is a normal fault, for the ore bodies on the west are lower than on the east. Its throw can not now be determined exactly, because the workings are inaccessible at critical points, but it is said to be more than 200 feet as measured on the fault plane. East of the Porter fault are four other faults approximately parallel to it in strike. (See p. 217.) The distance between the Kyle and Porter faults is about 750 feet on the tunnel level in the northern part of the mine, and increases toward the south. The block of territory between them is essentially entire and the Jubilee workings, through which the mine is now being operated are practically confined to it.

DISTRIBUTION OF ORE.

Jubilee workings.—In the Jubilee workings the two principal groups of ore bodies are intersected on the tunnel level near the top of the Golden Gate incline and at the Whitewash station.

At the Golden Gate incline ore occurs at two horizons in the limestone about 60 feet apart. These follow the bedding planes closely and trend nearly east, forming broad ribbon-like deposits pitching steeply with the beds. They are intersected by a narrow fissure vein, which strikes nearly east and is vertical or locally dips steeply southward. Figure 29, page 182, is a section drawn east and west through the ore bodies and nearly with the strike of the vertical vein, which is not shown in this figure. Figure 38 is drawn approximately at right angles to this and shows the vein in cross section. The lower ore body at the Golden Gate incline is best exposed in the large stope about 75 feet east of the top of the incline, where the ore is from 4 to 8 feet thick and lies almost flat. The longer axis of the stope strikes N. 30° E., and the ore dips steeply westward away from it and more gently toward the east, making an unsymmetrical saddle or anticline from which the deposit decreases in thickness in both directions. To the west the deposit is from 6 inches to 3 feet thick. It is exposed on the 100-foot level and in the 140-foot raise, which is 160 feet below the tunnel level. This is perhaps the most persistent ore body in the mine, and it has been explored for more than 500 feet down the dip and across the strike. It is not everywhere of payable width and grade, but was most profitable at the crest of the anticline or saddle on account of its greater thickness. The upper ore body of the Golden Gate incline is about 60 feet higher and lies with the bedding of the limestone. Along the incline driven westward on this ore the lode is from 1 to 3 feet thick. The hanging wall is a medium to coarse grained marble partly replaced by quartz, and the footwall is a fine-grained white marble stained by brown blotches of manganese oxide. Dark blue or black limestone occurs 1 to 3 feet below the footwall (fig. 40). In the Golden Gate incline the ore body is cut by two faults of slight throw, one of which is reversed (fig. 29). Flat stopes about 50 feet above the saddle of ore on the tunnel level indicate its position at the upper horizon, but the ore body has not been extensively developed at that place.

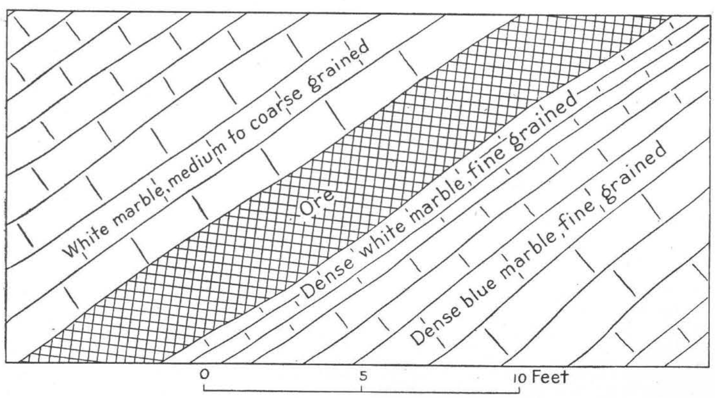


FIGURE 40.—Section of lode in Golden Gate incline, Hope mine.

Whitewash ore body.—The Whitewash ore body is exposed on the tunnel level at the Whitewash station. It is shown in figure 39, which is a vertical east-west cross section through the station. Below the tunnel the ore pitches steeply northwestward to the 100-foot level, where it is displaced a few feet by a fault dipping steeply westward. Below this point it extends downward on a dip of about 40° to the 300-foot level, where it is terminated by the Kyle fault. It lies with the bedding where exposed below the 100-foot level, and is at a horizon above the upper Golden Gate ore channel (fig. 38). Between this level and the tunnel level the relations to bedding are not clearly shown. This portion of the ore body follows a fissure which strikes N. 25° E. and dips 47° W. Above the tunnel level the ore is for the most part in the bedding planes, though small tortuous ore shoots from the main body cross the bedding. Eastward the ore descends gently and probably connects with an ore body which strikes N. 35° W. and dips eastward. This ore body is encountered in a short incline driven eastward from the floor of the tunnel level. Workings still farther east indicate that this dip is local and that the beds assume the normal southwest dip, the ore bed rising toward the Porter workings (fig. 39). The Whitewash ore body was very rich near the Whitewash station, and much of the ore is said to have carried several hundred ounces of silver to the ton.

Field shaft.—The Field shaft intersects the Jubilee workings 500 feet S. 73° E. from the top of the Golden Gate incline. Near the shaft, at a depth of about 160 feet, is a flat-lying ore body that can be followed westward for about 400 feet. It is narrow and in cross section is approximately circular. In places it follows the bedding of the limestone, and locally it sends out small tonguelike ore shoots. To some extent its position is controlled by joint planes and their intersections with bedding planes. The ore body is shown in figure 41, which is an east and west section through the Field shaft.

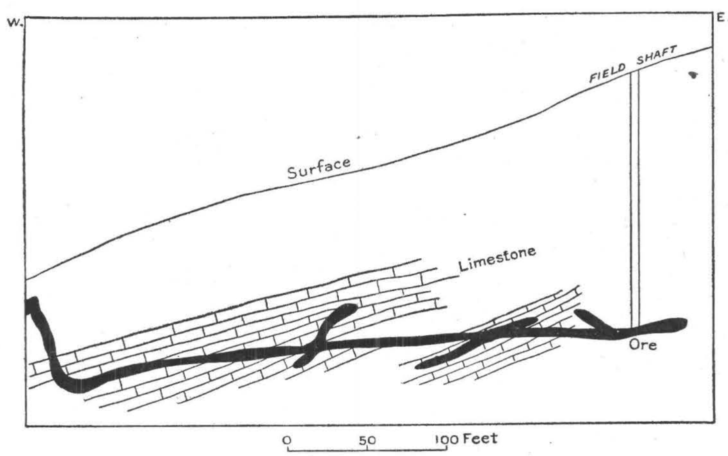


FIGURE 41.—Vertical east-west section through Field shaft, Hope mine.

Cuno shaft.—The Cuno shaft is about 750 feet S. 28° W. of the Porter shaft and near the outcrop of the Porter fault. The workings were holed through to the Jubilee workings but are now inaccessible. According to Mr. G. B. Ballard, the ore was west of the Porter fault and about 140 feet below the surface. The principal deposit was a lenticular mass 50 feet long which cut across the bedding planes.

Discovery workings.—The original Hope Discovery workings comprise about 5,000 feet of very irregular intersecting drifts, crosscuts, and inclines, a large part of which are inaccessible. The greater portion of the work was done 25 to 40 years ago, and data concerning the ore bodies are therefore vague. At the top of the Discovery incline the Jefferson limestone strikes N. 54° E. and dips 34° NW. The ore occupies the bedding planes, and near the surface it has been stoped eastward for a distance of 200 feet. At four places the ore has been followed approximately down the dip of the beds to the Ballard level, which is 100 feet below the surface. The broad ribbons or flat irregular patches of ore are apparently confined to one geologic horizon, but this horizon is not everywhere mineralized. All the ore bodies lie west of a fault which, on the Ballard level, strikes N. 30° W. and dips 70° W. This fault, projected upward, passes about 30 feet east of the vertical Discovery shaft (No. 1). West of the Discovery incline the workings are caved. The following description, taken from a paper by Goodale and Akers [1] was written when these ore bodies were exposed:

The width of the vein is very variable, running from a mere seam to 24 feet. Forming the footwall is a stratum of mottled limestone from 2 feet to 3 feet in thickness, and under this a stratum of very hard, white limestone. Next follows a 7-foot zone of black limestone; then from 10 to 25 feet of mottled limestone; then from 2 feet to 3 feet of barren quartz, and underlying all a very compact limestone, of a jet black color * * *. The strike of the vein is east and west, and in dip it is conformable to the stratification of the country. Developments in this mine, which have been quite extensive, have revealed four principal faults, all at right angles to the strike of the vein, the latter term being employed merely as a matter of convenience, and not to define its precise character. Going

[1] Goodale, C. W., and Akers, W. A., Notes on the geology of the Flint Creek mining district: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 245.

west on the strike of the vein from the extreme eastern workings, the ore drops 92 feet at the first fault, has its regular strike for a distance of 60 feet, faults up 65 feet, is unbroken for 50 feet, drops 18 feet, has its strike again for 45 feet, and then drops 265 feet. In all four of these faults the plane of fracture is more or less inclined, and in every instance the hanging of the fault drops.

The fault first referred to in the article is presumably the first one west of the Discovery shaft, not the one east of the ore bodies. The fourth fault is probably the Porter fault, though the throw appears to be excessive. It may have been measured on an incline said to have been driven westward on a fault toward the Jubilee workings. The Discovery ore bodies before faulting were probably connected with the Golden Gate ore bodies, but this can not be shown in the workings now accessible.

Take All incline.—The Take All incline is about 200 feet S. 28° E. of the Hope Discovery incline and is driven on an ore body that follows the bedding of the limestone, which strikes N. 55° E. and dips about 32° N. The ore is quartz, sprinkled sparingly with black argentiferous sulphides, and is about 3 feet thick. It occurs considerably lower in the limestone than the mineralized horizon in the Discovery workings, and presumably at the lowest horizon on which ore has been discovered in the Hope mine. Only a little ore has been taken out from this incline.

Porter shaft.—The Porter shaft is now abandoned and nearly all the workings leading from it are inaccessible, but an ore body about 200 feet east of the shaft was reached through the Prince Imperial adit, which intersects it about 175 feet below the collar of the shaft. At this place the ore is 12 to 15 feet thick and conforms to the bedding of the limestone. The old mine maps indicate another large body of ore about 200 feet west of it. The ground between the two ore bodies is in line with faults projected from the Discovery workings mentioned on page 217. It seems probable from the data there given that the ore was faulted downward at the west end of the ore body, 200 feet east of the shaft, on the Prince Imperial level (according to Goodale and Akers[1] 92 feet).

Little Emma claim.—The workings of the Little Emma claim are about 700 feet northeast of Discovery shaft No. 1, near the top of Hope Hill. Most of them are inaccessible, but the ore is exposed in a stope near the surface and conforms there to the bedding planes of the mottled limestone, which strikes N. 37° E. and dips 38° W. The ore occurs at two horizons separated by about 2 feet of brown-mottled limestone. It is very siliceous, average samples running as high as 92 per cent SiO_2, and it carries from 18 to 60 ounces silver. The Little Emma has produced comparatively little ore.

SWEET HOME MINE.

The Sweet Home mine is near the top of Hope Hill, about 600 feet N. 80° E. of the Hope Discovery incline. It has produced several thousand dollars' worth of silver ore, which was treated in the Patten mill, north of Philipsburg. The ore horizon is with the bedding planes of the Jefferson limestone, and the ore resembles that of the Hope mine. The deposit strikes eastward and dips toward the north. For several hundred feet along the outcrop the ore has been worked by open cuts and drifts, and one short incline has been sunk. Some of the ore is dark manganese-stained quartz cemented by white quartz of later age and gives evidence of movement parallel to the bedding. About 100 feet east of the incline the ore is displaced by a fault that strikes N. 8° W. and dips 56° E. West of the fault the ore strikes N. 77° E. and dips about 27° N. The ore horizon east of the fault is offset toward the south about 75 feet and strikes N. 55° E. As is the case with the prevailing faults in the Hope mine, the hanging wall has dropped, causing the ore on that side of the fault to offset toward the south.

CADGIE TAYLOR MINE.

The Cadgie Taylor mine is situated on the east slope of Hope Hill, about 1,400 feet N. 55° E. of the Hope Discovery incline. The ore resembles that of the Hope mine and like the latter is inclosed in Jefferson limestone. According to Mr. James Patten it has produced

[1] Loc. cit.

about $40,000 in silver, a large part of which was milled in the Patten mill, north of Philipsburg. The flat-lying ore bodies are exploited through tunnels driven on the ore, and all workings are at slight depth. The ore body outcrops on the surface at several places and follows the bedding of the limestone. Exposures on the surface are not continuous, but the general relation of the outcropping quartz indicates that the ore body is thickest at the crest of an anticline which strikes about N. 20° E. and pitches about 15° N., approximately with the slope of the hill. Below the surface to the east the mineralized bed strikes N. 22° E. and dips from 15° to 34° E. The deposit is there from 2 to 6 feet thick and is followed along the strike for 230 feet. The ore is largely oxidized, and the metal is in horn silver and silver glance.

TWO PER CENT MINE.

The Two Per Cent mine is on the south slope of Poorman Hill, half a mile southeast of the Hope Discovery incline. It was first worked in 1866, and before the Northern Pacific Railroad was built some very rich ore was shipped to Swansea, England. It has not been worked actively for many years, and the records of production are meager. Mr. James Patten places the total production at about $75,000. The mine is situated in the lower part of the Jefferson limestone, which carries thin beds of shale. The ore resembles that of the Hope mine, and the deposits in the main follow the bedding planes, but the horizon is lower than the mineralized beds of Hope Hill. The rocks strike about N. 34° W. and dip from 6° to 15° E. An incline follows the ore in the bedding planes for about 200 feet. The beds where mineralized are joined by a vein which strikes N. 80° E. and dips about 78° S. Where the replaced bed outcrops near the portal of the incline the hanging wall is a thin bed of calcareous shale. Below the ore stratum a brown limestone from 3 to 6 feet thick grades downward into darker limestones. The ore-bearing solutions presumably circulating in the fissure were in a measure controlled by the relatively impervious hanging-wall shale and deposited much of their load below it. At the breast of the incline the ore is said to carry from 20 to 30 ounces of silver and a little gold.

NEW HOPE CLAIM.

The New Hope claim is located on the north spur of Red Hill about 200 feet above the bottom of Stewart Gulch. An incline is driven 100 feet southwestward at an angle of 30° on a small shoot of rich siliceous silver ore which follows a slickensided plane that is approximately with the bedding of shaly limestone. At places the ore is much crushed and disturbed by movement.

COPPER JACK CLAIM.

The Copper Jack shaft is about 200 yards east of the summit of Red Hill. It is about 70 feet deep and is sunk near the contact of porphyry with limestone. At the bottom of the shaft a crosscut 50 feet long has been driven in the Madison limestone, which has been greatly metamorphosed by the intruding porphyry. Garnet, pyrite, and specularite have been developed in the limestone, and the ore in the crosscut is said to average about 2 per cent of copper. About one-fourth mile northeast of this shaft a crosscut tunnel has been driven westward 500 feet in metamorphosed limestone.

MAGNETITE DEPOSITS.

REDEMPTION IRON MINE.

The Redemption iron mine is located on the west slope of Franklin Hill near the sharp bend of the Philipsburg-Granite wagon road. According to Mr. Eugene Sifton, one of the owners, it has produced about 3,000 tons of ore. Car shipments run from 35 to 60 per cent FeO and from 8 to 16 per cent SiO_2, and the average value is about $3.

The ore body is in the Hasmark formation, which dips westward at steep angles, and is for the most part of fine-grained, relatively pure marble, though locally it contains thin, argillaceous bands. The contact of the limestone with the granite is about 1,000 feet south of the mine.

The main deposit, which is a rudely lenticular mass from 8 to 15 feet wide, is exploited through a crosscut tunnel, which reaches the ore 275 feet from the portal and follows it for about 150 feet. The longest axis of the deposit strikes about N. 30° W., and the ore body pitches steeply northeastward, cutting irregularly the bedding of the country rock.

The minerals present are magnetite, calcite, quartz, tremolite, green mica, diopside, and scapolite, all intergrown and contemporaneous. In an open cut above the mine and about 350 feet S. 30° E. of the portal of the tunnel a blackish-green fibrous mineral occurs intimately intergrown with magnetite and other minerals of contact-metamorphic origin. A partial quantitative analysis of this mineral by W. T. Schaller, of the Geological Survey, shows it to be ludwigite, a magnesian borate containing ferrous and ferric iron. Some masses of ore weighing several pounds are more than half ludwigite.

SILVER LODE IRON MINE.

The Silver Lode iron mine is located on the west slope of Franklin Hill just above the road from Philipsburg to Granite and about 1,200 feet south of the Redemption iron mine. It is the property of Mr. Frank Hughes, of Philipsburg. In 1904 and 1905 it produced 3,200 tons of iron ore carrying about 40 per cent iron oxide. The ore body is an irregular mass of magnetic iron and is reached by a crosscut tunnel 100 feet long. The country rock is dolomite of the Hasmark formation, and the contact with the granite is within 100 feet of the magnetite mass. The ore body is similar to that of the Redemption mine and the associated minerals are approximately the same, although no ludwigite was noted. Green mica is very abundant in altered limestone close to the contact near the portal of the tunnel and occurs in veinlets cutting the granite. The Kentucky claim, just above the Silver Lode iron mine, is also owned by Mr. Hughes. It has produced about 1,800 tons of iron ore.

CHAPTER XV.

MINES NEAR CABLE, GEORGETOWN, AND RED LION MOUNTAIN.

GENERAL STATEMENT.

In this chapter are described the mines on the slopes of Cable and Red Lion mountains, those on the eastern border of Georgetown Flat, those south of Cable on the slope of Silver Hill, and a few deposits in the drainage basin of Warm Spring Creek. Geographically they do not fall into a clearly defined group, but the area in which they lie includes several important gold-mining localities, between which are scattered a number of prospects or small mines. Good wagon roads connect the important mines with Anaconda or Philipsburg, most of the traffic being through Anaconda by way of Brown's siding, which is the terminus of the Butte, Anaconda & Pacific Railway and the site of the limestone quarries of the Washoe Copper Co. Ore is hauled by wagon to this siding and thence shipped by rail to the smelter, about 8 miles away. The wagon roads are in fair condition, and the grade is very good, considering the character of the topography. The treatment charges at the smelter are low for most of the ore. Owing to its high percentage of iron and lime, it is very desirable for mixing with the more highly siliceous ores from Butte. Should future developments prove that the tonnage could be increased sufficiently to justify the construction of a railroad, these ores and possibly the magnetite deposits would play an important part in the smelting of Butte copper ores. The low-grade ore is treated at the mines in mills, four of which were running in the summer of 1906. (See pp. 199–200.) The total production of this group of mines to 1907 was about $5,000,000.

The country is an area of faulted and folded sedimentary rocks mainly of Paleozoic age, cut by intrusive masses of granite and related rocks. The south edge of the great granite batholith which covers an extensive tract of country east of Philipsburg and which lies to the north of the area here discussed, is crossed by the north fork of Flint Creek near the head of its canyon. Southwest of this point, down the valley of the north fork of Flint Creek on the west side of the stream, is a smaller mass of intruding granite, and a third body of granite extends to the Cable and nearly to the Southern Cross and Gold Coin mines. It occupies an area of several square miles just east of Georgetown. Its boundaries are rudely circular, but at several places it sends off small apophyses into the surrounding sedimentary rocks, and a number of small dikelike masses not far from it are probably connected with it below the surface. The most important mines are in the sedimentary rocks near the granite contacts, though metalliferous deposits occur a mile or more from these contacts, and still other deposits are entirely within the intrusive granite (granodiorite).

The ore deposits are divided into the following groups, named in order of importance. All have been discussed in Chapter XI.

1. Gold-copper replacement deposits of contact-metamorphic origin.
2. Gold-bearing replacement veins in sedimentary rocks.
3. Gold-bearing veins in granite.
4. Silver-bearing replacement deposits in calcareous rocks.
5. Contact-metamorphic deposits of magnetic iron ore.

DETAILED DESCRIPTIONS OF MINES.

CABLE MINE.

LOCATION AND HISTORY.

The Cable mine is situated near the head of Cable Creek, 13 miles northwest of Anaconda and $7\frac{1}{2}$ miles from Brown's siding. It was discovered in 1866, and a mill was built in the following year to treat the ore.

According to Raymond's reports,[1] the total production of the mine up to 1872 was $400,000. Some of the ore was very rich, and a single ton is said to have yielded $30,000. A nugget of gold from this mine, worth $375, was shown by Salton Cameron at the Centennial Exhibition.

In 1877 J. C. Savery bought the mine and built a new mill, which was operated until 1891. During this period more than $2,000,000 in gold was recovered. Most of it came from the Cornish, Square Set, and Lake stopes, from 100 to 300 feet below the surface. The ore shoots were apparently exhausted in 1891, and the mine was idle until 1900, at about which time the management was obtained by F. W. and H. C. Bacorn, who undertook a vigorous plan of development with a view to opening up new ore bodies in the lower levels. In their hands a moderate production was sustained for some time and considerable new ground prospected. The total production of the mine since discovery is between three and four million dollars.

DEVELOPMENT AND EQUIPMENT.

A crosscut tunnel 888 feet long intercepts the ore zone about 245 feet below the surface and continues in a sinuous course along its general strike for about 2,000 feet. This zone is from 80 to 360 feet wide and has been explored by a large number of crosscuts and raises from the adit level. A blind shaft is situated about 1,600 feet from the portal of the adit. From this shaft levels are turned 65, 140, and 214 feet below the tunnel level, giving in the deepest workings a depth of about 500 feet. Above the adit three levels are turned from shafts now abandoned, and these workings are connected by stopes and raises with those below. The total development by crosscuts and drifts is about 7,500 feet.

The walls stand well, and very little timbering is necessary. The huge cavities from which the ore has been removed have remained for years without signs of collapse. Of these the Cornish, Square Set, and Showers stopes are above the tunnel level. The Cornish stope is a large rudely cylindrical cavity just above the engine station. The Square Set stope is east of and above the Cornish stope and is connected with it. The Showers stope, which is smaller than the Cornish stope, is about 100 feet west of the engine station and its base is that of the adit level. The Lake stope is a few feet north of the engine station and is a flat-lying cylindrical cavity 320 feet long. A large stope lies on the 65-foot level below the west end of the Lake stope and is connected with it, and there are several smaller stopes on the lower levels, most of them west of the shaft.

The mine is equipped with air compressors that furnish power for pump, hoist, and drills. A 30-stamp amalgamating mill is situated at the mouth of the tunnel.

GEOLOGY.

Country rock.—The ore bodies are replacement deposits in a mass of limestone which is rudely tabular in form and approximately vertical in attitude. It is about 300 feet in average thickness and about a third of a mile long. The trend of this limestone mass, which belongs to the Hasmark formation (Cambrian), is northwesterly. It is nearly surrounded by granite, but at its northern end it is faulted against quartzitic sandstones of the Spokane formation (Algonkian), which, anticlinally folded, form the crest of Cable Mountain and which are overlain on the flanks of the mountain by Cambrian quartzite, shale, and limestone.

The granite (granodiorite) which incloses the ore zone is fairly uniform in texture and composition. It is medium grained and is composed of quartz, orthoclase, plagioclase, green hornblende, and black mica. The contact facies has at some places a little finer grain than the normal facies, but its texture is not porphyritic. The granite is generally fresh, although calcite, sericite, and chlorite are developed at some places. Locally alteration has been more extensive, and the ferromagnesian minerals have been completely altered or removed, leaving a rock composed of calcite and sericite with the original quartz and altered feldspar. Such rocks are light in color, and hand specimens may be mistaken for aplite. This hydrothermal alteration does not appear to be directly connected with the deposition of the ore, for the places

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 276.

at which it is most pronounced are at some distance from the ore bodies. A good example of such alteration may be seen on the adit level in the south crosscut, 240 feet S. 13° E. of the engine station.

Contact metamorphism.—The calcareous sedimentary rocks are greatly metamorphosed near their contact with granite, being changed in places to rocks composed chiefly of garnet, actinolite, magnetite, pyroxene, specularite, epidote, and mica. Rocks of this composition outcrop on the surface north of the ore zone, and angular masses of garnet rock more than a foot in diameter occur at several places in the lower levels of the mine. They are especially numerous near the north wall of the 214-foot level.

The dolomite of the Hasmark formation has been extensively recrystallized near the intruding granite. The commonest facies is white or light-gray marble composed of interlocking grains of calcite a little smaller than grains of wheat. A little white mica has in places been developed in this facies. Locally this grades into a marble composed in the main of interlocking crystals of calcite more than an inch in diameter. As the grain of the marble increases, quartz, iron oxides, and iron and copper sulphides begin to appear, and in the coarsest varieties of the marble these minerals are commonly present in considerable quantities. Coarsely crystalline calcite occurs locally throughout the ore zone, most abundantly near the granite contacts.

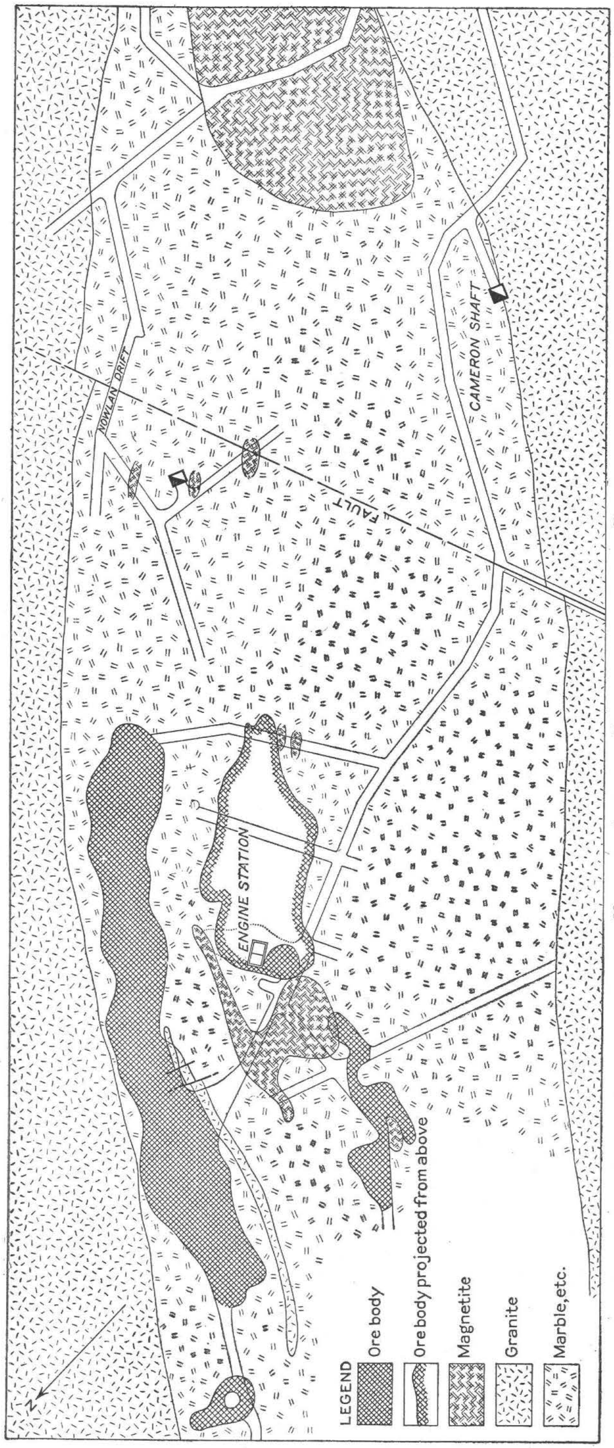


FIGURE 42.—Plan of portion of adit level, Cable mine. The granite is technically a granodiorite.

The chemical changes produced in the contact metamorphism involved the addition of iron and sulphur in large quantities, silica in less amount, and gold and copper in appreciable quantity. Aluminum, which enters into the composition of mica and other contact-metamorphic silicates, was not introduced in large quantities, for these silicates are very sparingly present, and a relatively pure limestone could have supplied sufficient alumina for their development. Carbon dioxide was removed from the limestone, and where it was replaced by magnetite much lime must have been removed also.

Magnetite bodies.—Magnetite is present throughout the ore zone as large, irregular bodies of rudely ellipsoidal outline, some at least 100 feet in longest diameter. These bodies appear to have no relation to the bedding. One of the larger masses lies just west of the engine station and forms in part the west wall of the Cornish stope (fig. 42). Calcite, olivine, diopside, sericite, pyrite, and pyrrhotite are intergrown with the magnetite of the larger masses, but are as a rule very subordinate in quantity, and nearly all of a large crushed sample is attracted by a magnet. Mr. H. D. Morse made a number of assays of magnetite, but only a few gave traces of gold. The contact of the large magnetite bodies with limestone appears rather sharp at some places, but the microscope shows that they grade one into the other within a narrow zone. (See Pl. IX, *B*, p. 60.)

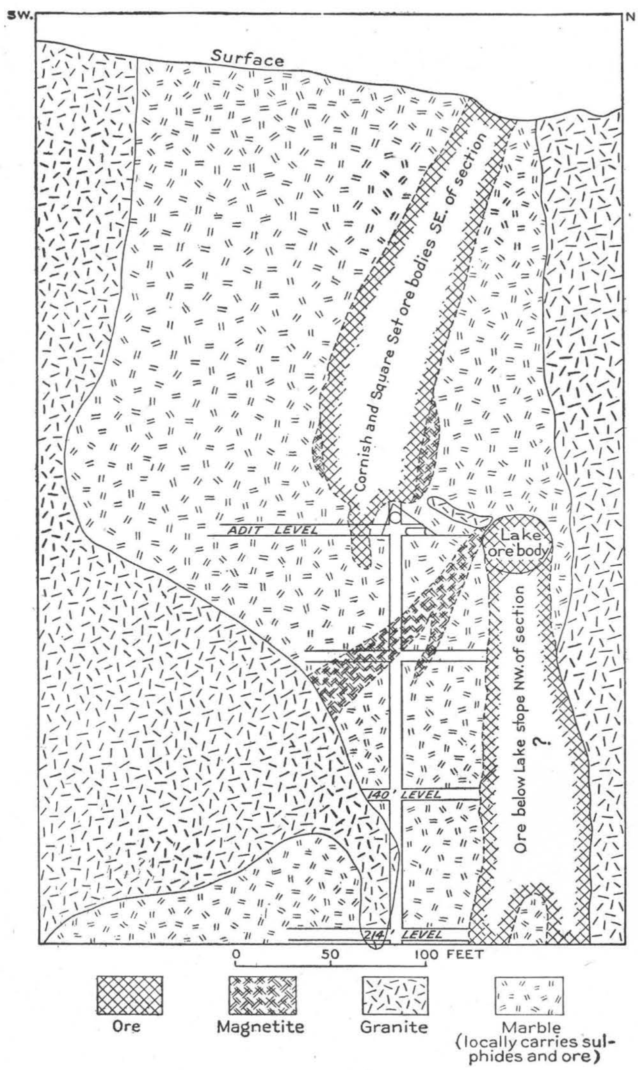


FIGURE 43.—Vertical section through Cable ore zone, Cable mine, looking northwest. Line of section is northeast. Upper parts of Cornish and Square Set ore bodies are projected on the section from the southeast; lower portion of ore body shown northeast of and below this is projected on plane of the section from the northwest.

The relation of the contacts to the bedding planes can not be made out. Wherever the contact of magnetite with limestone has been observed, the limestone is relatively pure and massive, and consequently its attitude is not apparent; indeed, the magnetite, as already stated, appears to form most extensively in the purer and more massive limestones. The irregular forms of the magnetite bodies, however, show that they do not follow any structural features closely (fig. 43).

Mica veins.—Veins of green mica occur at many places along the contacts between granite and limestone or between magnetite and limestone and have been observed to cut the magnetite at some distance from such contacts. These veins are from 1 to 3 inches wide, and many of the crystals of green mica are about an inch in diameter. The mica has a perfect cleavage, is highly flexible, and is not an alteration product. The veins are later than the granite and magnetite and may represent a late phase of the after effects of intrusion.

Recrystallization of calcite.—The recrystallization of calcite continued after some of the granite had cooled. When the sedimentary strata were intruded small sills extended from the main batholithic masses into the limestone ore zone. After these had solidified they were fissured and faulted. This faulting was followed by extensive recrystallization accompanied by the introduction of calcite and sulphides into the cracks of the smaller granite blocks. The fissures along which the faulting occurred were obliterated in the limestone, which was completely recrystallized, but in favorable places where the throw was only a few feet the line of displacement is shown (fig. 47, p. 230) by the position of the granite blocks, although the fissures are completely obscured by recrystallization of calcite. A block of granite cut by veinlets of calcite and sulphides and surrounded by the same minerals is shown in figure 44. Angular blocks of garnet rock are similarly surrounded by coarse-grained calcite, as shown in figure 45. The calcite which surrounds the granite and garnet rocks figured in these diagrams carried considerable sulphides and enough gold to be profitably milled. Considerable pyrite occurs in the veinlets which cut the granite block (fig. 44). Small calcite veinlets which in a few places cut the walls of the ore zone are relatively free from pyrite and are probably of later age.

Faulting after mineralization.—Fissures later than the ore cross the ore zone at several places. One of them is exposed on the adit level 250 feet S. 15° E. of the engine station, in the Nowlan drift north of this place, and on the level 63 feet above the adit. This fault, which is normal, strikes N. 70° E., dips eastward about 65°, and displaces the ore zone about 18 feet to the west. Several other fissures strike eastward across the ore zone. The displacements that they cause can not be calculated, but studies of drill cores indicate that such displacements are small.

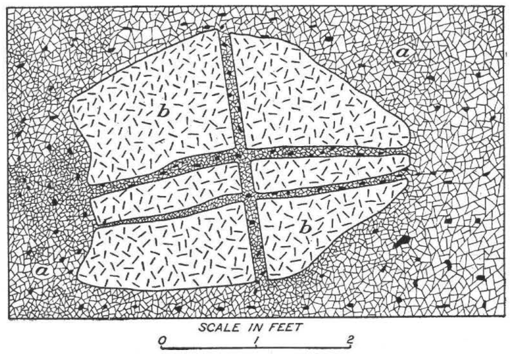


FIGURE 44.—Granite block surrounded and cut by coarsely crystalline calcite, quartz, pyrite, and chalcopyrite, 40 feet below northwest end of Lake stope, Cable mine. *a*, Calcite, quartz, pyrite, and chalcopyrite; *b*, granite.

ORE DEPOSITS.

The ore bodies are large irregular deposits replacing limestone. The ore consists mainly of calcite and quartz and contains a large amount of iron and copper sulphides, iron oxides, and gold. When a magnet is passed over the crushed ore magnetite and pyrrhotite are separated.

The zone of sedimentary rocks strikes southeastward, extends downward to an unknown depth, and is widest in the bottom of the mine. On the adit level the walls, or granite boundaries, are nearly parallel and about 240 feet apart. The contact surface of the north wall is approximately a plane surface and dips from 80° to 90° NE. The south wall is very irregular and from the tunnel level near the engine station has a low dip northeastward to the level 65 feet below, so that at this point the ore zone is only about 80 feet wide. Below the 65-foot level the contact dips again to the southwest, so that the ore zone is about 125 feet wide below this point, on the 214-foot level. East of this point, on the same level, the width of the ore zone increases to about 340 feet.

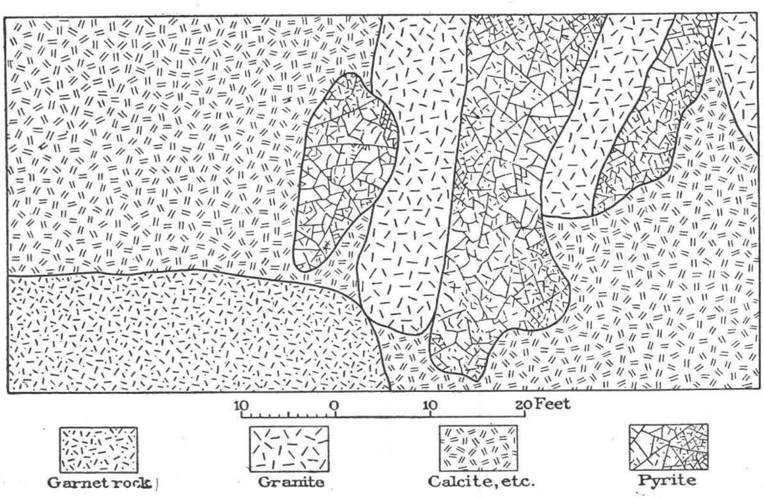


FIGURE 45.—Garnet blocks and granite (granodiorite) blocks surrounded by recrystallized limestone, Cable mine, 500 feet below surface, 214-foot level.

The coarse-grained calcite, quartz, pyrite, magnetite, and gold are very irregularly distributed throughout the ore zone, as shown in figure 46, where the nomenclature of the rocks is that used by the miners, "spar" designating the calcite of coarse grain and "lime" the recrystallized limestone or fine-grained marble. In general, marble whose crystals exceed the size of wheat grains is called "spar."

On the level 214 feet below the adit, at a depth of about 500 feet below the surface, three winzes are sunk in copper ore, and several carloads have been shipped. This ore is mainly pyrite, chalcopyrite, and calcite, though at some places the sulphides are coated with chalcocite and bornite.

The minerals of the ore zone are described in the following pages in four groups, comprising the primary minerals, secondary minerals other than sulphides, secondary sulphides, and minerals of rare occurrence in the mine and of obscure origin.

MINERALS OF THE ORE ZONE.

PRIMARY MINERALS.

Calcite.—Calcite is the chief gangue mineral and constitutes more than half of the ore. The calcite crystals range in complete gradation from the size of mustard seed to bodies more than an inch in diameter. The calcite of the ore is characteristically of the coarser variety, and its presence is considered a favorable indication, provided it does not occur in such quantity as to make the ore barren or too low grade to mill. It is intimately intergrown with all the other minerals, indicating that it is of contemporaneous age. The calcite is derived from the limestone, which became the ore zone when metamorphosed, and some of it, especially the coarsely granular variety, has probably recrystallized many times, for in places it has completely healed and obliterated fissures formed after some of the granite cooled (figs. 44 and 47). Apparently recrystallization of the limestone was the first event after the intrusion of the granite and was continued until at least some of the smaller apophyses of granite had solidified and perhaps much longer.

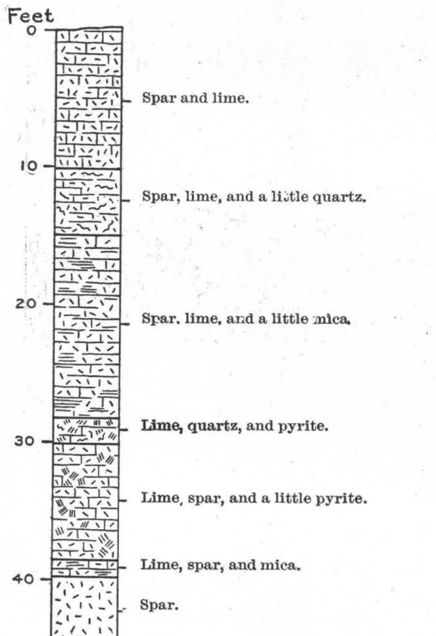


FIGURE 46.—Portion of the record of diamond-drill hole No. 136, in west drift adit level of the Cable mine. Hole inclined 60°. The record shows the complex structure of the ore zone.

Quartz.—Quartz, though generally present in the ore, is not so abundant as calcite. It occurs for the most part as small irregular bodies not showing the crystal boundaries, but intimately intergrown with calcite, pyrite, and other minerals. At some places masses of gold are embedded in it, and in general it is regarded as a favorable indication of ore. In the best ore bodies are irregular masses of quartz up to 1 foot in diameter. The limestone of the Hasmark formation is not cherty, and most of the quartz, unlike the calcite, was probably introduced into the ore zone by solutions given off from the intrusive.

Diopside.—Diopside occurs as small irregular grains and as idiomorphic crystals surrounded by calcite. It is present in considerable quantity in the transitional zone between calcite and the magnetite body which replaced the limestone at the Showers stope, though it is not abundant elsewhere in the ore body. It is of contact-metamorphic origin.

Actinolite.—Actinolite occurs at several places along the north wall of the ore zone but is not an abundant mineral in the mine. It is a product of contact metamorphism and where present is intergrown with magnetite and calcite. On the surface north of the granite mass that forms the northeast wall of the ore zone certain metamorphosed beds are composed almost entirely of actinolite.

Garnet.—At two or three places on the 140-foot and 214-foot levels near the northeast wall of the ore zone blocks of garnet rock several feet in diameter are completely surrounded by coarse-grained calcite. This mineral, as well as quartz, specularite, and magnetite, is intergrown with the garnet, which under the microscope shows the characteristic double-refracting rims frequently noted in andradite.

Biotite.—Brown biotite occurs locally in the ore zone intimately intergrown with calcite or with quartz. It results presumably from contact metamorphism.

Muscovite (sericite).—Muscovite is present at many places in the limestone as thin foils about one-tenth inch broad and as rosettes composed of such folia radiating from a common center. It is a product of contact metamorphism.

Chlorite.—Green chlorite is in many places associated with muscovite in the limestone.

Green biotite.—Veinlets of green biotite cut magnetite and occur in many places at the contact between granite and coarse marble.

Magnetite.—Small specks of magnetite occur intimately associated with pyrite, and are included in or intergrown with nearly all the contact metamorphic minerals. The nearly pure, coarse-grained calcite generally yields some magnetite when it is crushed, and appreciable quantities of the mineral may be obtained by passing a magnet over ore samples after crushing. Large bodies of magnetite occur at several places. (See fig. 42, p. 223.)

Specularite.—Specularite, or micaceous hematite, is not abundant. It occurs as thin foliæ or rosettes intimately intergrown with garnet, calcite, and magnetite. The bodies of magnetite contain very little hematite, for after the magnetite has been removed from the crushed rock little if any red powder remains.

Pyrite.—Pyrite is the most abundant sulphide and constitutes a large proportion of the unoxidized ore. It is very generally present in small crystals throughout the zone of metamorphosed limestone between the granite walls, and nearly pure massive pyrite occurs at many places. It generally carries more or less gold and is intimately associated with magnetite, pyrrhotite, chalcopyrite, and other minerals of contact-metamorphic origin.

Pyrrhotite.—Pyrrhotite is common though less abundant than either pyrite or magnetite. Appreciable amounts of pyrrhotite can generally be separated from crushed ore samples with the aid of a magnet. A specimen of pyrrhotite about the size of a walnut, taken from the mine years ago and now in the hands of Mr. F. W. Bacorn, of Butte, carried a large amount of visible free gold. The gold does not form a mere crust over the outer surface of the pyrrhotite but is distributed through it.

Chalcopyrite.—Chalcopyrite occurs intimately intergrown with pyrite, calcite, and magnetite. On the level 214 feet below the adit, about 500 feet below the surface, a considerable body of chalcopyrite ore yielded 10 per cent copper. Some chalcopyrite is probably secondary, for it appears to have been deposited on crushed pyrite.

Arsenopyrite.—Arsenopyrite intergrown with calcite occurs locally in masses of considerable size but is not an abundant constituent of the ore.

Zinc blende and galena.—Zinc blende and galena have been reported in the Cable ores but are very rare.

Gold.—Gold occurs as masses of unusual size, some of which are said to have weighed several pounds. One of the largest of these, according to Mr. Harvey Showers, came from the east end of the Lake stope and was approximately a foot square and nearly an inch thick and more than half gold. The metal also occurs finely disseminated in the iron sulphides, in calcite, and in quartz. Pyrite is generally associated with an appreciable amount of gold, and some masses of pyrite give high assays. White quartz commonly carries small particles of gold. Coarse-grained calcite is commonly rich in gold. Some of the gold occurs as thin elongated particles in the cleavage planes and elsewhere, and one specimen, the property of Mr. F. W. Bacorn, shows a mass of calcite more than half an inch in diameter surrounded by a thick hollow cylinder of gold. The fine-grained marble does not carry gold, and magnetite, though a common and abundant mineral in the gold ore, does not, when it occurs in large masses, contain an appreciable amount of the precious metal. Some of the pyrrhotite, on the other hand, is intimately associated with gold. At some places in the mine the rich gold ore occurs very irregularly, and masses as big as a barrel assaying well into the thousands may be surrounded by low-grade ore. The gold is pure and much of that recovered from the Cornish stope was sold at a premium for use in the arts.

Silver.—The gold bullion carries little silver. An $18,000 bar of gold taken from ore at the tunnel level is said to have yielded by weight only one-sixth of 1 per cent silver.

SECONDARY MINERALS OTHER THAN SULPHIDES.

Limonite.—Limonite, the most abundant metalliferous mineral of the oxidized ores, occurs in large quantities as the apex of the ore zone. It results from the oxidation of the iron sulphides, especially from pyrite. Magnetite alters to limonite much less readily than pyrite and crops out, only slightly decomposed, at the apex of the ore zone.

Hematite.—A red oxide of iron, either hematite or turgite, results from the oxidation of iron minerals, but it is not so abundant as limonite. It is either massive or amorphous, and is not easily confused with the specular hematite which occurs in the unoxidized portion of the mine.

Manganese oxide.—This compound is very rare. At one place a brownish oxide, possibly manganese, occurred as a thin coating on quartz.

Native copper.—A few small flakes of native copper were obtained by Mr. H. C. Bacorn in the upper workings of the mine.

Malachite.—Malachite is common in the oxidized ore and occurs in small irregular, botryoidal masses associated with limonite and quartz or in velvety green fibers lining vugs.

Azurite.—Azurite is not so abundant as malachite but is at some places associated with it.

Chrysocolla.—Chrysocolla is common but is less abundant than malachite. A piece of chrysocolla carrying specks of free gold was found in the upper workings.

Dolomite.—Dolomite occurs as crystals lining small vugs in the upper part of the mine.

Chalcedony.—Chalcedony, or amorphous silica, is rare, and where it does occur is secondary.

Kaolinite.—Kaolinite is a constituent of clay gouge and appears along postmineral planes of movement crossing the granite and the ore zone.

Miscellaneous minerals.—Quartz, calcite, and other minerals of the primary ore are also present in the oxidized ore but are in the main residual.

SECONDARY SULPHIDES.

Chalcocite films coating the surface of pyrite and chalcopyrite are of secondary origin and were precipitated by the mine waters on the iron-bearing sulphides. Bornite coating broken pieces of pyrite was noted in the lower levels of the mine. Chalcopyrite is probably in part a secondary sulphide, though it is in the main a primary mineral. The dark-yellow soft tarnish of some masses of pyrite is probably chalcopyrite.

MINERALS OF OBSCURE ORIGIN.

Tetrahedrite.—A dark-gray mineral with a very dark brown streak was noted on the 200-foot level associated with chalcopyrite. A test by W. T. Schaller showed it to contain copper, sulphur, arsenic, and antimony, and it is probably tetrahedrite.

Telluride.—A telluride compound, said to be a sulpho-telluride of bismuth by several observers, has been reported from the mine but was not seen in place by the writer. Several specimens tested for tellurium gave negative results. A telluride compound from this mine has been described by W. J. Sharwood.[1]

FORM AND DISTRIBUTION OF ORE BODIES.

The ore bodies are large, irregular masses in the limestone. The Cornish ore shoot is a large, rudely cylindrical mass pitching toward the west at an angle of about 30°. It is about 125 feet long, and its base is near the tunnel level. Its average diameter is from 50 to 75 feet.

Toward the east, above the Cornish body and connected with it, is the Square Set ore shoot, which continues upward tortuously to the surface. The Showers ore shoot, about 100 feet west of the engine station, is in line with the other two, a large irregular body of magnetite lying between them. The three ore bodies appear to be connected by coarsely crystalline calcite and quartz. The plane of these deposits is near the center of the ore zone and makes a

[1] Notes on telluride-bearing gold ores: Econ. Geology, vol. 6, 1911, p. 29.

small angle with its strike, trending more nearly east and west. Another group of ore bodies occurs north of this one, near the granite contact, and is not connected by ore with the Cornish group. Of the northern group the Lake ore shoot is by far the largest and most productive. This is a thin flat-lying cylindrical mass about 320 feet long, 40 feet wide, and 15 to 30 feet high. Its roof is approximately the tunnel level. Its northwest end is connected by low-grade sulphide ore with an ore body just below and a little farther north on the 65-foot level, and below this are still other ore bodies on the 140-foot and 214-foot levels. In these the ore does not extend so far to the southeast as in the Lake ore shoot. All the ore bodies of this group are nearer the northeast wall than the southwest wall and are north of and below the Cornish group. The Square Set and Cornish masses are connected by ore, as are the Lake ore body and the one below it on the 65-foot level, and these groups of deposits have supplied most of the ore of the mine. The Lake ore body is said to have averaged $10 to $12 a ton gold and the Cornish deposit from $30 to $40 a ton. The positions of the Lake and Showers ore deposits are shown in figure 42, page 223, which is a plan of a part of the main level. The east end of the Cornish ore body and all the Square Set ore deposit are projected downward to this level. Figure 43 is a cross section drawn northeast through the ore zone at the engine station. The upper portion of the Cornish group of deposits is projected upon it from the southeast and the ore below the Lake stope is projected upon the same plane from the northwest.

GENESIS OF THE ORE AND THE EFFECT OF FISSURES.

The Cable ore bodies are replacement deposits of contact-metamorphic origin. The primary ore is coarse calcite carrying a variable amount of quartz, pyrite, chalcopyrite, pyrrhotite, arsenopyrite, magnetite, and gold so intimately associated as to indicate that they must have been deposited at the same time. The metallic minerals occur as a rule in irregular masses in the calcite and quartz but locally in bands alternating with them. In this ore the gold is for the most part finely disseminated in the rock, although rich ore containing masses of gold larger than a grain of wheat is common. One specimen as big as a walnut contains about half pyrrhotite and half gold. The gold was introduced with the pyrite, pyrrhotite, magnetite, and other primary minerals by hot solutions given off by the intruding granite. It should be stated, however, that garnet and other heavy silicates are not abundant, and that the garnet rock is not particularly rich either in gold or in copper. The typical ore is not an intergrowth of heavy silicates and sulphides, as are many contact-metamorphic deposits of copper. Tetrahedrite and tellurides are generally not developed in contact-metamorphic deposits. They are of rare occurrence in the Cable mine and possibly were introduced along cracks and fissures after the principal ore bodies had been deposited.

The fissures formed subsequent to the ore (p. 225) are not highly mineralized. They do not cross the known ore bodies or displace the ore zone to any great extent and are therefore of little economic importance. Earlier fissures, probably formed while the sedimentary rocks were undergoing metamorphism, appear, however, to have influenced the deposition of ores to a certain extent. This fissuring has already been mentioned (p. 224) in connection with the discussion of the recrystallization of calcite, and the two processes are responsible for the peculiar relations shown diagrammatically by figures 44 and 45, which illustrate masses of granite and garnet surrounded by calcite. On the east side of the entrance to the Lake stope from the tunnel level a long tongue of granite cuts through the marble. This has clearly been faulted by movement planes which if extended would cross the Lake stope, but they can not be followed into the ore, for this has either been deposited since they were formed or else has recrystallized so extensively since the fissuring that all evidences of faulting have been obliterated (fig. 47). On the level 214 feet below the adit the contact between the coarse-grained marble and the granite shows movement along a plane striking about 15° east of north and dipping very steeply eastward. If projected upward this fault would cross the Lake ore body, but all evidence of its presence has been obliterated by the recrystallization of the coarse-grained calcite forming the walls of the stope. The association of sulphides, magnetite, and gold, which surround the granite blocks that occur below the Lake stope, shows that this deposition or recrystallization occurred under conditions of high temperature and pressure. The small apophyses of the intruding rock had solidified and had been fractured before the main body of the intrusive had ceased to give off mineralizing solutions. Evidence of fissuring of this character appears in the Lake stope and below it in the stope on the 65-foot level and in the stope of copper ore on the 214-foot level.

It appears probable that the entrance of the solutions which deposited the ore of the Lake group of stopes was facilitated by this early fissuring. The deposits taken as a whole, however, would not be classed as replacement veins, for repeated effort has failed to establish connections between many of them, though in form they resemble more closely some of the large, irregular replacement deposits or chambers of copper ore of Arizona and Utah. The early fracturing of the ore zone appears to have favored the introduction of ore, and it follows that the presence of the isolated blocks of granite and of garnet rock in the calcite is an indication of conditions favoring replacement. Consequently the north wall, along which such blocks are most abundantly distributed, is probably a favorable horizon for prospecting.

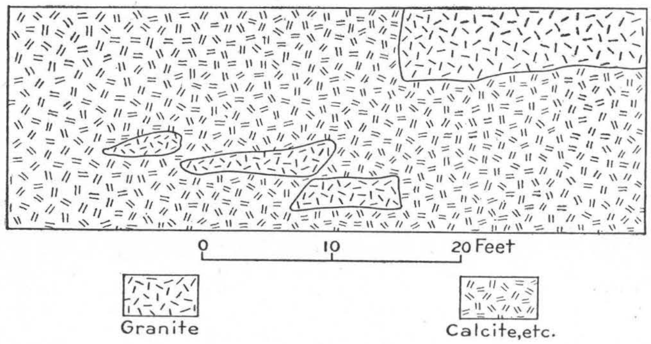


FIGURE 47.—Vertical section, south wall of Lake stope, Cable mine. The granite is technically a granodiorite.

OXIDIZED ORE.

The ore is oxidized above the water level. Originally the water level above the engine station was about halfway between the adit level and the surface. The outcrop of the ore, according to Mr. Showers, consisted chiefly of iron oxide and quartz carrying gold in appreciable amount. Some placers near the outcrop, worked in the early years of mining development, yielded several hundred thousand dollars.

Some of the oxidized ores from the upper workings carried considerable copper, and several thousand tons of tailings from ore milled years ago, before the present mill was built, were found to pay handsomely when smelted for their copper content. The average of analyses of seven cars of these tailings shipped to the Anaconda smelter is given below:

Average of analyses of tailings from the upper and partly oxidized ores in Cable mine.

	Per cent.
Copper	3.06
Insoluble matter	19.1
FeO	38.3
CaO	10
Moisture	11.2
Silver, 0.15 ounce per ton.	
Gold, $2.97 per ton.	

Tailings from sulphide ores milled later and from lower levels do not carry such high values in copper, so it appears that there was a zone enriched in copper in the upper part of the mine. Some of the sulphide copper ore on the 214-foot level is, however, richer in copper than the tailings of ore extracted near the surface.

The extent of the secondary enrichment of gold is not fully understood, for data concerning the condition of the ore in the large and very rich ore bodies taken from the upper part of the mine years ago do not give adequate grounds for forming a general conclusion, and it is not known that secondary enrichment, other than that due to the removal of valueless material from the ore, has been important. The extensive placers formed from the ore bodies indicate that the gold did not migrate downward to any great extent.

SULPHIDE ENRICHMENT OF COPPER.

Some secondary enrichment of copper is clearly shown on the level 214 feet below the adit, about 250 feet northwest of the blind shaft, where shattered pyrite and chalcopyrite are coated over with chalcocite and bornite. A number of winzes have been sunk on this level, and chalcopyrite ore carrying the richer sulphides has been found in three of these. The secondary sulphides appear only as a coating and chalcopyrite, which has the appearance of being primary, furnishes nearly all of the copper.

SUMMARY.

Sedimentary rocks consisting of limestone and shale were intruded by granite. Small tongues of granite extended also into the tabular mass of sedimentary rocks from either side. The limestone was in places metamorphosed to marble and elsewhere to garnet rock. Large masses of nearly pure magnetite were introduced into the limestone. Silica, sulphides and oxides of iron, and a subordinate amount of copper-iron sulphide, as well as the gold, were introduced into the marble by hot solutions. The marble recrystallized and locally formed very coarse grained calcite. After the small tongues of granite had solidified—possibly after the solidification of the magma immediately at the contact—disruptive stresses, caused presumably by further movement of the magma, fractured portions of the ore zone and ruptured the garnet rock and portions of the solidified intrusive. Fissures in magnetite, later filled with green mica pegmatite, are assumed to have been formed at this time. Calcite was extensively recrystallized. Some of the ore was deposited or recrystallized after the solidification of the smaller intruding tongues, probably after the replacement by magnetite. The mica veinlets which cut across the magnetite and which are commonly developed at the contacts between granite and the ore are eruptive aftereffects which in the main followed contact metamorphism. Subsequently the ore was changed through oxidizing surface waters.

SOUTHERN CROSS MINE.

LOCATION AND HISTORY.

The Southern Cross mine is situated in Flint Creek valley about 1 mile northeast of Georgetown and 1.1 miles northwest of the Cable mine. It was first located in 1866, but the location was allowed to lapse and it was relocated in the early seventies by Salton Cameron, who mined some ore that was shipped to the East Helena smelter. In 1884 a 10-stamp mill was built on the present site of the Glenn mill a few hundred yards below the mine, but the saving was unsatisfactory, and only a small amount of ore was milled. Later the property was acquired by the Southern Cross Gold Mining Co., of Butte. The mine was operated from time to time until the spring of 1904, when Lucian Eaves, who held a lease on the property, discovered a new ore shoot about 150 feet west of the hoist. For some months this ore body supplied about 50 tons of $25 ore a day, and it produced altogether $318,000, chiefly gold. A dry-crushing mill arranged for cyanide treatment was built at the mine to treat the lower-grade ore, and a considerable tonnage was milled with indifferent savings. Mr. Eaves estimates the total production of the mine before 1906 at $600,000, of which one-third came from the old workings, or East vein, and the remainder from the new workings, or West vein.

In the autumn of 1906 Messrs. Frank & Mantel purchased Mr. Eaves's interest in the mine and remodeled the dry-crushing mill, installing machinery to work the ore in the wet way. The mill as remodeled is described on page 199.

DEVELOPMENT.

The mine in 1906 was operated through a shaft inclined about 34° approximately N. 80° W. This shaft is 336 feet long and reaches a depth of about 200 feet below the surface. Five levels are turned from it, and on the 150-foot level a 300-foot crosscut connects with the workings of the old mine on the East vein, which has been explored on three levels through the old shaft inclined about 57° N. 50° E.

GEOLOGY.

The mine is on the western slope of the Cable anticline and is in limestones and shales near their contact with granite. The greater part of the workings are in dolomitic limestone of the Hasmark formation, which strikes about north and dips about 50° W. In the eastern portion of the mine the shale member of the Hasmark formation is exposed, with approximately the same dip and strike. Interbedded with the shales are thin beds of fine-grained marble, and east of them are white and light-gray marbles probably belonging to the lower member of the Hasmark formation. The calcareous sedimentary rocks have been recrystallized near the granite, and some mica has been developed in them, but they are not greatly metamorphosed.

The granite south of the mine is a part of the batholith forming the walls of the Cable ore zone. At the Southern Cross mine its contact with the limestone is exposed on the surface in a shallow pit a few yards east of the mill and in a crosscut on the 150-foot level. Though some movement has taken place along the contact, evidence of profound faulting is lacking. No slickensided surface or well-defined seam of gouge appears, but both limestone and granite are crushed near the contact. Small angular blocks of the intruding rock appear to be completely surrounded by the limestone. Very small apophyses of light-colored granite more siliceous than the common facies have been thrust into the cracks of limestone. Crystals of green mica occur along the contact plane where the contact is exposed on the surface a few yards east of the mill.

ORE DEPOSITS.

Character of the ore.—The ore deposits are replacement veins in limestones and calcareous shales. The ore is almost completely oxidized, and sulphides are of rare occurrence. The gangue is chiefly quartz and calcite, the quartz predominating in the better ores. Limonite and hematite are by far the most abundant metalliferous constituents. Malachite, azurite, and chrysocolla are of local occurrence. Pyrite occurs in thin tabular or nodular masses surrounded by iron oxides (fig. 31, p. 185) and associated with a little chalcopyrite. P. C. Waite, who assayed pyrite from the center of one of the nodules, found that, volume for volume, it contained gold about equal to that of the oxidized portion of the nodule. The gold is free but very fine, and in milling much of it is carried off with slime.

When the pyrite ore is crushed small particles of magnetite and pyrrhotite may be separated with a magnet. In the upper level of the old workings, near the shaft, a nodular mass of a copper-arsenic sulphide rich in silver was surrounded by limonite. Silver glance and a sulphotelluride of bismuth have been reported from the mine, but none were noted by the writers. At several places in the ore were cauliflower-like bodies of calcium carbonate several inches in diameter, which, when viewed in cross section, are seen to be made up of long, thin prisms radiating from a central point. They are usually sectors of spheres rather than complete spheres, and according to the miners all of them occur stem down. At some places the ore and country rock are coated thinly with manganese oxide, but manganese is much less abundant than in the silver-gold lodes near Philipsburg. The following table gives four analyses of carload lots of ore shipped to the Washoe Copper Co. at Anaconda. It will be noted that gold and silver are approximately equal by weight and that both increase with insoluble matter (silica). Copper in the shipping ore never comprises more than one-half of 1 per cent, and its quantity is not great enough to interfere seriously with cyanide treatment.

Analyses of ore from the Southern Cross mine.

[Made by Washoe Copper Co.]

	Gold (ounces).	Silver (ounces).	Insoluble matter (per cent).	FeO (per cent).	CaO (per cent).
First-class ore, selected	3.11	3.4	47.2	23.9	....
First-class ore, siliceous	1.47	1.5	34.9	24.9	17.0
Second-class ore	.48	.4	21.9	38.5	14.4
Heavy iron ore	.59	.2	18.1	57.0	4.2

Form of the deposits.—The ore deposits are fissure veins of irregular width, which lie approximately with the bedding of the country rock or cut steeply across it. The ore grades into the country rock, and at many places the limit of the vein can be made known only by careful assaying. The West vein, which has been the most productive, strikes a few degrees east of north and dips 50° W. (See fig. 30, p. 185.) Its maximum width is over 30 feet, and it has been followed to a vertical depth of about 200 feet. The stoping extends nearly to the grass roots, and the apex of the shoot is marked by a great cavity from which a large amount of ore was taken. According to Mr. Eaves, the ore was richer a few feet below the surface than at the outcrop. The ore is highly ferruginous and is oxidized as deep as exploration goes. The Hasmark formation, which forms the walls, has approximately the same dip as the vein. Some

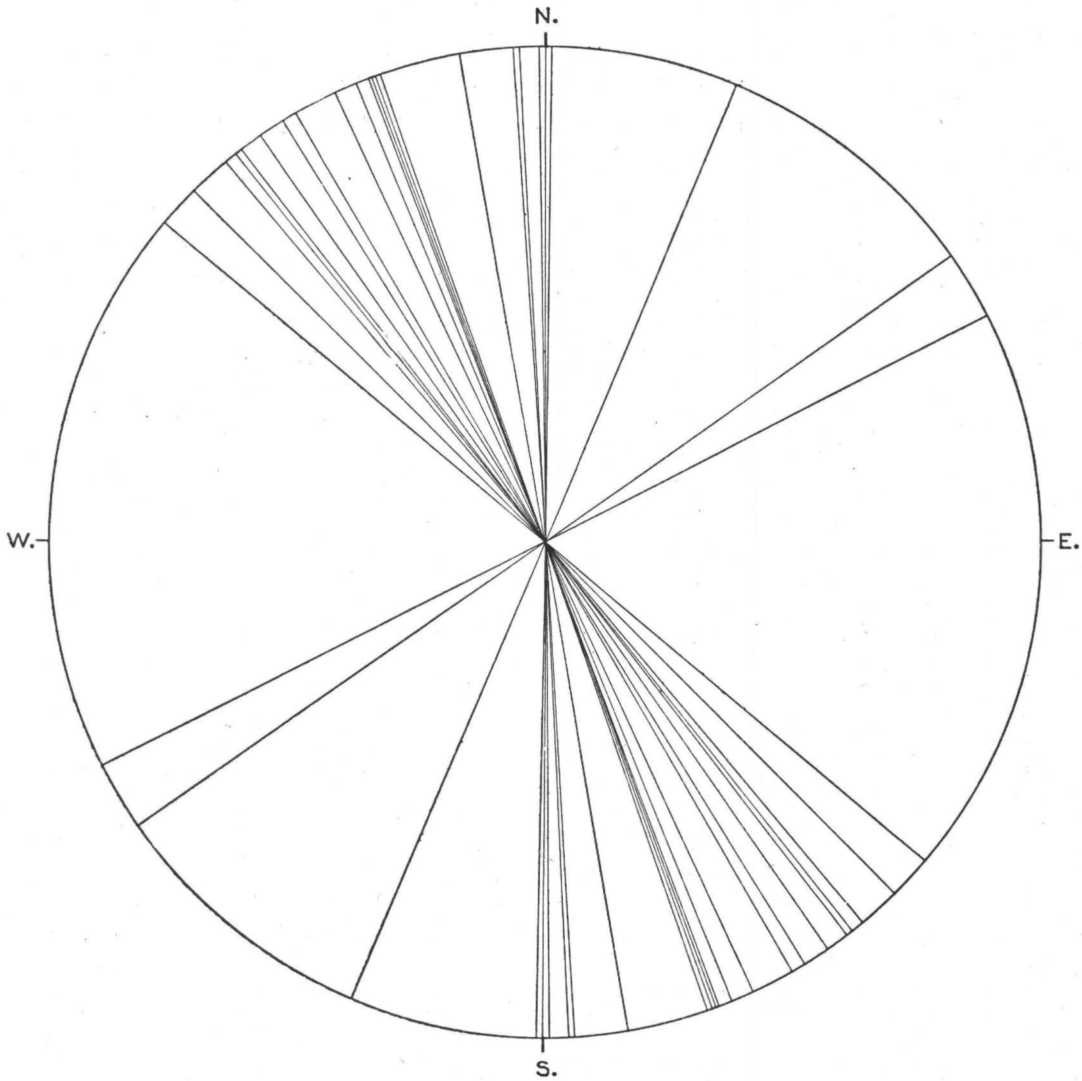


FIGURE 48.—Diagram showing direction of postmineral fissures in the Southern Cross mine.

movement has taken place since the ore was deposited, for it is cut by slickensided fissures that have a tendency to follow along the strike of the veins, though some cut across it at small angles. The postmineral movement, followed by extensive alteration, has so obscured the structure that identification of planes of movement and age determinations, with respect to primary deposition, are at many places impossible. The two principal ore shoots pitch steeply northward in the plane of the vein. One of these appears to be near the intersection of a cross fissure exposed 90 feet east of the station near the incline, on the 150-foot level.

The East vein cuts the bedding of the country rock at a large angle along both dip and strike. It is not so wide as the West vein and is of lower grade, but it is more persistent. It strikes N. 50° W., dips about 60° NE., and has been followed for more than 400 feet along its strike. A third vein, located between the other two, dips about 50° E., and smaller ore bodies occur at several places. The positions of the three veins are shown by figure 30 (p. 185), which shows a vertical section through the mine along a plane trending N. 75° E., approximately with the crosscut on the 150-foot level, which connects the new workings with the old.

Distribution of ore in the deposits.—Bodies of relatively high grade ore occur here and there along the veins. Not only are these ore shoots wider than the normal vein, but the ore is as a rule of better grade. The country rock is greatly disturbed and is traversed by a large number of fissures. In figure 48 are shown 23 of these plotted through a common center. As shown by this figure the predominant direction of strike is northwestward. The prevailing dip is about 60° E., though five of the fissures dip toward the west. Where some of the minor fissures cross the principal veins there is a swelling of the latter, and for a short distance the ore extends outward from the principal deposit along the smaller fissure. This condition is shown in the ore bodies of the East vein near the connecting crosscut on the 150-foot level, and the position of inaccessible stopes with respect to known fissures indicates similar relations elsewhere. Some of the minor intersecting fissures carry low-grade ore, and others were formed subsequent to mineralization, as is shown by the crushed quartz they contain, but oxidation is so extensive that these fissures can not always be distinguished from the older fissures along which the primary ore was deposited. The direction of the two planes of movement was in many places the same, and the wide replacement veins are cut by narrow slickensided fissures of later age, which are nearly parallel to them. This fact is of considerable importance. Where the veins are replacement bodies and are not strongly marked off from the country rock, a movement slip which parallels a wall for a certain distance and then leaves it is likely to be confusing, and one who is following it may lose the vein. The results of assays indicate the position of the vein much more closely than do late fissures, which locally follow the walls.

The displacement or faulting caused by the numerous fissures exposed in the mine can nowhere be made out. The sedimentary beds do not furnish a ready plane of reference and the veins can not be identified with certainty, but inasmuch as the Hasmark formation, which incloses most of the ore, appears to have about the normal thickness, it is inferred that the displacement is not great.

GOLD COIN MINE.

The Gold Coin mine is located a few rods west of Silver Lake and 1.6 miles south of Georgetown. Tunnels are driven on several claims, and altogether more than 2,500 feet of drifts and crosscuts have been run. Most of the ore has been treated in a stamp mill (p. 199) situated below the portal of the principal tunnel. According to Supt. L. E. Ireland the mine has produced over $200,000 in gold.

The ore deposits are replacement veins which cut across the bedding of the Paleozoic sedimentary rocks. In the immediate vicinity of the deposits the structure is relatively simple, and the beds dip from 30° to 40° NW. East of the vein are two great faults with a trend a little east of north and with downthrow on the east side. The veins, where exploited, are principally in the dolomite of the Hasmark formation, though they are not confined to it. Intruding igneous rocks do not appear in the mine, but granite is exposed about half a mile northeast. The sedimentary rocks are not greatly metamorphosed, although the more calcareous members are marmarized.

The veins outcrop on the surface and are stoped to grass roots. A considerable amount of gold was obtained by milling loose quartz bowlders scattered over the hill. The ore is ferruginous quartz locally stained with copper carbonates and carries several dollars in gold to the ton. Some of it is very rich, and in general the gold is not in such fine particles as that of the Southern Cross mine. Sulphide ore is said to be present in a lower level of the mine, which was inaccessible in the autumn of 1906. According to Mr. L. U. Loomis the sulphide ore is composed of pyrite, pyrrhotite, and a little chalcopyrite.

The principal vein, which is encountered in a crosscut tunnel 200 feet from the portal, strikes N. 30° W. and dips about 70° NE. It is followed westward for 200 feet, where the drift turns sharply to the north and follows a vein for about 400 feet. A large part of this vein has been stoped out above and below the level. About 35 feet above the turn of the drift just mentioned and 75 feet below the surface a body of ore was encountered which, for a width of several feet, ran about 5 ounces of gold to the ton. Development is insufficient to show whether this is a bend of the vein or the intersection with a second vein, but workings on the surface northwest of this point indicate that the vein first encountered continues nearly in a line beyond the turn of the drift and that the rich ore shoot is therefore at the intersection of two veins.

TWILIGHT MINE.

The Twilight mine is situated on the west slope of Cable Mountain, about 3,500 feet N. 35° E. of the Southern Cross mine. It was worked years ago, and about a thousand tons of ore were treated in a 10-stamp mill near Flint Creek below the mine. A crosscut tunnel driven northeastward intersects the lode 125 feet from the portal, from which point the lode is followed eastward for 400 feet. Some stoping has been done both above and below this level. A 100-foot winze is sunk on the vein 380 feet from the portal, and drifts are run from it midway of its depth and at the bottom. At the east end of the workings a shaft connects with the surface. The mine was recently acquired by Paul A. Fusz and John R. Lucas, of Philipsburg, and a long crosscut tunnel was being driven in the autumn of 1906 to explore the lode in depth. The mine is reported to have produced several thousand dollars in gold. The ore was relatively low grade but was easily mined, and a fair saving is said to have been made by stamping and amalgamation.

The country rock is the Hasmark formation, which, on the slope of the hill below the mine, dips from 40° to 60° W. The average strike of the lode is N. 80° E., and it dips from 60° to 85° S. A narrow vein 30 feet north of the main lode is approximately parallel to it in dip and strike. Veinlets of nearly pure calcite up to 4 inches wide, apparently later than the ore, cut the lode at large angles.

All the ore appears to have been taken from the south lode, which is a replacement vein of variable width. One hundred feet below the adit level it appears to have considerable width, but at the time the mine was visited only a little work had been done at the level. The ore is oxidized throughout the mine and is composed chiefly of hematite, limonite, and quartz. The original ore appears to have been a siliceous pyritic replacement of the country rock, as is shown by pseudomorphs of iron oxide after pyrite and by nodular masses of limonite with pyrite in the center.

MONTANA CLAIM.

The Montana claim is located in the valley of Flint Creek on Georgetown Flat, about one-fourth of a mile north of Georgetown. The principal developments consist of a shaft 104 feet deep, from which short drifts and crosscuts are run at depths of 50 to 100 feet. The country rock is Jefferson limestone, which strikes northward and dips toward the east. The lode is a crushed, mineralized, and almost completely oxidized zone of the limestone, striking nearly northwest and dipping about 45° NE. Where it is crosscut the lode is about 30 feet wide, and it is said to carry gold ranging from $2 to $20 a ton. The minerals present are quartz, calcite, pyrite, iron oxides, malachite, and azurite. A massive dark-gray copper mineral containing sulphur and antimony was also noted in the partly oxidized ore.

ORPHAN BOY MINE.

The Orphan Boy mine is a few rods east of the Southern Cross mine. Several shafts about 50 feet deep are sunk on limonite outcrops, which carry low contents of gold. Some of this ore has been treated in the Glenn mill, on the road from the Southern Cross mine to Georgetown.

ALMADEN CLAIM.

The Almaden claim is a few rods east of Georgetown at the contact between granite and limestone. A number of trenches and shallow pits are sunk in decomposed iron-stained limestone.

WAR EAGLE CLAIM.

The War Eagle claim is located southeast of Georgetown Lake, about 1 mile S. 58° W. of the Gold Coin mine and 200 feet above Georgetown Flat. A tunnel about 150 feet long has been driven on the vein and near the portal a shallow winze has been sunk in oxidized ferruginous quartz locally stained with copper. The vein strikes eastward and dips toward the south. It cuts across the bedding of the limestone, which near the mine strikes a little east of north and dips westward.

RELIANCE CLAIM.

The Reliance claim is situated on the south slope of the low ridge just north of Georgetown. A tunnel 182 feet long has been driven in the Jefferson limestone on a vein striking N. 6° W. and dipping steeply westward, and a shallow winze has been sunk from the tunnel level. The claim lies just west of the granite contact and is rudely parallel to it. The deposit is along a fissure which appears to be a fault, for the hanging wall is a sugary white or light-gray limestone and the footwall is more compact and darker. Gouge lies along the fissure, though not in great amount, and locally the country rock has been replaced by quartz. Small fragments of quartz containing flakes of free gold have been found in the brecciated rock along the fissure.

GOLDEN GATE GROUP OF CLAIMS.

The Golden Gate group of claims comprises the Golden Gate, Black Diamond, and Sirton, which are situated just north of the Cable mine. These have been extensively explored through a vertical shaft, which could not be entered in the autumn of 1906. An adit connected with the shaft was accessible for about 400 feet. It is driven on a faulted and slickensided contact between limestone and granite, which strikes N. 60° W. and dips steeply northward. Apparently the property has not been worked for many years. No ore was seen.

PYRENEES MINE.

The Pyrenees mine is situated a few rods northeast of the Luxemburg mine and half a mile southeast of Georgetown. It was discovered in the early seventies and was an important producer of gold in the late eighties. It has been worked through several tunnels close to grass roots and through a vertical shaft about 265 feet deep. All workings are now inaccessible. The mine is credited with $125,000 in 1887 and 1888, when a 10-stamp mill was in operation. According to Mr. Clinton H. Moore, of Butte, its gold production has amounted to about $250,000.

The country rock is granite, and the outcrop of the lode is concealed by surface débris. Near the surface the ore was oxidized, but heavy sulphide ore was encountered below. The principal vein strikes N. 30° E., dips westward, and is from 1 to 12 feet wide. Several smaller veins were encountered in the mine but were not extensively explored. Apparently the Pyrenees vein was the source of some of the gold of the Georgetown placer diggings.

LUXEMBURG MINE.

The Luxemburg mine is situated half a mile S. 25° E. of Georgetown, and about 400 feet above Georgetown Lake. It was discovered in 1875 by Salton Cameron, who, according to Mr. H. C. Bacorn, took out about $12,000 worth of ore, and it is now owned by Laribee Bros. and Mrs. Mary Kelly, of Deer Lodge, Mont. In 1905–6 it was under lease to Bacorn Bros. and produced about $8,000 worth of gold.

The mine is exploited through an adit tunnel and two shallow shafts, and about 700 feet of galleries are accessible. The country rock is granite, and the deposits are fissure veins of irregular width. The ore consists of quartz, calcite, pyrite, iron oxides, and gold. Most of that which has been exploited is highly oxidized. The adit crosscut is 275 feet long and crosses five narrow veins striking east of north (fig. 49). The veins dip westward at varying angles, and two of them intersect a short distance below the surface. The largest ore body, which occurred at this intersection and extended below it on both sides, was shaped in cross section like the top of the letter A. Its maximum width was about 7 feet, and the average value about $30 to the ton. Away from the intersection the vein was smaller and not so rich. Considerable granite is mixed with the ore, and the country rock is sheeted along planes parallel to the vein.

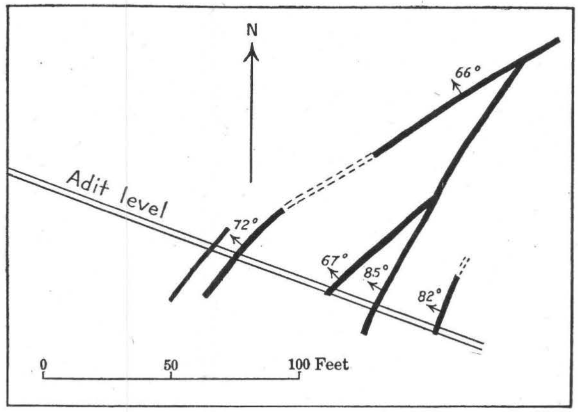


FIGURE 49.—Plan of adit level, Luxemburg mine; width of veins approximate.

BLACK MOON CLAIM.

Considerable work has been done on the Black Moon claim just east of the Luxemburg. An incline has been sunk and hoisting machinery installed, but the workings were inaccessible in the autumn of 1906. According to Mr. Eugene Sifton, of Philipsburg, the vein is about 18 inches wide, is composed of quartz and pyrite, and carries a small content of gold.

SILVER REEF MINE.

The Silver Reef mine is situated 1,600 feet north of and about 400 feet above Silver Lake. It was discovered by Mr. N. Walters in 1884 and soon afterward was sold by him for $50,000. Preparations were begun for active development of the property, but before they were consummated the purchaser died, and little or no work has been done on the property since. It is said to have produced about 14,000 ounces of silver and $1,000 gold. Most of this ore was shipped to smelters in Butte and Omaha, but a small amount was worked in an arrastre on Warm Spring Creek below the mine. The main workings consist of two shafts, each about 40 feet deep, connected below by a gallery about 150 feet long, sloping eastward. An adit 100 feet long connects this level with the surface. Altogether about 300 feet of workings have been driven on the ore body. The country rock is a grayish impure limestone containing thin argillaceous beds. It has a general dip of about 20° SW. Closely folded rock is indicated by a considerable variation of dip and strike in the neighborhood of the mine. The main ore body is a rudely tabular replacement of the limestone about 6 feet thick and cuts across the bedding planes, dipping about 5° E. It is joined by a nearly vertical vein which strikes N. 40° E. Quartz with subordinate amounts of dolomite and calcite constitutes at least 98 per cent of the ore. Galena and gray copper are the principal sulphides present, and associated with them is a black, sooty silver mineral, probably argentite. The sulphides, though sparingly present, are rich. Selected ore runs several hundred ounces of silver to the ton, and a fair proportion of the ore appears to be within the workable limit. A little malachite and chrysocolla are present. Some of the ore is a breccia of reddish-brown quartz and dolomite cemented by milky-white quartz.

OKOREAKA MINE.

The Okoreaka mine is situated three-eighths of a mile N. 50° W. of the summit of Silver Hill at an elevation of 7,600 feet. It is in the Maywood formation, which consists of limestone with thin argillaceous layers. On the top of the hill and along the crest of the ridge to the west calcareous rocks are more or less metamorphosed and contain tremolite, diopside, and other contact-metamorphic minerals. At the mine the limestone strikes N. 5° E. and dips 32° W. The lode is a tabular body of ore parallel to the bedding (fig. 50). The workings consist of an incline driven down the dip of the ore body and short drifts about 75 feet below the surface on the ore. Below 100 feet the shaft is under water. Little or no stoping has been done above the water level, though the mine is said to have produced several thousand ounces of silver, which was recovered in an arrastre on Warm Spring Creek, below the mine.

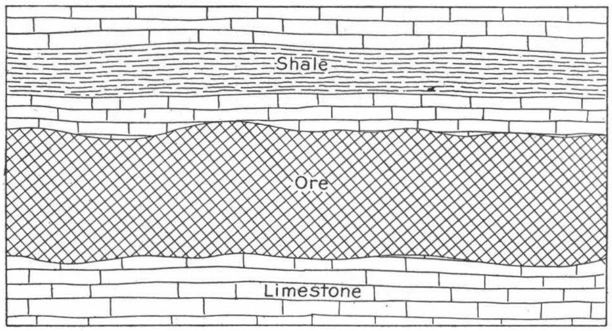


FIGURE 50.—Section on the strike of the deposit of the Okoreaka mine.

The sulphides are galena, pyrite, and gray copper, which are sparingly distributed through a quartz gangue. The metalliferous minerals of the oxidized ore are limonite, malachite, azurite, chrysocolla, pyromorphite, and probably lead carbonate. The values are chiefly silver, and the ore is said to be rich. The ore closely resembles that of the Silver Reef, but the ore body conforms more closely to the bedding of the country rock.

SILVER HILL MINE.

The Silver Hill mine is situated on the south slope of Silver Hill less than 100 feet below its summit. The workings consist of two shallow shafts, only one of which was accessible in the summer of 1906. The country rock is the limestone of the Hasmark formation and shale of the Red Lion formation, which strike N. 35° E. and dip 26° NW. The ore body exposed is a bedding-plane replacement deposit from 1 to 4 feet thick and occurs in the limestone just below shale. The gangue minerals are quartz and calcite stained with copper carbonates and iron oxides. Some of the ore appears to have been brecciated and later recemented by white quartz.

SILVER MOSS MINE.

The Silver Moss mine is situated on the north slope of Silver Hill about 200 feet above Silver Lake. It is said to have produced a small amount of rich ore, but like the other mines of Silver Hill it has been idle for many years. Two shallow shafts have been sunk on the lode. The country rock is limestone, which dips about 20° W. The ore occurs as very irregular bunches along an ill-defined fissure zone, which as a whole strikes southeastward. The character of the stopes seems to indicate that the ore extends from the fissure into the bedding planes of the limestone just below an argillaceous layer. It is a replacement body but, like the Okoreaka, contains fragments of brecciated limestone. The ore is very siliceous, the metalliferous minerals constituting only a very small portion of the mass.

ONTARIO MINE.

The Ontario mine, which is situated on the Georgetown Flat about one-third of a mile northwest of Georgetown, is said to have produced several thousand dollars' worth of silver. In the summer of 1906 it was inaccessible. Except for an abundance of barite, the ore on the dump is in many respects similar to that of the Silver Reef and Okoreaka mines.

RED LION MINE.

The Red Lion mine is situated at the head of Flint Creek, on the west slope of Red Lion Mountain, at an elevation of about 8,000 feet. It was worked in the late eighties, when the ore was treated in a 10-stamp amalgamating mill, and for a time the mine is said to have been profitable in spite of the low saving made. According to Mr. George Savage it has produced $38,000 gold. Two shafts 350 feet apart have been sunk on the ore body. One of these is 180 feet deep, and in it drifting has been done at two levels, but in the summer of 1906 the workings were inaccessible. The other shaft has been sunk about 100 feet, and considerable stoping has been done near the surface. Most of the workings from this shaft are caved.

The mine is in limestone about 2,000 feet south of the border of the Philipsburg batholith. Certain beds just above the mine openings contain considerable amphibole and other metamorphic minerals. The ore body is a rudely tabular mass which dips about 73° SE., approximately with the bedding of the limestone. It is a replacement vein from 2 to 4 feet wide, and according to Mr. N. B. Gillis, who sampled the mine in 1905, carries from $5 to $20 in gold. The minerals of the ore are quartz, calcite, pyrite, limonite, specularite, and magnetite. Nodular masses of iron oxides contain pyrite in the center, and pseudomorphs of hematite after pyrite are common. The original ore contains considerable pyrite. Specular hematite, or specularite, occurs in flakes or rosettes and is, like pyrite, original.

HANNAH MINE.

The Hannah mine is situated on the west slope of Red Lion Mountain, 1,000 feet N. 30° E. of Red Lion mine and probably on an extension of the same fissure. It is the property of the Milwaukee Gold Extraction Co., which has recently erected a mill on Flint Creek 750 feet below the mine and has constructed a 3,800-foot gravity tramway between the mine and the mill. The treatment is by amalgamating and cyaniding. According to the manager, Mr. George Savage, the mine has produced about $15,000 worth of gold.

The mine is operated through an adit, which cuts the ore body 220 feet from the portal. A shaft sunk in ore connects with the adit 120 feet below the surface. In the autumn of 1906 this shaft was being extended below the adit level, and a gasoline hoist was installed to raise the ore.

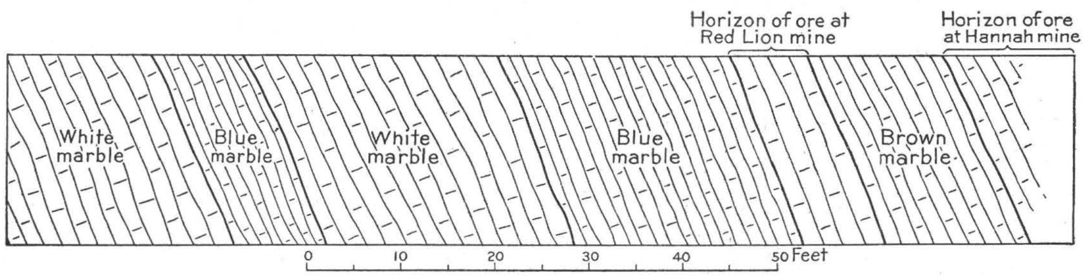


FIGURE 51.—Partial section of lower limestone in Hasmark formation, showing the ore horizons at the Red Lion and Hannah mines.

The country rock is magnesian limestone of the Hasmark formation, which strikes N. 30° E. and dips from 65° to 75° E. The ore resembles that of the Red Lion mine and consists chiefly of partly replaced limestone carrying quartz and iron oxides. On the adit level the plan of the ore body is rudely elliptical about 30 feet wide and 40 feet long; the longer axis conforms approximately to the bedding of the country rock and to the strike of the Red Lion vein. Four fissures striking northwestward are visible in the walls of the stope, and apparently the ore body is a swelling of the Red Lion vein at its crossing with other fissures. The relations of the ore body to the bedding at the Red Lion mine and at the Hannah mine are shown diagrammatically by figure 51, which is a partial section of the Hasmark formation. The ore horizons are only 14 feet apart stratigraphically, though the places observed are 1,000 feet distant from each other. The vein therefore cuts the bedding of the country rock at a very small angle.

MODOC AND AMERICAN FLAG CLAIMS.

The Modoc and American Flag claims lie north of the Hannah mine on the saddle between the valleys of Flint Creek and Warm Spring Creek. Several prospects are opened on these claims by shallow shafts, short tunnels, and trenches, and some ore has been milled in an arrastre at the head of Warm Spring Creek below the mine. A crosscut tunnel several hundred feet long has been driven westward from the Warm Spring Creek side to reach the ore in depth, but this was inaccessible at the time the mine was visited. The border of the Philipsburg batholith passes through these claims, and the deposits are in the limestone near the contact. The limestone is changed to marble and locally contains white mica, tremolite, and other minerals of contact-metamorphic origin.

Two shallow shafts have been sunk on limonite outcrops that carry some gold. One of them is on a fissure having approximately the same strike as the Red Lion vein and nearly in line with it. An open cut in limestone a few rods to the east shows bunches of copper oxides and carbonates associated with barite and quartz.

On the Modoc claim, the granite near its contact with limestone is impregnated with iron and copper sulphides. The altered zone is from 30 to 75 feet wide, strikes N. 40° E., and is exposed in places for a distance of several hundred feet. This zone of altered granite grades into the normal fresh granite on the west. Some specimens show relatively fresh quartz and orthoclase, surrounded by large crystals of calcite. In some specimens one-third of the rock is calcite, which contains small crystals of pyrite, chalcopyrite, and bornite.

This facies of the border of the batholith is uncommon. At many other places the granite at its contact with limestones has its normal composition and contains little or no calcite. The copper and iron sulphides present are more or less irregularly distributed through the rock just described but locally exceed 2 per cent of the mass. They are said to carry some gold, and the owner believes that the deposit may yield concentrating ore.

MONTANA MINE.

The Montana mine is on the crest of the saddle between Red Lion Mountain and Cable Mountain. The lode is in quartzite of the Spokane formation, strikes S. 57° E., and is nearly vertical. A shaft sunk to a depth reported to be 100 feet was under water below the 50-foot level. The lode is a sheeted zone from 1 to 2 feet wide, and where the fissures are closely spaced they form a breccia of quartzite, the fragments of which are cemented by quartz and pyrite. The ore mined is composed of quartz and oxidized pyrite carrying small flakes of gold. A small quantity of sorted ore has been shipped to the smelter, and a few tons of ore were run through a 3-stamp mill built by Patrick Dougherty about half a mile below the mine.

GREATER NEW YORK MINE.

The Greater New York mine is situated near the head of the valley of the west fork of Warm Spring Creek. A shaft inclined 52° from the horizontal is sunk to a vertical depth of about 100 feet, and three short crosscuts are driven from the station at the bottom of this shaft. The ore body, so far as developed, is a fracture zone striking northeastward and dipping southeast. In the mine the northwest wall is limestone of the Hasmark formation, and the southeast wall is shale of the Silver Hill formation. The ore consists of fragments and bunches of iron-stained auriferous quartz in abundant soft clay gouge, which has probably resulted from alteration of the crushed shale. The present workings do not show the width of the fracture zone but indicate that it is more than 20 feet wide. The minerals of the ore are quartz, pyrite, limonite, and magnetite.

YELLOW METAL MINE.

The Yellow Metal mine is situated at the head of the west fork of Warm Spring Creek, about 1 mile S. 55° E. of the summit of Red Lion Mountain. The workings include some 500 feet of drifts and crosscuts driven from two tunnels, one about 125 feet above the other. The country rock is quartzite of the Spokane formation and at the portal of the lower tunnel strikes N. 36° W. and dips 60° SW.

The vein is a sheeted zone in the quartzite. It cuts across the bedding planes, strikes about N. 88° E., and dips southward. The ore is composed of quartz and pyrite and carries free gold. A small amount of ore has been shipped.

NINETEEN HUNDRED MINE.

The Nineteen Hundred mine is situated 1.2 miles east of the summit of Red Lion Mountain, on the west slope of a steep ridge between the forks of Warm Spring Creek. It is said to have produced some $3,000 worth of gold ore, which was treated at Georgetown. The workings consist of about 500 feet of drifts and crosscuts. The country rock is siliceous shale or calcareous sandstone of the Spokane formation, which near the portal of the tunnel strikes N. 79° W. and dips 20° S. The lode is a narrow sheeted zone, apparently a fault fissure. Its average strike is nearly east and it dips 50° S. The ore is iron-stained quartz locally carrying pyrite and at some places cementing broken fragments of the country rock.

ST. THOMAS MINE.

The St. Thomas mine is about 200 feet north of the Nineteen Hundred mine. The ore body is reached by a crosscut tunnel 150 feet long, from which a 50-foot drift is run on the vein. From this drift the ore is followed by a raise and a shallow winze. According to Mr. Thomas Heffern, the owner, the mine has produced several thousand dollars' worth of gold ore, which was smelted in Anaconda and Butte. The lode cuts across the bedding planes of the country rock, strikes N. 79° E., and dips 47° S. It is a very narrow fissure filling, said to carry much gold. The ore is composed of quartz and iron oxides containing specks of free gold.

ROBINSON MINE.

The Robinson mine is situated on the west slope of the valley of the west fork of Warm Spring Creek, 2 miles S. 15° W. of the summit of Red Lion Mountain. An inclined shaft 80 feet deep is sunk on the lode, and a tunnel is driven about 150 feet below to explore the vein in depth. The workings include several hundred feet of drifts and crosscuts. The country rock is quartzite dipping 60° NW., and the lode is a relatively narrow sheeted zone striking S. 40° E. The ore consists of quartz and pyrite and is said to carry both gold and silver. When this mine was visited in the autumn of 1906 a small amount of ore had been taken to the Dougherty mill for experimental treatment.

CLAIMS SOUTHWEST OF RED LION MINE.

On the northwest slope of Cable Mountain, between the Red Lion mine and the Golden Eagle mine, a number of shallow pits, shafts, and short tunnels have been driven in ferruginous decomposed limestone. The rocks in this area are complexly faulted Cambrian sediments with a general northeasterly strike. Those of sufficient throw to be mapped cut across the strike of the beds, and the directions of most of them range from west-northwest through east-west to about east-northeast. No extensive ore bodies have been opened.

GOLDEN EAGLE MINE.

The Golden Eagle mine is situated on the west slope of Cable Mountain about 3 miles northeast of Georgetown and is connected with the Flint Creek wagon road by a steep zigzag trail about half a mile long. The property has been prospected for a number of years and some rich ore has been found, but only a small amount has been shipped. The country rock is the Flathead quartzite, which dips steeply northwestward. A crosscut tunnel, 900 feet long, has been driven southeastward to several veins supposed to have supplied a considerable amount of rich float found in the slide rock on the west slope of Cable Mountain. The four narrow veins which this tunnel cuts strike northeastward nearly parallel to the bedding of the country rock but dip eastward across it. The ore is composed of quartz, pyrite, and iron oxides. The veins, where they are cut by the tunnel, are not of workable size and grade. In 1905 some very rich ore was found on the surface, about 100 feet below the main tunnel, at the contact between the quartzite and shale and in the quartzite near by. This occurrence has been prospected superficially in two or three places by narrow pits and short tunnels, and a small amount of ore has been shipped. Near the contact between the shale and quartzite are bunches of blue quartz carrying flakes of gold. According to Bohm [1] this ore contains

[1] Bohm, W. D., The Cable Mountain gold mining district of Montana: Min. Mag., vol. 13, 1906, pp. 373-380.

also silvanite and a sulphur-tellurium compound of bismuth. Tourmaline fills the joint planes of the quartzite near the contact, and sprinkled liberally through it are flakes and specks of gold, some of which are as big as No. 6 shot. The zone in which free gold is found can be traced some distance southwest from the prospect pits. The quartzite is a clean quartz sand cemented with silica, and the small crystals of tourmaline replace both the cement and the original grains. A little pyrite or iron oxide is present in most of the ore. The visible gold seems to be confined to joint planes and to the vein quartz near the contact with the shale, not appearing in the quartzite itself. The exact relations of the ore to the quartzite and shale contact could not be made out, but surface indications suggest the presence of a fissure at or near the contact and appear to warrant further prospecting.

FLINT CREEK MINE.

The Flint Creek mine is on the west slope of Cable Mountain about 1,500 feet northeast of the Golden Eagle mine. Several crosscut tunnels have been driven southeastward, the principal one being about 1,000 feet long. The mine is said to have produced several thousand dollars' worth of ore, which was hauled out by wagon and treated at the Gold Coin mill, south of Georgetown. A number of narrow veins were cut, and some have been stoped. All are either narrow fissure fillings or sheeted zones in quartzite. They vary in strike from N. 6° E. to N. 50° E., and dip at a considerable angle with the bedding. Near the portals of the tunnels the steep slope of Cable Mountain is covered with slide rock, mainly quartzite, but at many places rich quartz float shows specks of free gold; some of this material was sorted from the barren slide and milled at the Gold Coin mill. The long crosscut tunnels were driven to find the veins from which the rich float came, but the results were disappointing, because the veins encountered were too small to be worked profitably. At the entrance to the lower tunnel black shale of the Silver Hill formation appears, and the position of the contact between the quartzite and the shale can be estimated within a few feet. In view of the relations at the Golden Eagle mine, it would seem worth while to trench this contact, for if it is a mineralized fissure the fact could be cheaply established.

NORTHERN CROSS MINE.

The Northern Cross mine is located at the head of the east fork of Warm Spring Creek on the south slope of the divide between the Racetrack Creek and the Warm Spring Creek drainage basins. The property consists of a group of several claims, among them being the Anna, Maude, and Caledonia.

The country rock is quartzite, calcareous shale, or impure limestone. In the lower tunnel these beds are well exposed. A fault traced for considerable distances northeast and southwest of the mine has been extensively prospected from a shaft and two tunnels. In the mine it strikes a few degrees east of north and dips steeply eastward. At some places it is mineralized for a width of 1 to 3 feet. The ore is quartz and oxidized pyrite and according to Mr. S. R. Slosson, of Anaconda, carries several dollars to the ton in gold.

CHAPTER XVI.

MINES IN THE AREA BETWEEN CABLE AND ANACONDA, AND SOME OUTLYING MINES.

GENERAL FEATURES.

Small mines and prospects showing metalliferous ores occur here and there over a large area of mineralized country in the basin of Warm Spring Creek and its tributaries and at the headwaters of Lost Creek, but they are not so closely spaced as in the more highly mineralized country near Philipsburg and Cable. The general character of the mineralization with respect to geographic distribution of deposits is somewhat similar to that in the basin of Boulder Creek and its tributaries, but gold predominates in the latter and silver is the principal metal of the deposits on lower Warm Spring Creek. The only mine of this group which has produced much ore is the Blue-eyed Nellie, just north of Brown's siding, from which several hundred thousand dollars in silver was taken. The Antelope, Chain, Welcome, and several other mines have produced some ore, but so far as could be learned none of them has yielded as much as $50,000. Very few of these mines were accessible when they were visited in 1906 and none of them had been actively worked for several years. A forest fire had devastated the country around the Blue-eyed Nellie mine and a large number of shaft houses had been burned away and the shafts filled with débris. Such information as could be gained was from outlying workings of subordinate importance.

On the slope to the northeast of Warm Spring Creek the prevailing rocks are sedimentary. For the most part they are Paleozoic limestones, complexly faulted and in places closely folded. They are intruded by granites and basic igneous rocks which locally have caused considerable contact metamorphism. Nearly all the ore bodies are argentiferous replacement deposits in calcareous rocks. Some are thin tabular bodies, which follow the bedding planes, but most of them appear to be chimneys or pockets of very irregular shape. The Morgan Evans vein is a fissure filling in basic diorite, and the Black Chief iron mine is a contact-metamorphic deposit of magnetite.

In the high country south of Warm Spring Creek and at the head of the drainage of the East Fork of Rock Creek a few scattered prospects show metalliferous deposits, but practically no ore has been produced and not many locations have been made. Considerable work has been done at the Carp mine, near the west end of this area, and in the southwest corner of the quadrangle.

MINES OF WARM SPRING CREEK AND TRIBUTARIES.

BLUE-EYED NELLIE MINE.

The Blue-eyed Nellie mine is on the ridge east of Olson Gulch, 1¼ miles north of Brown's siding. In the eighties this mine produced considerable rich ore with a comparatively small amount of development. The country rock is a marmarized limestone of the Hasmark formation, locally of very coarse grain. The mine was inaccessible in 1906, the shaft having been destroyed by fire. The dump indicated that the ore is a siliceous replacement of limestone. The ore minerals noted are galena and gray copper and their oxidation products.

MAYFLOWER CLAIM.

The Mayflower claim is in the valley of a small tributary of Olson Gulch, about 2 miles above Warm Spring Creek. The lode is a crushed zone in granite, contains quartz and pyrite, and is said to carry gold. A tunnel is driven northwestward on the lode for 175 feet. At a lower level a 600-foot tunnel has not encountered the lode.

GREY ROCK CLAIM.

The Grey Rock claim is about one-fourth mile northeast of the Mayflower. About 350 feet of work has been done from a tunnel driven northeastward across a contact of Madison limestone with granite. Near the contact the limestone contains considerable magnetite, garnet, and diopside. Subsequent to the metamorphism of the limestone the granite and the limestone were fractured near the contact. The granite in the fractured zone is said to carry gold.

BLACK CHIEF IRON MINE.

The Black Chief iron mine in Olson Gulch, about 2 miles above Warm Spring Creek, is a deposit of magnetite replacing Madison limestone near granite. Garnet, actinolite, mica, and other contact-metamorphic minerals are associated with the magnetite. Several thousand tons of iron ore mined from an open cut were shipped for flux.

CAMERON MINE.

The Cameron mine, near the summit of the low ridge between Olson Gulch and Warm Spring Creek, is said to have produced several thousand dollars' worth of highly siliceous silver ore. A number of pits and shallow shafts are sunk in limestone to exploit pockets of lead-silver sulphides which carry a small amount of copper.

ANTELOPE AND CHAIN MINES.

The Antelope and Chain mines are situated on Olson Gulch, about 3 miles above Warm Spring Creek. These two mines, which were not accessible in 1906, are said to have produced about $60,000 worth of silver ore in the late eighties. The country rock is limestone, and judging from the ore on the dumps the deposits resemble those of the Blue-eyed Nellie mine.

MORGAN EVANS CLAIM.

The Morgan Evans claim, which is in Olson Gulch, a few rods southwest of the Antelope mine, has been developed by two tunnels, one above the other, comprising in all about 600 feet of work. The country rock is basic diorite. The vein is a simple fissure filling which strikes N. 73° W. and dips about 80° N. It is about 3 feet wide and is composed mainly of white quartz, with here and there small bodies of pyrite, chalcopyrite, and bornite. About 100 feet from the portal the vein is faulted and offset some 15 feet to the north.

GEORGE MINE.

The George mine is near the summit of the high ridge between Foster Creek and Lost Creek, about 2 miles northeast of the Silver Chain mine. The country rock is dolomite of the Hasmark formation, which dips from 20° to 40° S. Several short tunnels and inclines have been driven to explore pockets of siliceous silver-lead ore which lie approximately with the bedding of the country rock.

JETTY MINE.

The Jetty mine is on the south slope of Warm Spring Valley, 1 mile above Brown's siding. An incline is driven southwestward 175 feet at an angle of 35°, and from this stopes are carried short distances. The deposit is a tabular body of siliceous silver ore lying approximately with the bedding, and is situated near the top of the Madison limestone.

NEW YEAR MINE.

The New Year mine, known also as the Emma, is on the west slope of a ridge west of Foster Creek, about 3½ miles east of Cable. This mine has been worked now and then for about 10 years, and several thousand dollars' worth of ore has been shipped. The country rock is dolomite of the Hasmark formation, which dips northeastward at high angles and is disturbed by faulting. The ore body is a tabular mass from 1 to 6 feet wide which lies approximately with the bedding. An incline is sunk on the lode to a depth of about 100 feet, and stopes are carried from it on either side. The ore, which is highly siliceous, contains gray copper and galena and is similar to that of the Blue-eyed Nellie mine. A small smelting furnace was built on a tributary of Warm Spring Creek below the mine, but it has never been in successful operation.

WELCOME MINE.

The Welcome mine, on the west slope of the ridge between Warm Spring and Foster creeks, about 1½ miles north of the New Year claim, is said to have shipped several thousand dollars' worth of ore. The country rock is Jefferson limestone, somewhat marmarized, and dips about 7° N. Shales outcrop about 250 feet above the mine. A tunnel is driven southeastward about 500 feet and several shallow winzes and raises are turned from it. When the mine was visited in 1907 much ice had formed in the tunnel and most of the workings were unsafe. The ore occurs as pockets in the fractured limestone and consists of quartz, zinc blende, gray copper, and silver-bearing galena, stained here and there with copper carbonates and pyromorphite.

SILVER KING MINE.

The Silver King mine, on the south slope of the ridge north of Lost Creek, is said to have produced a small amount of rich ore. Two shallow inclines are connected by a level turned a few feet below the surface. The country rock is dolomite of the Hasmark formation, and the principal deposit is a lode, which dips steeply southeastward. The ore is composed of quartz, galena, gray copper, and a sooty black sulphide which carries silver and copper.

SILVER QUEEN MINE.

The Silver Queen mine is on the north slope of Lost Creek canyon, about 2 miles below the Silver King. The lode strikes northeastward and outcrops conspicuously at the surface. The country rock is impure gnarled limestone of the Newland formation. The lode is a sheeted zone in the bedding planes about 20 inches wide and consists largely of crushed limestone, partly silicified. Near the walls are several inches of iron-stained quartz, presumably auriferous. A crudely constructed tramway was built to convey the ore to Lost Creek, where it was worked in a small Huntington mill operated by a water wheel. There is no evidence that much ore was treated.

CARP MINE.

The Carp mine is situated in the southwestern part of the quadrangle about 2 miles northeast of Carp Lake, on the south slope of a very steep canyon drained by a fork of Rock Creek. According to D. F. MacDonald, who visited the mine in 1907, about 1,000 feet of work has been done in drifts and crosscuts. The country rock is dolomite of the Hasmark formation, which strikes N. 20° E. and dips 50° W. The lode is a zone of shattered limestone, silicified and somewhat brecciated, which strikes N. 30° E. and dips 55° E. The ore consists of white quartz and silicified limestone stained with copper carbonates and carries a little pyrite and copper glance. The richest ore, according to Mr. MacDonald, is near a crosscutting body of quartz porphyry encountered in the tunnel about 200 feet from the portal. A few small shipments of ore have been made, but apparently the mine has not been worked for some time. A carload of ore was on the dump awaiting shipment.

MINES OF BOULDER CREEK AND TRIBUTARIES.

GENERAL FEATURES.

A number of mines and prospects are situated in the basin of Boulder Creek, which joins Flint Creek near Flint station. The camp known as Princeton on Boulder Creek, about 6 miles by wagon road above Flint, was at one time the center of considerable mining and prospecting activity, but in the autumn of 1906 the mines were not being vigorously exploited and not more than 40 men were employed in the entire district. The boundaries of the mineralized area are not definite, but the deposits occur here and there throughout a broad area. The country is a mountainous area of steeply tilted sedimentary rocks ranging in age from Algonkian to Mesozoic, all cut by intruding biotite granite. The sedimentary rocks are extensively faulted, and in places the granite is involved in the faulting movements.

The deposits are fissure veins inclosed in granite and in sedimentary rocks. Most of the veins outcrop on the surface. Quartz float and outcrops of quartz are distributed here and there over a large portion of the area. The fissures vary greatly in dip and strike and do not fall into well-defined groups. The Royal, Sunday, and Tussle veins strike eastward; the Gold Hill vein strikes northward; the Albion veins strike northwest. The lack of parallelism for this group of veins is the more noticeable when contrasted with the systematic arrangement of the veins near Philipsburg, Granite, and Tower.

The veins now accessible are chiefly in granite, in siliceous Algonkian rocks, and in Carboniferous or Mesozoic quartzites and impure limestones. In such rocks the veins are fissure fillings, and in general the wall rock along them is not rich enough to work. The Gold Hill vein, the Jefferson vein, and some of the silver veins near Princeton, which occur in relatively pure Paleozoic limestones, are in part replacements of the wall rocks; but these veins where developed are for the most part inaccessible, and information concerning them is meager. Some of the veins, including those of the Powell and Tussle mines, were faulted after the deposition of the ore.

The metals of this group of deposits in order of their importance are gold, silver, lead, and copper. The Royal, Sunday, Bluebird, Gold Reef, and Gold Hill are gold-bearing veins and contain very little silver. The Nonpareil, Princeton, Tussle, Albion, Mountain Lion, and Goat Mountain veins are silver or silver-lead deposits, and generally carry a little gold. The Jefferson vein is a low-grade copper deposit. The principal sulphides of the gold ores are pyrite and galena; the silver ores carry also gray copper and zinc blende.

The total production of this group of mines, so far as it can be estimated, is between \$1,250,000 and \$1,500,000. The greater part of this amount came from the Royal mine.

ROYAL MINE.

The Royal mine is on a small tributary of Boulder Creek about 5 miles from Princeton. It was worked principally in the late nineties and is said to have produced nearly \$1,000,000 in gold. A 10-stamp amalgamating mill built near the mine in 1892 was in operation for several years. The mine was worked through five drift tunnels driven one above the other on the slope of the ridge, which rises steeply toward the east. The workings make up about 8,000 feet in length and consist almost entirely of drifts along the vein. In the summer of 1906 the mine was under lease and some ore was stoped from tunnel 3, but a large part of the workings was inaccessible.

The lode is a fissure vein striking about S. 65° E. and dipping 60° SE. The apex is at most places concealed by surface débris, and the lode was discovered through the presence of rich float on the hillside. The vein is from 4 inches to 2 feet wide, is composed of quartz, pyrite, and galena, and carries from \$8 to \$200 gold to the ton. Much of the better-grade ore is spongy quartz stained with iron oxide.

The country rock is granite and granite porphyry. In tunnel No. 2, about 500 feet from the portal, the drift cuts through a dike of granite porphyry approximately 75 feet wide, which strikes northwest and dips about 80° SW. The fissure is not mineralized where it cuts the quartz porphyry dike but carries ore on either side of it. The relations of the ore to the dike are shown by figure 52.

The fissure in which the vein was deposited is a fault of small throw. This is shown by the slight displacement of the porphyry where it is cut by tunnel No. 2, and also by the position of the contact in tunnel No. 1, about 173 feet lower. Other evidences of movement are the slickensided streaks of gouge present at many places in the vein. The movement along the fault was apparently normal, and the hanging wall was depressed not more than a few feet.

In the granite wall rock near the vein, biotite and feldspar are altered to calcite, sericite, and chlorite by the solutions that deposited the ore. The granite porphyry is also altered and contains much calcite and sericite. Metasomatic changes are greater in the feldspar and in the biotite phenocrysts than in the microcrystalline quartz-rich groundmass, and in some places the phenocrysts are completely replaced by pseudomorphs of calcite. Apatite remains unchanged.

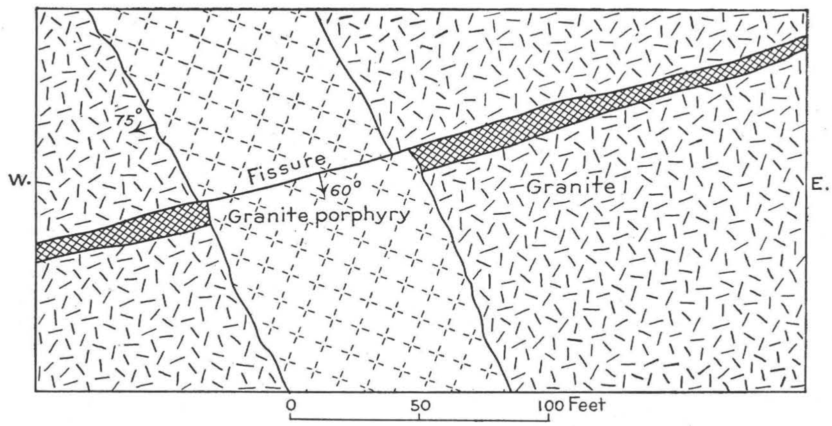


FIGURE 52.—Plan of Royal tunnel No. 2, 500 feet from portal.

The best ore was found in granite near the porphyry dike. The ore was rich on both sides of the dike and stopes were raised to grass roots. At this place the vein is about 4 feet wide. The fissure where it crosses the dike carries about 4 inches of low-grade gouge.

The granite porphyry was intruded into the granite before the fissure which carries the ore was formed. The conditions favoring deposition appear to have been physical rather than chemical. It appears that the solutions could not readily traverse the tight gouge in the fissure where it cuts the porphyry and that they were held in check or dammed back by it, so that they deposited a large part of their load near the dike.

SUNDAY MINE.

The Sunday claim side-lines the Royal claim on the north. The ore body, which was discovered in 1900 and worked actively in 1902, is reported to have produced altogether about $73,000 gold. An amalgamating mill built a few rods below the shaft house has treated several hundred tons of ore. The shaft, which is inclined 50° S., is sunk on the vein and is intersected by an adit a short distance below the surface. Near its intersection with the adit the lode is a sheeted zone in granite composed of three or four narrow parallel veins (fig. 26, p. 179). The country rock between the veins is more than half sericite. The adit follows the vein eastward for 940 feet, but for much of this distance the vein is not of stoping width and grade. In the level below, which was under water when the mine was visited, the vein is said to be about a foot wide and to carry high-grade gold ore.

TUSSLE MINE.

The Tussle mine, which is about 1 mile N. 25° E. of the Royal mine, was located in 1904 by Frank Wahlgren, and from 1904 to 1906 produced about $12,000 worth of ore. The deposit, a fissure vein in granite, strikes N. 87° W., dips 63° S., and is about 3 feet wide. An inclined shaft 160 feet long is sunk on the vein, and short levels are turned 22, 65, and 110 feet below the collar of the shaft. The 110-foot level was submerged when the mine was visited.

The unsorted ore carries about 30 ounces silver, $2 gold, 2 per cent copper, and some lead. It is composed of quartz, pyrite, galena, gray copper, and copper carbonates. Much sericite and some pyrite are developed in the wall rock and thin seams of sericite cut the vein quartz.

On the 65-foot level, 67 feet east of the shaft, a reverse fault striking S. 60° E. and dipping about 50° N., throws the vein about 1½ feet to the south. On the 22-foot level the same fault is 15 feet east of the shaft and offsets the vein 7 feet to the south.

BLUEBIRD MINE.

The Bluebird mine is on a tributary of Little Gold Creek about one-half mile northeast of the Sunday mine. A crosscut tunnel driven southeastward cuts the vein 320 feet from the portal. The vein is in granite, strikes nearly east, and dips about 50° S. It has a maximum width of about 2 feet and is composed of quartz, pyrite, galena, copper carbonates, and iron oxides. Its valuable content is mainly gold. Near the point where it is intersected by the tunnel the vein is cut by a fault striking N. 10° W. and dipping 65° E. The hanging wall has been depressed, causing a horizontal shift of the vein about 50 feet to the north. Higher on the hill a second crosscut tunnel is driven on this fault, and the vein is explored on both sides.

ALBION MINE.

The Albion mine is situated in Deerlodge Basin about 1 mile south of the Royal mine. Two tunnels are driven on two veins and altogether more than 1,000 feet of drifts have been run. The ore mined is for the most part too low grade to ship, and the production of the mine has not exceeded a few hundred dollars. The principal vein is in the quartzites and sandy or calcareous shales of the Quadrant formation, which dip about 80° W. The vein occupies a shear zone, which conforms approximately with the bedding planes of the rocks. It has been followed for about 800 feet and is from 1 to 3 feet wide. About 400 feet from the portal a dike of porphyry striking eastward ends abruptly at the vein. Since it occurs only to the east of the vein it has presumably been faulted by movement along the zone which the vein occupies. The minerals are quartz, limonite, malachite, chrysocolla, pyromorphite, pyrite, and gray copper, and the values are chiefly silver.

About 200 feet east of this vein and connected with it by a crosscut is another vein, which strikes S. 32° E. and dips 77° W. Its footwall is granite and its hanging wall calcareous shale. It is narrower than the west vein and has not been so extensively explored. The ore, which is not greatly oxidized, consists of quartz, fluorite, zinc blende, galena, and gray copper, and is said to carry about 20 ounces in silver and $2 gold to the ton.

GOLD HILL MINE.

The Gold Hill mine is situated about 1¼ miles southwest of Princeton on the north end of the ridge between Swamp Gulch Creek and South Boulder Creek. It was worked in the early nineties, and a few hundred tons of ore were treated in a small mill near Swamp Gulch Creek on the road between the mine and Princeton. Six shafts, none more than 50 feet deep, have been sunk on the vein, and stoping has been carried to the grass roots at several places along the line of the shafts. The country rock is blue limestone and dips steeply westward. The average strike of the vein is about north, and it dips from 70° to 85° W. The workings lie a short distance east of and parallel to a great fault shown on the geologic map. Where stoped the vein is from 2 to 6 feet wide. The ore consists of quartz, calcite, and iron oxide and is locally stained with copper carbonate. A little magnetite is present in some of the ore.

BLOOMINGTON MINE.

The Bloomington mine is one-half mile S. 50° W. of the Royal mine. A crosscut tunnel driven 875 feet southward intersects four narrow veins in granite which strike toward the northeast. Present development does not show them to be of stoping width or grade. The widest vein, 400 feet from the portal, is composed of quartz, pyrite, and galena. Small stopes have been raised here and there. A stamp mill was built near the mine in 1896, but it was operated only a few months.

TRAVONIA CLAIM.

The Travonia claim is situated on Boulder Creek, near Princeton. About 250 feet of drifts and crosscuts have been run from a tunnel some 200 feet above the stream. The country rock is gray cherty limestone, which, at the portal of the tunnel, strikes N. 40° W. and dips 55° NE. A vein encountered about 75 feet in from the portal strikes eastward and dips 68° N. The ore is composed of quartz, calcite, galena, zinc blende, chalcopyrite, iron oxide, and copper carbonates.

NONPAREIL MINE.

The Nonpareil mine is on Boulder Creek, 1½ miles above Princeton. It was discovered in 1886 and was actively worked from 1891 to 1893. According to the owner, Mr. P. F. Scherr, it has produced altogether about $50,000 in silver and lead. A shaft 280 feet deep is sunk on the lode, and levels are turned at 100 feet and 280 feet below the surface. The main shaft was inaccessible in the summer of 1906, but entrance was gained to a portion of the upper workings through an air shaft 120 feet northwest of the main shaft. The country rock is limestone, and the ore occurs along a fissured zone near the faulted contact of the Jefferson and Madison limestones. The country rock shows much brecciation, and the disturbed zone is said to have a maximum width of 120 feet. In this zone the rock is greatly altered and consists of iron-stained limestone and abundant soft clay, containing here and there nodules of galena and lead carbonate. Some of the ore is stained green with malachite. The nodules of galena were found within a few feet of the surface and are said to have extended downward to the bottom of the mine.

BROOKLYN MINE.

The Brooklyn mine, formerly known as the Pierre mine, is 2 miles above Princeton on the south slope of Pierre Hill. A 600-foot adit driven northward through limestone and shales intersects a porphyry dike 500 feet from the portal. This dike trends southeastward and is exposed in two shallow pits below the mine. The dike cuts across the Madison limestone, and garnet is developed near the contact. The porphyry of the dike is decomposed almost beyond identification and is crossed at many places by slickensided movement planes. The porphyry carries much pyrite and locally contains nodules and bunches of rich lead ore. The minerals present are quartz, barite, zinc blende, galena, gray copper, and lead and copper carbonates. Considerable ore has been mined from a shaft above the adit. This ore is presumably a deposit in limestone, but the workings were inaccessible when the mine was visited. An 80-ton shipment, made in 1907, averaged 37 ounces silver, 13 per cent zinc, 8 per cent lead, and 1.7 per cent copper.

POWELL MINE.

The Powell mine is on the southwest slope of Racetrack Peak, about 7 miles above Princeton. The vein outcrops at several places on the steep mountain slope. More than 2,500 feet of drifts and crosscuts have been run, mainly in two adit tunnels, one driven about 125 feet vertically above the other. Some ore has been shipped from the mine, but though great expenditures have been made for prospecting no profitable deposit has yet (1907) been discovered. The workings are in steeply tilted limestone of the Ellis formation and quartzite of the Quadrant formation, both of which have been metamorphosed by intrusion of granite and contain locally considerable diopside.

The vein is about 2 feet wide and is composed of quartz, gray copper, pyrite, and copper carbonates. It fills a fault along which there has been some displacement, and the ore contains numerous slabs of rock broken from the walls. Where free from waste the ore is said to carry about 60 ounces of silver and 3½ per cent of copper.

The vein is displaced at three places by northward-striking faults, which are best exposed in tunnel No. 2, about 125 feet above the lowest tunnel. Where first encountered in this tunnel the vein strikes S. 50° E. and dips 77° SW. At this place a winze is sunk on the vein to tunnel No. 1. Forty feet southeastward from the winze the vein is offset to the northeast by a fault which strikes northeast and dips 65° SE. Seventy feet farther on the strike of the vein a second fault, striking northeastward and dipping 80° SE., offsets the vein 140 feet to the northeast. Two hundred and thirty feet from the second fault the vein is displaced by a third fault, and it has not been found beyond this point. At those places where the vein furnishes a datum plane on either side of the faults, its positions indicate that the hanging-wall blocks were depressed.

GOLD REEF MINE.

The Gold Reef mine is situated on the east slope of the valley of South Boulder Creek at an elevation of about 6,700 feet. It is about 3 miles southwest of Princeton by trail and is connected by wagon road with Flint, a station on the Philipsburg branch of the Northern Pacific Railway, and with a mill on South Boulder Creek below the mine. The mine is opened by two tunnels, and the workings total about 1,500 feet, this figure including 900 feet of drifting on the vein. The country rock is of the Spokane formation and consists of red sandstones and shales dipping steeply northwestward. Siliceous sandstone predominates in the mine. The average strike of the vein is S. 50° E., and at most places it dips steeply southwest. The maximum width is about 2½ feet, and the walls are well defined. It is a fissure filling consisting of quartz and sulphides, and the siliceous wall rock shows little or no replacement by ore. The ore that has been mined is oxidized, and it contains gold. The outcrop of the vein carries less than the average amount of gold, but good ore was found within 20 feet of the surface. The minerals of the oxidized ore are quartz, iron and copper oxides, and copper carbonates. Pyrite and subordinate chalcopyrite are encountered in the lower levels. The ore contains small grains of magnetite, and a little specular hematite was noted on the dump.

OTHER MINES AND PROSPECTS NEAR BOULDER CREEK.

The Princeton mine situated at the junction of Princeton Gulch and Boulder Creek canyon was explored extensively through a deep shaft now under water. The deposit is said to be a silver vein in limestone.

The Mountain Lion mine, on the east slope of Princeton Gulch about 1¼ miles above the Princeton mine, is said to have produced about $3,000 worth of silver and lead. It is a sheeted zone in quartzite of the Quadrant formation. The lode strikes northeastward and dips a few degrees from the vertical toward the southeast. It has been stoped for about 30 feet along the strike.

The Bryan and Banker claims are on the south slope of Boulder Creek canyon, a few rods south of Princeton. Two narrow veins cutting across the bedding of limestone carry quartz, galena, lead carbonate, and zinc blende, and are said to have yielded about $1,000 worth of silver ore.

The Jefferson mine on Copper Creek, about 1¼ miles above Boulder Creek, has produced several hundred tons of low-grade copper ore carrying a high percentage of iron. On the surface, the vein strikes N. 67° W. across the Madison limestone and dips steeply toward the south. It was worked through two tunnels driven on the vein, both of which were for the most part inaccessible when the mine was visited in 1906. The deposit appears to have been formed by the oxidation of a vein carrying much iron pyrite and quartz and more copper than the other veins near it.

The Mayflower vein, about 900 feet south of the Jefferson mine, has been explored by a short tunnel, now caved, and a few tons of ore have been shipped. The dump indicates the ore to be similar to that of the Jefferson mine.

The Caroline and Iron Mountain claims are a short distance below the Brooklyn mine. Several short tunnels have been driven in iron-stained limestone which carries low values in gold.

The Rombauer claim is on Boulder Creek a short distance below Granite Creek. Garnet, actinolite, tremolite, magnetite, and pyrite have formed in limestone near a granitic intrusive, and small bunches of chalcopyrite and galena are said to occur in the metamorphosed limestone.

The Sixteen to One claim is in Deer Lodge Basin, about half a mile southeast of the Albion mine. The vein, which strikes southeast and dips 35° SW., approximately with the bedding planes of the Quadrant formation, is composed of quartz, pyrite, and chalcopyrite, stained here and there with copper carbonates.

The Goat Mountain vein, near the summit of Goat Mountain, is composed of ore similar to that of the Sixteen to One claim, but it strikes eastward, cutting the sandy rocks of the Ellis formation at a high angle.

PROSPECTS ON GOLD, SOUTH GOLD, AND PIKES PEAK CREEKS.

A number of tunnels have been driven to prospect quartz veins in the mountainous country at the head of the drainage of Gold Creek, South Gold Creek, and Pikes Peak Creek, near the northeast corner of the quadrangle. The country is very rugged and not easily accessible, and the ore is not rich enough for exploitation under the existing conditions. None of the deposits now developed have been worked at a profit. The placer deposits of Gold Creek have encouraged prospecting, but thus far the quartz lodes have been disappointing. The country rock is granite. In all the lodes deposition in open spaces is small. The ore so deposited consists in the main of quartz, calcite, pyrite, and chalcopyrite, though some of the veins carry zinc blende, galena, and gray copper. In places the granite wall rock has been greatly changed by the ore-bearing solutions, much more than have the walls of larger veins in the area near Philipsburg. Some of the granite is now only a felty mass of sericite, calcite, quartz, and pyrite, in which little evidence of the original texture remains. The replacing solutions deposited gold and copper sparingly, and these replacements, though of very low grade, may have contributed an important part of the gold for the placers in the streams below.

The John G. Carlisle mine, in the basin of Pikes Peak Creek on the east slope of Rose Mountain, was worked from 1897 to 1899, and according to Mr. W. A. Gilmer has produced about $2,500 worth of silver and gold. About 600 feet of work has been done from a tunnel which in the main follows a vein striking N. 55° W. and dipping 73° S. The country rock is granite. The principal vein is a fissure filling 3 to 12 inches wide, composed of quartz, galena, pyrite, zinc blende, gray copper, chalcopyrite, and copper carbonates. This vein is joined by several smaller veins which have been followed for short distances along their strike.

The Clear Grit claim is about one-fourth mile southeast of the Carlisle mine and several hundred feet below it. A shaft, through which it has been explored, is now inaccessible. The ore on the dump is quartz carrying considerable sericite, pyrite, and chalcopyrite. Some of the granite on the dump is greatly altered and is impregnated with pyrite, chalcopyrite, and bornite.

The Majestic claim is about one-half mile east of the Clear Grit claim. The vein is in granite, and is a foot or more wide. The ore is composed of quartz and pyrite stained with iron oxide, and according to Mr. W. A. Gilmer, one of the owners, it carries on the surface up to $30 gold. Several shallow pits are sunk on the lode, and a crosscut tunnel 200 feet long has been driven to cut it in depth, but when the mine was visited this tunnel had not yet reached the lode. The walls of the tunnel are granite, in places greatly decomposed. The altered granite is cut by many small quartz veinlets, and much sericite and pyrite have been developed in the granite, presumably by the solutions that deposited the quartz veinlets. According to Mr. Gilmer the altered granite carries a little gold.

The Queen lode is on the west slope of Pikes Peak, about 1 mile southeast of the Majestic claim. About 250 feet of work has been done on a sheeted zone, in crushed and altered granite containing bunches of ore made up of quartz, barite, galena, gray copper, and copper carbonates. The values are in silver and lead.

The Ophir claim is about 1 mile S. 30° W. of the summit of Rose Mountain. A tunnel driven in altered granite is cut by several veinlets of quartz and pyrite said to carry gold.

The Eldorado claim is about one-fourth mile northwest of the Ophir. The deposit is a crushed and sheeted zone of granite and is said to carry gold. A tunnel has been driven about 200 feet on the lode.

On the dump at the Potosi shaft, about 500 feet north of the Eldorado, is a large quantity of granite which has been almost completely replaced by sericite, calcite, pyrite, and chalcopyrite.

The Morning Star claim is at the head of Gold Creek. A crosscut tunnel has been driven 600 feet to cut a vein said to carry gold and silver, but the workings were inaccessible in 1906.

CHAPTER XVII.

MINES IN THE NORTHERN PART OF THE PHILIPSBURG QUADRANGLE AND ON ANTELOPE CREEK.

MINES OF COMBINATION AND HENDERSON.

GENERAL DESCRIPTION.

Combination and Henderson are small mining camps near the north margin of the quadrangle between Flint Creek and Willow Creek. The sedimentary rocks in this area are all of Algonkian age and include extensive areas of both the Newland formation and the Spokane formation. The Newland formation consists chiefly of impure limestones with calcareous shales and massive calcareous argillites. It forms the bulk of Henderson Mountain and extends northward beyond Henderson Gulch to form the summit of Sunrise Mountain. It is the country rock for most of the deposits near Henderson.

The Spokane formation is composed of red and green shales and red and white quartzites. The upper portion of the formation is a comparatively pure quartzite composed of rounded grains of quartz and feldspar with a small amount of clayey material between the grains. This rock forms the long north-south ridge upon which Combination is situated and incloses the Combination vein. The sedimentary rocks are steeply tilted and faulted.

Granite porphyry is exposed as a dike on the north end of the Combination ridge about 1 mile northwest of the Combination mine. An irregular intruding body of granodiorite also forms a part of the north end of Henderson Mountain and is exposed on the north side of Henderson Gulch back of the Henderson mill. Where intruding igneous rocks have cut through the sedimentary formations the latter have been metamorphosed near the contact, with development of much diopside, epidote, tremolite, and magnetite, especially in the impure limestone of the Newland formation.

The ore deposits of known importance are confined to the sedimentary rocks. They are fissure veins in quartzite and replacement veins along fissures that cut limestone and calcareous shales. Some of them occur very near the intruding igneous rock and in the metamorphosed contact zone, but they are not contact-metamorphic deposits. Though most of the mineralized fissures follow the bedding planes of the country rock, they are not confined to them exclusively. Some of the lodes are very extensive along both dip and strike. The country rock has been faulted since the ore was deposited, and nearly all the lodes are displaced by normal faults of small throw, most of which strike northwestward. All the deposits are low grade. In the Combination deposits silver is the principal metal, but in the Henderson deposits the values are chiefly gold. Copper is present in small quantities in the sulphide ores, but the deposits have not been worked for this metal. The two camps have produced altogether about $1,650,000.

COMBINATION MINE.

Location and history.—The Combination mine is west of Henderson Mountain on the crest of the ridge between Smart Creek and Lower Willow Creek approximately 6,500 feet above sea level. It is about 12 miles northwest of Philipsburg, and the nearest railroad station is Stone, 10 miles away by wagon road. The mine was discovered in 1882 but was not exploited until 1885, when a few hundred tons of ore were put through the Hope mill at Philipsburg. That year the property was bonded for $25,000 to James A. Pack, who formed a syndicate and organized the Black Pine Mining Co. A 10-stamp mill was built on Willow Creek 1½ miles northwest of the mine in 1887 but ran only a few months, when the company became unable to meet its obligations and the property was sold at auction by the sheriff. A new syndicate formed to purchase the property later organized the Combination Mining & Milling Co., stockholders of the Black Pine Co. receiving pro rata allotments of stock in the new company. The new organization was controlled by C. D. McLure and other owners of the Granite and Bimetallic mines. In 1891, 10 additional stamps were added to the mill, and concentrating machinery and roasters were used to facilitate separation by pan amalgamation. Except for a few months both mine and mill were operated continuously from 1888 to 1897. In 1897 owing to the low grade of the ore and the low price of silver, operations were suspended. The gross production of the mine since the organization of the Combination Mining & Milling Co. is 2,135,000 ounces of silver and 1,411 ounces of gold, valued at $1,496,862. The cost of extraction was approximately equal to the receipts from the sale of bullion. The mine exploits a large, low-grade silver deposit which requires great skill in the treatment of the ore to pay a small margin of profit.

Development.—The mine was exploited through eight vertical shafts and three tunnels. The ore body is a large blanket deposit, and most of the openings are situated near the village of Combination on the crest of the ridge. The Lewis shaft, which cuts the ore body several hundred feet in depth and 960 feet from the Harrison shaft, is on the west slope of the ridge, near the road from the mine to the mill. It was designed to be used as the main working shaft, but the mine was closed down soon after it was completed and comparatively little rock was hoisted through it. Levels are turned at intervals of about 100 feet down the dip of the vein and have a difference in elevation of about 20 feet. A long incline is driven on the vein from a station near the bottom of the Harper shaft to the Harrison shaft, and another is driven from a point near the Harrison shaft to the Lewis shaft. The workings comprise in all about 12,000 feet of intersecting drifts, inclines, and crosscuts. When the mine was visited in September, 1907, the workings below level 14 were under water, but above this level a large part of the mine was accessible and in fairly good condition, considering the long period of its idleness. The method of milling the ore is described on pages 197–198.

Geology.—The only rock identified near the mine is the Spokane formation, composed of quartzite interbedded with red shale. The ore, so far as known, is confined to the quartzite members. The quartzite is either reddish-brown or gray and is the slightly metamorphosed equivalent of a medium-grained sandstone which contains a small amount of clay. Under the microscope the grains are seen to be well rounded and closely packed. Most of them are clear quartz, but a few are feldspar, chiefly microcline. Some secondary quartz has been added to the original quartz grains by circulating waters, and white mica or sericite has been developed from the clay between the grains of sand. Otherwise the sandstone has not been greatly metamorphosed, and at no place does it approach quartz-mica schist. The rocks strike about N. 30° W. and dip from 10° to 20° SW. No igneous rock occurs in the mine, and the nearest known intrusive is a granodiorite porphyry dike about a mile north of the Harrison shaft.

The country is traversed by a number of faults which cut across the ore and displace it. Many of these strike northwestward, following very closely the strike of the quartzite, but some of them cut across the strike approximately at right angles. The throw is at most places less than 35 feet. So far as known all the faults are normal. The character of the faulting is illustrated by figure 15, page 171, a cross section through the mine approximately down the dip of the vein.

Ore deposits.—The Combination lode is a fissure vein in quartzite and nearly everywhere conforms to the bedding of the country rock. At many places it is a simple fissure filling deposited in an open space along a single bedding plane, but here and there it is divided by large slabs of the country rock (fig. 53). The vein dips from 10° to 20° SW. and is from 6 inches to 4 feet wide. It is of unusual persistence and extent, for it has been explored along the strike for 1,000 feet and down the dip for about 2,400 feet. A second vein is said to have been encountered by diamond drilling about 500 feet below the Combination vein.

A great many of the drifts which follow the strike of Combination vein show at the breasts fair-sized faces of quartz or ore, and the mineralization appears to be exceptionally uniform and regular for a bedding-plane fissure. Evidence that the ore was deposited in open spaces, and is not a replacement of the country rock, is clear and unmistakable, for the contacts between the quartzite country rock and the ore are sharp and distinct. The vein contains slabs of angular quartzite, and much of the ore shows comb structure, the quartz crystals terminating in pyramids that point to druses near the center of the vein. Small druses, or unfilled portions of the vein, are numerous at many places in the lode. (See fig. 27, p. 179.)

The oxidized ore is highly siliceous and is stained with iron and manganese oxides and with copper carbonate. Pyromorphite is commonly present in small quantity coating the fragments of ore or staining the cellular quartz. Small specks and thin films of a sooty black mineral, probably a mixture of chalcocite and argentite, occur in the oxidized ore and at the apex of the vein. Silver chloride is sparingly present. Silver ranges from 12 to 75 ounces to the ton and averages about 17 ounces. The richest ore carried also $2 to the ton in gold.

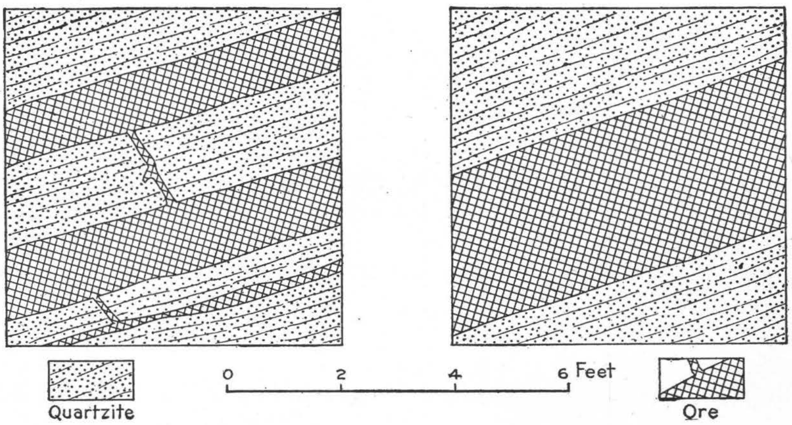


FIGURE 53.—Cross sections of the Combination vein.

The ore taken from the lower workings, 300 to 600 feet below the surface, is only slightly oxidized. The sulphides are gray copper, pyrite, zinc blende, and galena. Hübnerite, a tungstate of manganese, was noted in ore from the dump at the Harper shaft. A notable quantity of this mineral is probably present, for according to Goodale and Akers[1] the concentrates of the ore carry one-third of 1 per cent of tungsten.

Gray copper is present in considerable quantity and is probably the main source of silver. Pseudomalachite, a hydrated phosphate of copper, has been identified by Mr. Richard Pearce. Where the vein is not fractured and is for that reason less highly oxidized the ore consists in the main of ribbons of quartz, gray copper, and pyrite, which parallel the walls, alternating one with the other. The primary ore is not as rich as the more highly oxidized ore in the upper levels. An analysis made by Von Schulz & Low, of Denver, of a sample of the mill battery for October, 1888, is given below.

Analysis of ore from the Combination mine.

[Von Schulz & Low, Denver, analysts.]

Silica	84.09
Sulphur	.19
Iron	7.05
Copper	1.31
Lead	1.01
Zinc	.30
Manganese	.35
Antimony	.66
Silver	.08
Arsenic	.05
	95.09

Structural features.—Except for faulting since the ore was deposited, the structure of the lode is comparatively simple, for nearly everywhere the vein follows the bedding planes of the quartzite, which in the main has a gentle monoclinal dip. On level 5, near the Harper shaft, the vein strikes N. 30° W. and dips 15° SW., and these figures represent approximately the dip and strike at most places in the mine. About 375 feet southeast of the Harper shaft the vein

[1] Goodale, C. W., and Akers, W. A., Concentration before amalgamation for low-grade, partially decomposed silver ore, with notes on the geology of the Flint Creek mining district: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 242.

cuts across the bedding at an angle of 50° and dips S. 43° E. about 65°. Twenty-five feet below this point the vein becomes flatter and again follows the bedding planes of quartzite but dips nearly due south. The relations are illustrated by figure 54. What is presumably a continuation of this roll of the vein is exposed in the workings between level 5 and tunnel No. 2. On level 6, northwest of the lower part of this roll and toward the Harper shaft, the quartzite assumes the usual southwest dip, making a very broad and gently sloping saddle in which the mineralization is not notably different from that elsewhere in the vein.

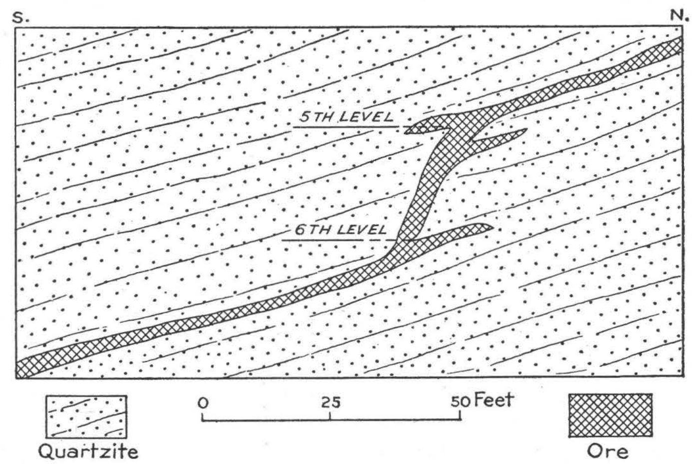


FIGURE 54.—Vertical cross section of Combination lode through levels 5 and 6, 375 feet southeast of Harper shaft.

A composite section of the mine is shown in figure 15, page 171. The line of this section is not straight but follows the major workings on the lode. From the outcrop of the lode to the Barrett shaft, a distance of 570 feet, it is S. 60° W.; beyond the Barrett shaft it continues S. 30° W. to the Harper shaft, a distance of 240 feet. The lode is not accessible east of the second fault from the Williams shaft No. 1 nor at the second fault south of the Barrett shaft, and these portions of the section are restored from mine maps of the company.

Figure 55 is a section drawn S. 65° W. through the Harper shaft from a drift on level 2 to a drift on level 12, which connects with the Harrison shaft. The vein passes under the present

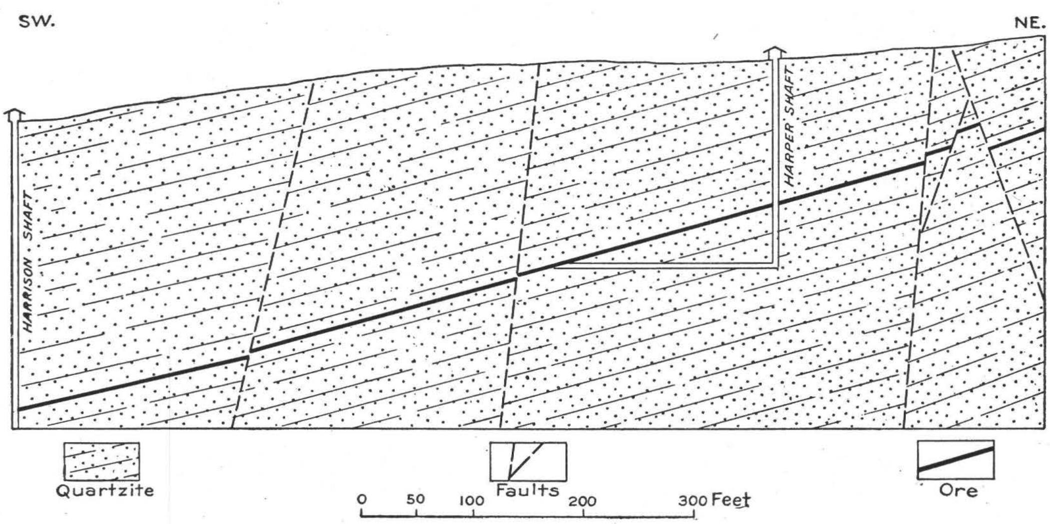


FIGURE 55.—Cross section of Combination lode through Harper shaft to Harrison shaft.

water level 300 feet beyond the point represented at the south end of this section. The faults shown on these sections are as a rule clean-cut fissures with smooth walls. Along some of the fault planes between the east ends of the faulted-ore horizon are small bodies of crushed quartz and fine-grained clayey material, which has resulted from the movement of one wall on the other. Along the first fault north of the Harper shaft this zone of crushed material is more than 2 feet wide. As shown by the sections, all of the faults are normal, the hanging wall having been depressed at every locality.

DOUGLAS MINE.

The Douglas mine, owned by Paul and W. C. Scott, is situated on the west slope of Henderson Mountain about 2 miles east of the Combination mine. Development amounts to about 700 feet, on two tunnels, one 50 feet above the other. A mill built a few rods below the mine is equipped with rock crusher, steam stamps, and cyanide tanks, and about 200 tons of ore has been run through it, but the saving has been indifferent, owing, it is said, to a lack of facilities for treating slimes, which carried away much of the metals.

The country rock is the Spokane formation, which is composed of shales and shaly sandstones. The deposit is a fissure vein from 1 to 3 feet wide and cuts across the bedding of the sedimentary rocks. All the ore is highly oxidized and consists of quartz stained with iron oxide. The better grade of ore is said to carry about $13 gold and 25 ounces silver. The vein is first encountered in the lower tunnel about 300 feet from the portal, where it appears to be faulted toward the west. Here the lode is about 18 inches wide, strikes N. 70° E., and dips 40° S. The walls are red shales, which carry sandy beds. Forty feet toward the east the vein ends abruptly at a fault, which dips steeply northwestward. Ninety feet southeast of the fault the vein is again encountered, and it is followed S. 57° E. for about 80 feet to the breast. In the upper tunnel the vein has been explored on the east side of the two faults encountered in the lower tunnel and has been stoped overhead for about 60 feet along the strike. At the east end of this drift in the upper tunnel the vein is much broken and disturbed.

PEACOCK MINE.

The Peacock mine, which is three-quarters of a mile N. 30° E. of the Douglas mine, is also owned by the Scott Brothers. About 700 feet of work has been done in two tunnels driven eastward into Henderson Mountain. The country rock is dark-gray or bluish limestone of the Newland formation, which on the surface a few rods below the mine dips 10° NW. The lower tunnel intersects the lode about 45 feet from the portal and follows it N. 65° E. for 150 feet, where the lode is displaced by a fault which strikes S. 65° E. and dips steeply southwestward. The fault plane is followed for 40 feet, when the lode is again encountered striking N. 68° E. In places near the hanging wall is a shoot of rich ore from 1 inch to 8 inches wide, carrying much silver and copper. Forty-five feet above this tunnel a second tunnel is driven to the lode, and some 300 feet of drift and crosscut have been run at this level.

QUEEN MINE.

History and development.—The Queen mine, also known as the Sunrise mine, is situated on Sunrise Mountain just north of Henderson, which is a small camp in Henderson Gulch about 5 miles above Stone station. The mine was worked from time to time between 1892 and 1903, during the greater part of which period the owners were in troublesome litigation. According to Mr. C. D. McLure, the present owner, the mine has produced altogether about $120,000 gold.

The lode is a flat tabular body dipping about 18° W. It outcrops about halfway up the south slope of Sunrise Mountain. For a distance of 2,200 feet along the apex of the lode the ore body has been exposed in 20 drift tunnels ranging from 50 to 600 feet in length, driven northward into the mountain along the strike of the deposit. Owing to the character of the topography, the line of their portals makes a rude semicircle which incloses the south end of Sunrise Mountain. Drifts, crosscuts, and inclines are driven from the tunnels, and altogether about 6,700 feet of work has been done, most of it on the lode.

The mill is situated in Henderson Gulch south of the mine, with which it is connected by a surface gravity tramway. The ore from the various tunnels was collected into a bin at the top of the gravity tramway through a number of surface chutes and level tramways, and was treated by wet-crushing, amalgamation, and concentration. (See p. 199.) When the camp was visited in 1907 the mine and mill were idle.

Geology and ore deposits.—The rocks at Sunrise Mountain are in the main the Newland formation, which consists of impure limestones with calcareous shales. The country rock of the Queen lode is a calcareous member of the series, at most places massive. At the mine it strikes nearly due north and dips about 18° W. No igneous rocks were noted in the mine, but a decomposed granodiorite outcrops in Henderson Gulch back of the mill. The limestones in the gulch below the mill are highly metamorphosed, and epidote, garnet, magnetite, pyroxene, and other contact-metamorphic minerals are extensively developed.

The deposit is a replacement vein in limestone. The oxidized ore near the apex is composed of quartz, calcite, limonite, and cuprite, with here and there small bodies of copper carbonate and copper silicate. It carries from $4 to $10 gold to the ton. The sulphide ore is composed of quartz, calcite, pyrite, chalcopyrite, and bornite. It contains considerable quartz but is not so highly siliceous as the oxidized ore. Some of it contains from 3 to 6 per cent copper. It is said to average about $3.50 gold to the ton.

The sulphide ore is encountered in the longer tunnels about 500 feet from the portal and at a vertical depth of approximately 200 feet. At places where the vein and country rock are crushed by post-mineral movement small pockets of high-grade gold ore were found in the oxidized zone.

The vein is a tabular body, which varies in thickness from 1 to 10 feet and averages about 3 feet. The walls of the vein are very much alike, and the roof does not appear to be more argillaceous than the floor. Owing to the massive character of the limestone it is not everywhere possible to ascertain how closely the vein follows the bedding planes. In the main the agreement is close, but at some places the vein appears to cut across the bedding. Near the portal of the third tunnel west of the Discovery tunnel two horizons are mineralized. At that place the limestones dip about 28° W., and two lodes about 30 feet apart follow the bedding. These lodes are joined by a horizontal body of ore presumably deposited in a joint plane.

The mineralization of the fissure is regular and persistent so far as exploration has gone. The vein has a dip in places as low as 9°, but the average is about 18°. It is crossed by post-mineral fissures, but these are not nearly so numerous as in the Combination mine, and their walls have not been greatly displaced by faulting. About 250 feet from the portal of the third tunnel west of the Discovery tunnel a fault strikes S. 10° E. and dips 35° E. The east wall, or the hanging wall of the fault plane, has dropped about 12 feet, indicating that the fault is normal. The vein, which near the Discovery tunnel dips 19° W., becomes steeper toward the west, its dip being about 30° in tunnel No. 3 and about 80° W. near the breast of tunnel No. 4. It is not exposed west of this point.

BUNKER HILL MINE.

The Bunker Hill mine is situated in Henderson Gulch, about one-half mile below the Henderson mill, and is the property of the Henderson Mining Co. The mine was opened in 1894 and has produced $20,000 gold and silver. About 2,200 feet of work was done from five tunnels having a vertical range of elevation of about 80 feet driven near the bottom of Henderson Gulch. The country rock, which is impure limestone, carries a notable amount of epidote, diopside, and other contact-metamorphic minerals. Granite is said to occur in the mine at two places not accessible in 1907.

The deposits are tabular bodies from 1 to 6 feet thick and are nearly everywhere approximately flat. In tunnel No. 5 a vein dips 35° E. An incline driven along the dip shows that 25 feet below the level of tunnel No. 5 this vein joins another deposit, which is approximately flat and extends westward below the inclined vein. A few feet east of the point of intersection this second vein dips about 3° E., and it may be followed down the dip for 250 feet. Farther east it is said to be faulted by several northward striking faults, but this eastern part of the mine was not accessible when the property was visited.

The sulphide ore is composed of quartz, calcite, pyrite, and copper pyrite. The oxidized ore is composed mainly of iron-stained quartz, the sulphides having been oxidized and in most places almost completely removed. Some of the siliceous spongy oxidized ore is liberally coated with small crystals of native sulphur. The oxidized ore carries from $6 to $8 in gold and 2 or 3 ounces of silver. In places the siliceous ore carried crystals of quartz pointing to a central druse indicating that some of the ore was deposited in open spaces. The ore minerals are not intergrown with the contact-metamorphic minerals, and although the country rock is metamorphosed the deposits are not typical contact-metamorphic deposits but are rather tabular bodies formed by deposition in fissures and through replacement of the limestone walls along their margins.

BELLEFLOWER MINE.

The Belleflower mine, 1 mile northwest of the Queen mine. is owned by the Henderson Mining Co. It was not accessible in 1907.

DEPOSITS OF ANTELOPE CREEK.

Southwest of Philipsburg is a large area of low mountainous country for the most part grass covered and in some places supporting a growth of small trees. Algonkian sedimentary rocks outcrop extensively. Here and there small masses of intruding igneous rocks cut through the sedimentary rocks, but none of these intrusions are large. Several deposits of low-grade gold ore occur in this country, but the Mountain Ram mine, in the South Fork of Antelope Creek, is the only one within the quadrangle upon which any considerable amount of development has been done.

MOUNTAIN RAM MINE.

The Mountain Ram mine is about 12 miles southwest of Philipsburg by wagon road. The property has been developed by several drifts, inclines, and crosscut tunnels. A few cars of ore have been shipped, but the bulk of the ore is too low in grade to bear the expense of smelting and freight charges and has been reserved for treatment on the ground.

The country rock is the Newland formation, which at the mine is greenish gray or blue. It has a wide range in dip and strike even within short distances, but the prevailing dip in the principal workings is from 12° to 20° SW. The lode is a bedding-plane deposit from 5 to 20 feet thick. It outcrops at several places as large bodies of iron-stained quartz, and its position on the surface is shown by a number of pits and shallow inclines driven here and there along the apex.

The unoxidized ore is composed of pyrite, quartz, calcite, and barite. Much of the ore is more than half pyrite. In the principal workings an incline is driven S. 22° W. on the vein, the angle of inclination being 12°, or approximately the dip of the lode. About 160 feet from the portal the incline is connected by chutes with an adit level driven at an elevation 60 feet below the portal of the incline. Approximately 190 feet below the apex, measured along the incline, the lode is displaced by a fault which strikes exactly with the strike of the deposit and dips 50° N. The footwall drops 7 feet, indicating it to be a reverse fault. A second fault encountered 125 feet down the dip of the vein dips about 68° NW., and the hanging wall has dropped about 7 feet, causing a block of the vein to settle an equal amount between the two faults.

The border of the zone of oxidation is very erratic, locally extending within a few feet of the surface and along watercourses extending downward as far as exploration goes. Both the sulphide and the oxide ore, according to Mr. Ed Brown, average $5 a ton gold. In seams in the ore body, especially along watercourses, higher contents have been obtained. In its structural features this deposit resembles the Queen deposit at Henderson.

MINES NEAR FLINT STATION.

FEATURES OF THE DEPOSITS.

Flint is on the Philipsburg branch of the Northern Pacific Railway, near the junction of Flint Creek and Boulder Creek. The country rock consists of quartzite, limestone, and shales of Algonkian and Cambrian age. These have been tilted, fissured, and faulted and are cut by veins bearing silver, gold, and copper. The country rock has been faulted since the ore was deposited, and slickensided planes of movement very commonly follow the walls of the deposits. A number of mines and prospects are situated within 3 miles of Flint, but to date none of them has been very productive. Altogether about $75,000 worth of ore has been shipped to smelters, and of this the greater part came from the Durand mine just west of Flint. Of late years there has been considerable prospecting in a small way, especially for copper, and ores of this metal have been found at many places in the district. None of these deposits has been extensively developed, however, and their value is problematic.

The copper deposits southwest of Flint occur in limestone as ill-defined and highly ferruginous quartz veins. So far as they have been developed they do not appear to be persistent. The ore occurs commonly in small pockets along the fissures, and for the most part it is low grade, though locally it is very rich. The veins northwest of Flint are more siliceous and better defined but do not carry so much copper. West of Flint, near the summit of the ridge between Flint and Smart creeks, the limestones have locally been metamorphosed and carry small masses of carbonate ore. In Wyman Gulch, 2 miles south of Flint, copper ore occurs in sandstone as carbonates filling joint planes and interstitial spaces between sand grains. Though of low grade, some of these deposits appear to be rather extensive. On Gird Creek, about 4 miles east of Flint, organic remains in sandstone are coated with copper oxide.

DURAND MINE.

The Durand mine, which is situated a few rods northwest of Flint station, has been worked now and then since 1892 and has produced altogether about $40,000 worth of silver and gold. The country rock is Flathead quartzite, which strikes northward and dips toward the west. Two veins have been developed by six tunnels having a range in elevation of about 125 feet. The north vein strikes northwestward and dips from 60° to 70° SW. In the principal tunnel it has been followed along the strike for about 200 feet. It is a sheeted zone in quartzite, and its maximum width is 3 to 4 feet. Several stopes extend above and below the tunnel level. The ore consists in the main of quartz and iron oxide, and it is said to carry $7.60 gold and 65 ounces silver. A tunnel driven near the level of Flint Creek intersects this vein about 125 feet below the surface and follows it for about 50 feet. In this tunnel the ore is composed of quartz, pyrite, and arsenopyrite and carries low values in gold and silver but is not of stoping grade. Higher on the hill a second vein outcrops about 30 feet farther south. It has approximately the same strike as the north vein and dips about 30° SW. It has been exploited through three short tunnels driven on the vein one below the other. In the lowest of these tunnels two 4-inch stringers of crushed ore and gouge, dipping 20° SW. and 42° SW., join to form a body of rich ore about 2 feet wide.

LONDONDERRY MINE.

The Londonderry mine is about one-half mile north of the Durand mine and 400 feet above the level of Flint Creek. The country rock is quartzite and shaly red sandstone of the Spokane formation. Two approximately parallel lodes strike N. 40° W. and dip about 70° SW. They are a foot or so in width and consist of iron-stained sandstone more or less silicified carrying both silver and gold. The lodes have been opened by a number of short tunnels and open cuts. About 5 cars of ore have been shipped, and the average yield has been $6.50 gold and 50 ounces of silver per ton.

HOMER CLAIM.

The Homer claim is a few rods northwest of the Londonderry claim. A tunnel driven 210 feet N. 20° W. intersects a lode which strikes about N. 40° W. and dips steeply southwestward. The footwall is sandstone or quartzite and the hanging wall a calcareous shale containing lenses of quartzite. The lode consists of iron-stained quartz and is said to carry about $5 in gold and 13 ounces in silver. The lode is displaced by a fault which at most places follows the hanging wall of the vein. The fault is marked by smooth slickensides and by a large amount of soft clay gouge. In the hanging wall of the fault the limestone appears to dip approximately with the most clearly defined planes of movement. The fault may be traced southward on the surface for a considerable distance. The fault forming the hanging wall of the vein splits at the end of the tunnel and bending slightly to the north cuts off the vein.

MOTHER VEIN CLAIM.

The Mother Vein claim is about half a mile west of the Homer claim. A tunnel driven S. 37° E. encounters, in quartzite 80 feet from the portal, a fractured zone of broken country rock and white quartz said to carry small quantities of gold and copper for a width of 20 feet. The country rock near by is much fractured, and the joint planes are locally stained with green copper carbonate.

JOHNSON CLAIM.

The Johnson claim joins the Mother Vein claim on the south. The country rock is quartzite which dips 46° W. It is locally fractured, and some of the fractures are stained with copper carbonate. The vein dips 38° SW. and is from 2 to 3 feet wide. It is followed by post-mineral fissures with slickensided walls parallel to the vein. The ore is quartz highly stained with iron oxide and is said to carry low values in copper and gold.

EAGLE CLAIM.

The Eagle claim joins the Johnson claim at the southwest. Several short tunnels and shallow pits have been dug in a dense, even-grained limestone containing a notable amount of tremolite, diopside, and other minerals of contact-metamorphic origin. Small bodies of copper ore, mainly quartz and copper carbonates, are exposed at several places. About 50 tons of 5 per cent ore is said to have been shipped to smelters.

LAST CHANCE MINE.

The Last Chance claim is about one-half mile northwest of the Eagle workings. Development is along a quartz vein oriented approximately with the bedding of the gray limestone of the Newland formation, which strikes N. 25° E. and dips 41° W. Locally this vein is 3 or 4 feet wide. It carries small amounts of copper oxide and carbonate, also pyrite and chalcopyrite. An incline 115 feet long is driven on this vein, and about 150 feet west another incline is driven on a similar deposit, which dips 40° W.

COPPER STATE MINE.

The Copper State mine is a few rods north of the Mother Vein claim. The ore deposit is a zone of shattered limestone impregnated with iron and copper oxides and carbonates. The mine has produced about $2,000 worth of ore. A number of short tunnels and shallow shafts have been driven, but most of these were inaccessible when the mine was visited in 1907.

TWIN BUTTES CLAIM.

The Twin Buttes claim is about one-half mile south of the Durand mine. A tunnel is driven in limestone 180 feet, following in the main a fissure which strikes S. 38° E. and dips 69° S. The fissure is locally slickensided and forms the hanging wall of a vein in places several feet wide. The ore carries considerable iron oxide and is said to run from 2 to 4 per cent copper At the bottom of a shaft sunk at a point about 40 feet above the tunnel level, in altered ferruginous limestone to a depth of 20 feet, are small bunches of high grade copper and lead ore. The limestone on both sides of the fissure is highly stained with iron oxide.

HEILMAN CLAIM.

The shaft on the Heilman claim is sunk in iron-stained limestone about 1,500 feet southwest of the Twin Butte tunnel. The lode strikes northward and dips about 75° W. It has a maximum width of 3 or 4 feet and locally carries high values in copper with some silver and gold. It is composed of quartz, calcite, limonite, cuprite, malachite, azurite, and native copper. The ore is followed 100 feet down the dip by a winze.

HOWARD CLAIM.

The Howard claim is about 1,000 feet southwest of the Heilman claim and is a deposit of the same general character. The lode strikes N. 15° E. and dips 47° W. From a point near the level of Flint Creek a tunnel is driven about 325 feet to cut the lode in depth, but no ore was seen in the tunnel.

JOE HANKS CLAIM.

The Joe Hanks claim is about 2,000 feet southwest of the portal of the Howard tunnel. A tunnel driven about 50 feet above the level of Flint Creek explores several small masses of iron-stained copper-bearing ore in altered limestone.

LAST CHANCE CLAIM.

The Last Chance claim, owned by Bennett Bros., is on Flint Creek just north of Sawmill Creek. On the surface the lode dips about 85° NW. The country rock is hard blue limestone of the Newland formation, and the lode strikes across the bedding. The vein, which is about a a foot wide, is composed of calcite, quartz, iron oxide, gray copper, malachite, and azurite and is said to carry about $30 in gold and silver. A crosscut tunnel is driven 500 feet into the hill about 55 feet below the outcrop of the lode.

BARNES MINE.

The Barnes mine is located on Gird Creek about 4½ miles above its junction with Flint Creek. The country rock is dark-gray calcareous sandstone of the Ellis formation. These beds strike north and dip 66° E., this dip being reversed by overturning of the beds. A tunnel is driven 120 feet on the strike of the beds along a smooth wall which appears to be a movement plane parallel to the bedding plane of the shale. The sandy members are rich in fossils and other forms, probably fragments of wood Locally the organic remains are coated with red copper oxide and some of the ore is said to carry several per cent of copper. In the summer of 1907 a shaft was being sunk to cut the lode in depth.

DELAWARE MINE.

The Delaware mine is about three-fourths of a mile south of the Barnes mine and about 1,000 feet higher. The lode is a shear zone in quartzite of the Quadrant formation and carries iron oxide and lead carbonate. Fourteen tons of ore have been shipped. This ore ran 22 per cent lead and carried 28 ounces of silver to the ton. A 100-foot shaft has been sunk on the lode, and about 200 feet of work has been done from an adit below. Most of the workings were inaccessible when the mine was visited by the writer.

SALLIE MELLEN CLAIM.

The Sallie Mellen claim is on Smart Creek, about one-half mile north of the Copper State mine. A sheeted zone in Flathead quartzite is said to carry about 60 ounces of silver and $4 in gold. The lode strikes east and is approximately vertical. The pay streak is about 5 inches wide and is composed of quartz, limonite, malachite, pyrite, cuprite, native copper, and pyromorphite.

ANNIE CLAIM.

The Annie claim is on Smart Creek about 1⅗ miles above the Sallie Mellen claim. The country rock is gabbro, and the lode dips 43° W. A tunnel about 150 feet above the bed of the creek follows the lode along its strike for 120 feet. The ore is quartz and pyrite and is said to carry $7 in gold.

BONANZA CLAIM.

The Bonanza claim is a few rods northwest of the Annie tunnel, on the opposite side of Smart Creek. A shear zone in limestone impregnated with pyrite is said to carry gold.

NORTH STAR MINE.

The North Star mine is on the west slope of Wyman Gulch near its junction with South Boulder Creek and is about 3½ miles by wagon road from Flint station. The country rock is quartzite of the Spokane formation, and dips 45° W. The quartzite is impregnated by copper carbonate, which fills the spaces between the sand grains and appears to follow the general direction of the bedding. The ore extends to the bottom of a shaft about 80 feet vertically below the surface. A prominent slickensided plane striking N. 9° W. forms in places the hanging wall of the deposit. The breast of a 9-foot crosscut is in the ore at a depth of 40 feet. The dump is said to carry 3 per cent of copper, and two carloads of 6 per cent ore have been shipped.

A tunnel designed to intersect the lode in depth had been driven 200 feet from a point about 80 feet below the collar of the shaft. This tunnel passes first through red sandstone dipping steeply westward and then encounters gray sandstone. The gray sandstone is at several places highly impregnated with copper carbonate and carries here and there specks of pyrite. The country rock is much disturbed and is crossed by several well-defined slickensided fracture planes probably related to a great fault a short distance west of the mine. For the small amount of development a considerable quantity of low-grade copper ore is exposed. Because of its siliceous character it would serve as lining for copper converters, and a low smelting rate could probably be obtained.

CHAPTER XVIII.

PLACER DEPOSITS.

GENERAL FEATURES.

In comparison with other Montana placers, such as the great deposits of Alder, Last Chance, and Confederate gulches, the gravels of the Philipsburg quadrangle have not been highly productive. Altogether these deposits have yielded something less than $2,000,000. Many of the richer lodes are deposits chiefly of silver, and this metal, owing to its solubility in mineral waters, does not readily accumulate in placers. The gravels resulting from the degradation of the Combination lode, the Blue-eyed Nellie vein, the cluster of lodes near Philipsburg, and other deposits predominantly argentiferous are not known to contain gold in paying quantities. The gold-bearing placers of the quadrangle have been supplied by the Henderson, Cable, and Georgetown deposits and by the lodes of the Boulder and Gold creeks basins. At present the placers are not actively worked and their annual production is not more than a few thousand dollars. In the summer of 1907 about a score of men were employed in their exploitation. The methods employed are ground sluicing and hydraulicking. At some places drifts are run along the bedrock.

The auriferous gravel beds are stream deposits and glacial deposits. As a rule the material is so coarse that it is expensive to remove, and profits of operation are small. It is possible, however, that the lower portion of the Henderson bar and the flat below the Cable mine may be worked by some of the more elaborate and cheaper methods, providing the depth to bedrock is not prohibitive.

DESCRIPTION OF PLACERS.

HENDERSON GULCH.

The Henderson placers were discovered in 1866 and prior to 1870 had produced $300,000. In the seventies Emmetsburg, a camp located in this gulch, was the seat of considerable activity, and a branch stage made regular trips from New Chicago, connecting with the stage from Deer Lodge to Missoula. According to Mr. C. D. McLure, the camp has produced more than a million dollars. The gold has a high degree of purity and occurs mainly as a fine dust with small nuggets weighing up to one-fourth ounce. The metal is undoubtedly derived from the gold deposits of Sunrise and Henderson mountains and has been washed down from these deposits in the course of the denudation of the country. The gravels of the gulch are gold bearing from a point a mile or so below Henderson to a point near Flint Creek. The higher gravels on either side of the gulch proper constitute the bar. The gulch and the upper end of the bar have been worked over pretty thoroughly by sluicing and drifting, but small values still remain in some of the dirt and three or four Chinamen appear still to find their operations satisfactory. The lower end of the bar is too flat to be worked easily with sluice boxes. According to Mr. F. D. Brown, of Philipsburg, who has sampled the ground, a considerable acreage could be worked profitably with dredges or with hydraulic elevators.

GOLD CREEK.

Gold Creek rises in the northeast corner of the quadrangle and flows northward to Clark Fork. As has been already stated, this creek was the source of the first gold discovered in Montana, and the richer portions of the gravels were worked out years ago. McFarland's placer and Tibbit's placer are situated near the source of this stream, and each of these has produced several thousand dollars worth of gold. McFarland's placer has been worked intermittently since 1896 and is said to have produced $35,000. The gold is coarse, in the main about the size of No. 8 shot, and has yielded nuggets weighing more than 10 ounces. It is not so pure as the Henderson gold and sells for $16 or $17 an ounce. The dirt, which is said to carry 40 cents a cubic yard, is worked in sluice boxes, and the largest bowlders are blasted and removed with a hand derrick. The richest dirt is at bedrock, which is as a rule comparatively regular. Dredging and hydraulic elevators would be unprofitable in this ground, owing to the great size of many of the bowlders.

PRINCETON GULCH.

The gravels of Princeton Gulch are said to carry some gold from its junction with Boulder Creek nearly to its source. A tunnel driven into a thick bench of the gravels a few rods north of the Princeton shaft shows considerable coarse gold to be present, and if it were not for the high cost of handling the material, owing to the presence of large bowlders, some of this ground could probably be worked profitably. The Summit placer on Princeton Gulch, about 2 miles above Boulder Creek, yields gold of the same character. At this place practically all the gold is concentrated in about 18 inches of the bedrock, which has an overburden of 22 feet. The gravel is mined by drifting. It is not practicable to dredge this ground, owing to the large bowlders.

LITTLE GOLD CREEK.

Some sluicing has been done at several places on Little Gold Creek, but the production has been inconsiderable. About 5 pounds of black sand is said to be present in each ton of gravel. A sample of this black sand sent to the United States Geological Survey testing laboratory at Portland, Oreg., is reported to contain $30 gold and $1 platinum to the ton. Ilmenite, wolframite, monazite, and zircon were also present in small quantities, but the total value of the sand is far below the cost of extraction.

CABLE PLACER.

The Cable placer, like the Cable mine, was a bonanza deposit. In 1872 Mr. Kohrs, who had a lease on the property, took out $18,000 in eight weeks, and the following year the lease yielded $37,000. The deposit of rich gravel was worked for many years. For a part of the time it was exploited by the owners of the mine, so that it is impossible to segregate its production from that of the Cable mine, but the total returns from the placer were probably several hundred thousand dollars. The gold is clearly derived from the deposits of the Cable mine. The richest part of the gravel was near bedrock, a short distance below the outcrop of the lode, and the ground just below the outcrop of the ore and on the relatively steep hillside was best situated for working. In the summer of 1906 a Keystone drill was used to prospect the flat below Cable. It was found to be gold bearing, but where prospected the depth was beyond the limit of easy operation for most types of dredges.

GEORGETOWN PLACERS.

The small gulch which drains westward through Georgetown to Georgetown Lake carries auriferous gravels for a portion of its length. These deposits have never been an important source of gold, and presumably they have been untouched for many years. According to the national commissioner of mining statistics[1] this placer had in 1870 produced about $40,000 gold. The sources of the gold are the Pyrenees, Luxemburg, and other lodes near by.

The Daly placer, which is 1½ miles southeast of Georgetown, was exploited in the seventies, but was less productive than the Georgetown placer. The Wellington placer, northwest of Georgetown, was likewise unprofitable.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870, p. 273.

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