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ORE DEPOSITS OF THE HELENA MINING REGION MONTANA

BY

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ORE DEPOSITS OF THE HELENA MINING REGION, MONTANA.

By Adolph Knopf.

OUTLINE OF REPORT.

The dominant geologic feature of the Helena mining region is the granite mass which forms the northern extension of a great intrusion in southwestern Montana, known as the Boulder batholith. This body of granitic rock represents an invasion of the upper zones of the earth's crust by an enormous volume of fluid magma in late Cretaceous time. The cover under which the granite cooled was largely stripped off by the prolonged erosion of the Tertiary period and the granite was laid bare and now forms the predominant surface rock of the region.

As a consequence of the granite invasion a series of ore deposits, the principal source of the metallic wealth of the region, was formed around the margin of the granite and in the roof rocks overlying it.

The rocks of the region may be broadly subdivided with reference to the great granite mass as (1) those formed prior to its intrusion, and (2) those formed subsequent to its intrusion—in short, as prebatholithic and as postbatholithic rocks. Of these two groups the prebatholithic rocks are the main repositories of the ore bodies of the region.

The prebatholithic rocks consist principally of sedimentary rocks which range in age from Algonkian to Cretaceous. They include mainly limestone, shale, and quartzite and lie in angular conformity from the lowermost member to the top of the series. These rocks are present chiefly in the northern part of the region. They are overlain by andesite and latite lavas and breccias which are definitely known to be post-Jurassic and are probably of late Cretaceous age. The andesites and associated latites are the youngest rocks intruded by the granite, save perhaps a small area of thermally metamorphosed sandstones overlying them west of Helena.

After the andesites had been erupted the rocks were folded; subsequently the granite magma came to place beneath the region. The granite broke irregularly across the folds of the stratified rocks, the most notable example being the truncation of the southern limb of the Prickly Pear dome. This is shown to best advantage south of Helena, where the strata dip steeply toward the batholith. At other localities, however, the covering rocks of the batholith—principally andesites—dip away from the granite.

The granitic rock of the Boulder batholith is termed a quartz monzonite because of its high plagioclase content. It is composed of plagioclase (near labradorite), orthoclase, quartz, biotite, and hornblende. As a whole, the mineral and chemical composition is remarkably uniform and homogeneous.

Large intrusions of aplite in irregular masses and dikes are common throughout the area of the batholith and constitute 5 per cent of its superficies.

The covering rocks, forming a roof of unknown thickness under which the granite came to place, crystallized, and cooled, consisted principally of andesites and latites, remnants of which still remain within the central portion of the batholith. The most extensive of these roof remnants is the large andesitic area west of Wickes, and this has been the great repository of the mineral wealth of the region.

A series of dacites, comprising lavas, breccias, and tuffs, locally 2,400 feet thick, rest on the deeply eroded surface of the granite and andesite. In the southwest corner of the region they form part of an extensive area extending to Butte and forming Big Butte at that city. They were formed contemporaneously with the lake beds west of Butte and are of upper Miocene age.

Rhyolites also rest on the eroded surface of the granite and the older rocks. Their relation to the dacites was not determinable. They were erupted on a surface whose relief was much like that of the present topography, and they are apparently the youngest bedrock formation in the region. At the head of Tenmile Creek, in the Rimini district, they have been mineralized and constitute low-grade gold ore.

The ore deposits fall into two distinct groups, widely separated in time of origin. The older are late Cretaceous or early Tertiary in age, the younger are post-Miocene.

The older ore bodies are mainly silver-lead and gold-silver deposits. In metallic content they contrast strongly with the ores of the near-by Butte district, which are predominantly copper ores, although formerly silver ores were of importance. The scarcity of copper deposits in the Helena region is a notable feature, doubly so from the fact that the deposits belong to the same metallogenetic province as those of Butte, being formed at approximately the same time and presumably from the same magma.

The ore bodies of the older group have furnished the greater part of the production of the region; in fact, the value of their output has been roughly three times that of the post-Miocene deposits.

The silver-lead deposits constitute the prevailing type of ore body of the Cretaceous deposits. They are commonly situated near the contact of the granite and the rocks invaded by it. Hence, as a rule, they are inclosed in andesite or granite. The ore bodies are replacement-fissure lodes containing galena, sphalerite, pyrite, and arsenopyrite.

The older ore bodies are commonly tourmaline bearing. In certain deposits, as at Rimini, tourmaline is extremely abundant; in fact, it is there developed in the same abundance that characterizes the tin lodes of Cornwall. The premier ore deposit of the region—the Alta, credited with an output of $32,000,000 in silver-lead ore—shows notable tourmalinization. Three types of tourmalinic lodes with transitions between them are recognized—lead-silver, copper-silver, and gold. The predominant type is the tourmalinic lead-silver, a type that is unique, as far as shown by the literature of ore deposits.

The extreme depth to which any of these deposits has been worked is 1,200 feet. At Rimini, where the extreme depth attained below the present surface is only 600 feet, it is probable that this depth is 2,000 feet below the intrusive contact surface of the granite.

The ores were formed at high temperatures, and it is regarded as probable that the ore-forming solutions were derived from a final differentiate of the quartz monzonite magma.

The post-Miocene ore bodies are essentially precious-metal deposits. They are characterized by the tendency of the quartz gangue to display a cryptocrystalline development, either flinty, chalcedonic, or densely saccharoidal, resembling porcelain. Equally characteristic is the thinly lamellar calcite of the gangue and its pseudomorphic replacement by quartz, forming a type of ore common in so many of the late Tertiary gold fields of the West. These deposits are typically developed in the upper Miocene dacites of Lowland Creek, but their analogues at Marysville, which have yielded $30,000,000, have furnished the bulk of the output.

The extreme depth attained on veins of this class is 1,600 feet, at the Drumlummon mine, where the lode was found to be barren below the 1,000-foot level, and the greater part of the production has come from above the 500-foot level.

In early days the ..ines of the district furnished extremely rich surface ores. The evidence, although inadequate, suggests that the richness of the ores was due largely to mechanical concentration and to the elimination of worthless and objectionable constituents. In depth an objectionable amount of zinc in the form of sphalerite appears in many mines, but in the carbonate ores formerly worked the sphalerite had been oxidized and removed in solution. Secondary enrichment, especially such as has led to the production of great bodies of copper ore, has taken place nowhere in the region. The Marysville district is possibly an exception, for the ore bodies there may have been enriched in gold by descending solutions; the evidence, however, is not conclusive, and the indications are that the impoverishment in depth was due, in part at least, to failure in the primary metallization.

GEOGRAPHY.

LOCATION OF THE REGION.

The Helena mining region, as it is termed in this report, is an area of 1,300 square miles in southwestern Montana. A large number of mining camps are included in the confines of this area, among which,

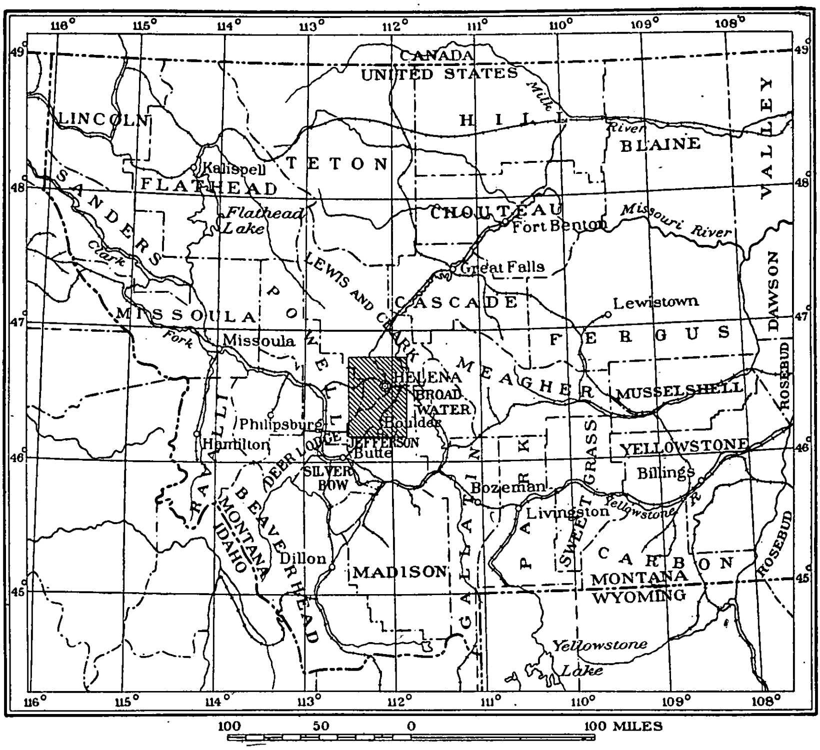

FIGURE 1.—Index map showing the location of the Helena mining region, Montana.

in point of production, Elkhorn and Marysville are the most important. Helena, however, is by far the largest and best known city in the region, and although it long ago yielded preeminence to other localities as a mining center, it is perhaps still appropriate to speak of this as the Helena mining region, for it was the discovery of the extraordinarily rich placers at Last Chance, where Helena now stands, that led to the development of the mineral wealth of the surrounding territory.

The Marysville mining district is situated in the northwest corner of the region, Elkhorn lies in the southeast corner, and the southwest corner is 14 miles north of Butte.

The area lies within the rectangle formed by parallels 46° 12′ and 46° 48′ north latitude and meridians 111° 50′ and 112° 30′ west longitude. It includes portions of the Helena and the adjoining Fort Logan quadrangles, and accordingly does not form a regular quadrangle of the Geological Survey.

A large part of the area lies within Jefferson County, a part within Lewis and Clark County, and that part west of the Continental Divide in Powell County. A considerable number of organized and unorganized mining districts are included in the region, but these subdivisions are no longer well known nor employed frequently in local usage, so they will not be used in this report.

The region is traversed from east to west by the main line of the Northern Pacific Railway and from north to south by the Havre-Butte branch of the Great Northern Railway; branch lines of the Northern Pacific extend to the mining camps of Marysville, Rimini, and Elkhorn, so that in comparison with most mining regions it is unusually well-favored with transportation facilities. Good wagon roads render nearly every part of the area readily accessible.

PHYSICAL FEATURES.

The region, broadly considered, is mountainous and has a considerable and abrupt relief. The western portion constitutes the broad back of the Continental Divide, which here averages 7,000 feet in altitude. The topography, however, is neither rugged nor alpine, but is characterized by smoothly rounded profiles, due to the prevalence of domelike summits.

Red Mountain, 14 miles southwest of Helena, is the highest mountain in the northern part of the region; it attains an altitude of 8,200 feet, and its broad, rounded summit looms up above its fellows for many miles around. The Elkhorn Mountains, on the eastern side of the region, are separated from the mountainous country on the west by the broad Boulder Valley. They are the highest mountains in the region, Elkhorn and Crow peaks reaching a height of 9,300 feet. On the northeast flanks of these peaks are a series of finely developed glacial amphitheaters, whose sheer walls and heavy talus slopes make this the most rugged part of the area.

The largest stream is Boulder River, flowing across the southern part of the region from west to east in a narrow valley deeply sunk between the surrounding mountains. On the east this valley opens out abruptly into the broad valley at Boulder; on the west beyond Bernice it again broadens and shows a fine series of terraces, the highest 250 feet above the stream. The irregular mountainous area through which Boulder River flows, and which forms the larger part of the area concerned in this report, is sometimes known as the Boulder Mountains.

Missouri River crosses the extreme northeast corner of the region. Its principal tributaries are Prickly Pear, Tenmile, and Silver creeks

The most important stream west of the Continental Divide is Little Blackfoot River, which flows westward beyond the confines of the region, joining Clark Fork at Garrison. The Northern Pacific Railway in crossing the Continental Divide eastward ascends the valley of the Little Blackfoot to Elliston, and thence parallels an affluent from the northeast. The ascent is gradual through a comparatively broad and open valley bordered by smooth, rounded hills. Near Mullan Pass, at the mouth of Dog Creek, there is a wide expanse of flat, so that it is difficult to realize that this is the summit of the Rocky Mountains.

CLIMATE.

The climate is semiarid, the annual precipitation ranging from 10 to 13 inches. The summers are warm and pleasant; the winters are comparatively mild, despite the altitude and inland position of the region. The winter weather is ameliorated by the warm chinook wind that blows from the northwest; snow does not cover the ground in the open valleys during long periods, but disappears before the chinook.

The important climatic elements are given in the subjoined tables.[1]

Monthly and annual precipitation, in inches, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena	1.00	0.66	0.83	1.06	2.13	2.26	1.13	0.69	1.13	0.77	0.76	0.79	13.21
Boulder	.65	.43	.50	.86	1.66	1.95	1.02	.76	.92	.41	.38	.46	10.00

Mean temperature, in degrees Fahrenheit, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena	20.0	22.7	31.7	42.1	51.8	59.1	66.9	66.2	56.2	45.8	32.3	26.3	43.6
Boulder	20.0	21.7	23.2	41.5	49.5	55.9	62.9	62.8	52.2	42.9	31.1	24.7	41.1
Marysville	20.9	21.9	25.7	40.4	47.4	55.0	62.9	62.1	51.5	43.0	29.8	25.9	40.5

Average number of days with 0.01 inch or more of precipitation in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena	9	7	8	8	12	12	8	5	7	6	7	8	97
Boulder	5	4	6	6	8	8	6	4	6	3	4	4	64
Marysville	8	7	8	7	14	10	8	6	5	5	7	9	94

[1] These tables are taken from more extended data given by R. F. Young, U. S. Weather Bureau, in the Twelfth Rept. Montana Bur. Agr., Labor, and Industry for 1909 and 1910, pt. 1, pp. 82–91.

Average snowfall, in inches, in the Helena region, Montana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Helena	11.5	8.0	9.6	5.8	1.4	Tr.	0.0	0.0	0.6	3.1	6.6	8.1	54.7
Boulder	6.7	4.8	4.9	4.2	1.1	Tr.	.0	.0	1.1	.9	2.3	4.4	30.4
Marysville	16.2	13.5	18.8	8.1	5.9	.5	Tr.	.2	1.6	5.4	14.9	15.0	100.1

HISTORICAL SKETCH OF MINING.

The first important find of metallic wealth in Montana was the discovery of placer gold at Bannock in 1862. In the following year the far greater discovery at Alder Gulch was made, and from this stream was taken within the next three years $30,000,000. The extraordinary richness of these placers immediately attracted a large population, and so strong was this influx that within 18 months a town of 10,000 people sprang up, which was named Virginia City. Alder Creek was the longest and most productive creek ever discovered in Montana; 20 miles of stream bed, comprising about 1,000 claims, were worked and yielded a profit at a time when wages were from $10 to $14 a day.

Montana was soon overspread by eager prospectors, and in the next few years all the important placers were discovered. Last Chance, on the present site of Helena, was located in the summer of 1864. This was the first important discovery in the region that is the subject of this report. The Whitlatch-Union vein, carrying rich gold ore, was found a few miles south of Helena in September of the same year. Lode and placer discovery were thus contemporaneous. The finding of gold in place caused a quartz excitement which stimulated prospecting all over the Territory.

Last Chance yielded $16,000,000, the bulk of which was taken out before 1868. Many streams in the vicinity of Helena were also found to be auriferous—Prickly Pear Creek, Nelson Gulch, Silver Creek, and others. In fact some of these prior to the discovery of Last Chance had been found to contain placer gold. Prickly Pear Bars, a few miles east of the site of Helena, were found to be auriferous in August, 1862, and led within a few months to the discovery of gold on Silver Creek. Here Silver City was founded, which became, before Last Chance was organized, the political and commercial center of Lewis and Clark County.

West of the Continental Divide placers were found in 1865 at Ophir Creek, Carpenter Bar, and Snowshoe, small affluents of Little Blackfoot River from the north. Here sprang up Blackfoot City (now called Ophir), which has long ago lapsed into decay. By 1875 the diggings had been abandoned to Chinese. In 1911, however, the gravels at the mouth of Snowshoe Gulch were tested for their possibility as dredging ground.

The silver-lead ores and true silver ores in the vicinity of Wickes, Jefferson, and Clancy were discovered simultaneously with the finding of the placers. The Gregory lode, one of the earliest finds, was located in 1864 by a party going from Alder Gulch to Helena. An American hearth was erected here in 1867 to smelt the ore; this was the second smelter established in Montana, the first being that built at Argenta.

The great need of the Territory at this time was an adequate transportation system, with rail connection with the centers of civilization. By 1870 the placers had been largely exhausted and a period of stagnation set in, for lode mining was not likely to flourish when high freight charges consumed the profits. According to the historian Bancroft, "Freights during the first decade were enormous, costing the country between a million and a half and two millions annually, even after the population had shrunk to 18,000." The chief overland transportation route was Missouri River, by which steamers could reach Fort Benton, 150 miles from Helena, during high-water stages. But this period of high water lasted only 4 to 6 weeks, and steamers were often forced by low water to stop at Fort Union, at the mouth of the Yellowstone. On the completion of the Union Pacific Railroad in 1869 much of the traffic was diverted to this route, Corinne in Utah, being the initial point for freight bound for Montana. In addition to the handicap of high transportation charges most of the ores were of the kind that required expensive metallurgic treatment. Under these adverse conditions only the richest ores could be worked. The ores were either hauled to Fort Benton, thence sent to the seaports, and shipped to Swansea, Wales, or were hauled by wagons to Corinne on the Union Pacific Railroad, a distance of 450 miles, sent to San Francisco, and shipped to Europe.

The Northern Pacific Railway reached Helena in 1883, the first train crossing the Continental Divide west of Helena on August 7, 1883, and the golden spike signalizing the completion of the overland road was driven on September 8, 1883, near Garrison.

The advent of the railroad exerted a strong stimulus on the mining industry. During the latter part of 1883 the Helena & Jefferson Railroad was built. This is now part of the Great Falls branch of the Great Northern Railway and connected Helena and Wickes, a distance of 20 miles. In the same year the Helena Mining & Reduction Co. acquired by purchase from the Alta Montana Mining Co. the Alta, Comet, and other well-known mines near Wickes. The smelter at Wickes was rebuilt and enlarged, so that it was for some years the most extensive reduction plant in Montana and drew ores from a large radius, even as far as the Cœur d'Alene district. In 1893 it was shut down and dismantled. The same fate has overtaken the many small smelters built at the various mines throughout the region, so that now the only smelter in operation is the East Helena plant of the American Smelting & Refining Co.

The period from 1883 to 1893 comprises the years during which the bulk of the silver-lead ore was produced. The lode gold of the region has come mainly from the Marysville district. Mining flourished there principally from 1880 to 1900, although during the latter part of the period the yield came largely from the cyanidation of tailings piles.

PRODUCTION.

The total production of the region, including the yield from silver-lead ore, placer gold, and lode gold, is not accurately ascertainable but is roughly in the neighborhood of $150,000,000. The estimates of placer production are particularly unsatisfactory, and for many of the streams no data are available. The output of Last Chance, the most productive of the placers, is estimated in widely different amounts by different writers, ranging from $10,000,000 to $35,000,000. Bancroft's estimate of $16,000,000 is accepted here.

The total output is distributed as follows: Silver-lead, $80,000,000; lode gold, $40,000,000; and placer gold, $30,000,000. Of these figures probably that for lode gold is entitled to the most confidence.

During 1910 the total production from the deep mines of the region, as compiled from Mineral Resources of the United States for 1910, was $997,359. Of this amount gold represented $275,134, and silver, lead, and copper the remainder. The Elkhorn district furnished the preponderant part of the production—$652,738. Placer mining in the region is now insignificant, and in 1910 yielded only $4,312.

The total production for 1911 was $864,050, of which gold constituted $267,914.

The following table shows that in recent years the production of the region has fluctuated around $1,000,000.

Production of the Helena mining region, Montana.

1906	$917,165
1907	1,617,379
1908	1,118,884
1909	908,044
1910	997,359
1911	864,050

FIELD WORK AND ACKNOWLEDGMENTS.

Field work was commenced at Helena on June 20 and completed September 24, 1911. While this work was carried on, the writer was efficiently assisted by Henry G. Ferguson, to whom fell most of the task of mapping the areal geology of the region. The examination of the mines and prospects was undertaken mainly by the writer.

During the preparation of this report in the office the writer has availed himself of certain collections of rocks ores, and thin sections from Elkhorn, Marysville, and the Boulder quadrangle, which had been gathered by W. H. Weed and Joseph Barrell for the United States Geological Survey and are now deposited in the United States National Museum. Some of the mines from which they had collected specimens are no longer accessible, and such specimens were often found to be of much value for comparative purposes.

LITERATURE.

The following list includes the principal papers bearing on the geology and ore deposits of the region. The literature concerning the ore deposits is scanty and is limited to papers on the Elkhorn and Marysville districts.

BANCROFT, H. H., History of Washington, Idaho, and Montana, 1848–1889, San Francisco, 1890.

Gives an interesting account of the history of Montana and much valuable information concerning the growth of the mining industry.

BARRELL, JOSEPH, Microscopical petrography of the Elkhorn mining district, Jefferson County, Mont.: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 511–549.

—— The physical effects of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 13, 1902, pp. 279–296.

A theoretical discussion of contact metamorphism, based largely on the phenomena at Elkhorn, Mont.

—— Geology of the Marysville mining district, Mont.; a study of igneous intrusion and contact metamorphism: Prof. Paper U. S. Geol. Survey No. 57, 1907, 178 pp.

As indicated by the subtitle, this report deals mainly with the phenomena of igneous intrusion and contact metamorphism exhibited at Marysville; it presents the strongest detailed evidence in favor of the magmatic stoping hypothesis yet published.

—— Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, 1906, pp. 553–560.

It is argued that the Belt series of Montana is largely of terrestrial origin.

CLAYTON, J. E., The Drumlummon group of veins and their mode of formation: Eng. and Min. Jour., vol. 46, 1888, pp. 85–86, 106–108.

An able study of the structural features of the Drumlummon lode.

GRISWOLD, L. S., The geology of Helena, Mont., and vicinity: Jour. Assoc. Eng. Soc., vol. 20, 1898, pp. 51–68.

A careful description of the character and distribution of the rocks at Helena, accompanied by a geologic map.

KEYES, W. S., Mineral resources of the Territory of Montana: Mineral Resources of the States and Territories west of the Rocky Mountains, 1868, Appendix, pp. 38–56.

Gives many valuable facts concerning the early mining history.

LEESON, M. A., History of Montana, 1739-1885. Chicago, 1885, 1367 pp.

Gives much detailed information concerning the settlement and history of the mining camps.

LINDGREN, WALDEMAR, Relation of the coal of Montana to the older rocks; Appendix B, Eruptive rocks: Tenth Census, vol. 15, 1886, pp. 733–734.

Concludes that the intrusive granite at Mullan Pass is of Jurassic age.

STONE, R. W., Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 75–98.

Deals principally with the area east of that concerned in this report.

WALCOTT, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244.

In this paper are given the type descriptions of certain divisions of the Belt series.

WEED, W. H., Granite rocks of Butte, Mont., and vicinity: Jour. Geology, vol. 7, 1899, pp. 737–750.

The Boulder batholith is defined in this paper, and chemical analyses of the rock from different localities are given.

——— Mineral vein formation at Boulder Hot Springs, Mont.: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 227–255.

It is shown that the hot waters are forming veins filled with quartz, stilbite, and calcite, and containing small but appreciable amounts of gold and silver.

——— Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont., with an appendix on the microscopical petrography of the district, by Joseph Barrell: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 399–549.

——— Gold mines of the Marysville district, Mont.: Bull. U. S. Geol. Survey No. 213, 1903, pp. 88–89.

Outlines briefly some of the salient features of the gold veins at Marysville.

——— Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912, pp. 26–30.

Gives a geologic reconnaissance map of the area underlain by the Boulder batholith and a brief description of the general geology.

WINCHELL, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, pp. 287–294.

Attention is called to the tourmaliniferous character of the ore, and various rocks occurring at the mine are described petrographically.

GENERAL GEOLOGY.

CHARACTER AND DISTRIBUTION OF THE ROCKS.

Sedimentary rocks occur in the main only in the northern part of the region. They consist for the most part of an apparently conformable succession of limestone, shale, sandstone, and quartzite, ranging in age from Algonkian to Cretaceous. At certain localities deposits of poorly consolidated clays, gravels, and tuffs of Tertiary age—so-called lake beds—rest unconformably on the older rocks.

The prevailing rocks of the region are igneous—andesite and latite, quartz monzonite and aplite, dacite, and rhyolite. Of these the quartz monzonite predominates; it is of intrusive origin and invades all the rocks older in age than the lake beds. The other igneous rocks, except the aplite, which is closely associated with the quartz monzonite, are of extrusive origin and form thick stratiform series of lavas, tuffs, and breccias. The andesites and latites are older than the quartz monzonite, and the dacites and rhyolites are younger.

The distribution of these rocks is shown on the geologic map forming Plate I of this report. The small scale of the map—1:250,000 or approximately 4 miles to 1 inch—allows the broader features only to be shown. It is believed that for the greater part of the area the boundaries of the geologic formations as given are accurate to scale. An earlier geologic map of a portion of this region, based on reconnaissance work, appeared as Plate I in the report on the Butte district.[1] In that map, while in press, certain new data obtained during the present investigation were incorporated, with Mr. Weed's concurrence, but the older map was not completely revised.

Plate VII (p. 86) of this report shows the areal geology of Helena and vicinity on a scale of 1:62,500. This map was prepared by Mr. Weed and his assistants, and is published for the first time in this report in order to show the detailed distribution of the rocks in a district which is highly interesting geologically—details necessarily lost on the small-scale map of Plate I.

PROTEROZOIC ROCKS.

ALGONKIAN SYSTEM.

BELT SERIES.

The oldest rocks of the region are a series of limestones and shales, known collectively as the Belt series. Walcott recognizes eight formations, aggregating at the maximum 12,000 feet in thickness. The rocks occupy a large area in the northern part of the region of this report, but only the four uppermost formations are present. These in ascending order are known as the Spokane shale, Empire shale, Helena limestone, and Marsh shale. At Helena these attain a thickness of 3,300 feet, of which the Helena limestone makes up 2,400 feet, increasing to 4,000 feet at Marysville, according to Barrell.

In the present mapping no attempt was made to differentiate the various formations of the Belt series, and all rocks below the Flathead quartzite were mapped under the same symbol. They are the rocks termed by W. M. Davis "the barren slates, shales, and sandstones," encountered in the area between Helena and Mullan Pass on the Continental Divide and regarded as of probable Cambrian age.[2] They were assigned to the Algonkian system by Walcott, who believes that the unconformity at the base of the Flathead quartzite of Middle Cambrian age is of sufficient magnitude to justify the placing of the Belt series in the pre-Cambrian.

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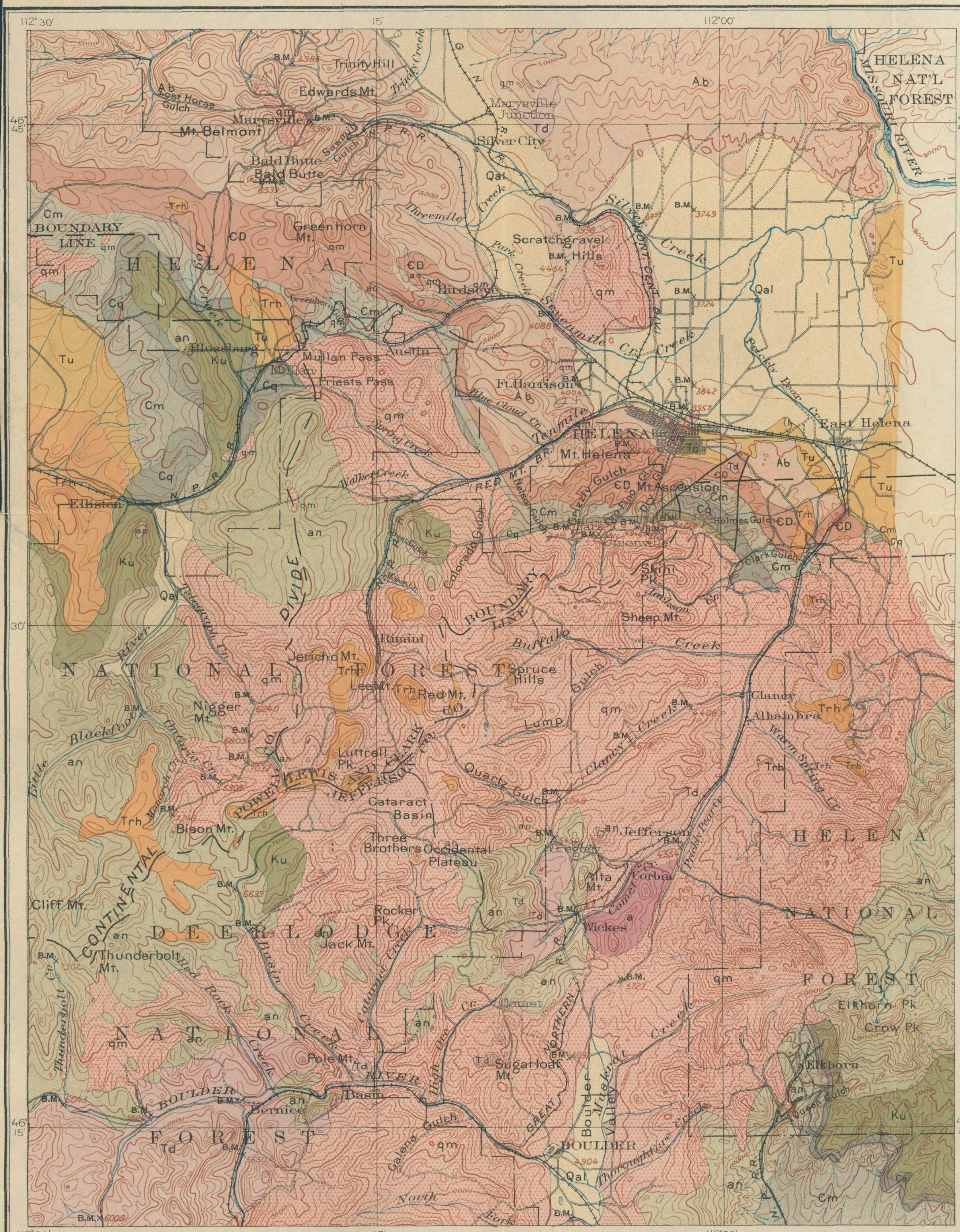
[1] Weed, W. H., Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912.

[2] Tenth Census, vol. 15, 1886, p. 703.



LEGEND

SEDIMENTARY ROCKS

Symbol	Description	Age
Qal	Alluvium	QUATERNARY
Tu	Undifferentiated sand, clay, shale, limestone, and conglomerate	TERTIARY
Ku	Undifferentiated limestone and sandstone, with some shale and conglomerate	JURASSIC AND CRETACEOUS
Cq	Quadrant quartzite	CARBONIFEROUS (Pennsylvanian (?))
Cm	Madison limestone	CARBONIFEROUS (Mississippian)
€D	Chiefly limestone and shale; some quartzite	CAMBRIAN AND DEVONIAN
Ab	Belt series *(Including Marsh shale, Helena limestone, Empire shale, and Spokane shale)*	ALGONKIAN

IGNEOUS ROCKS

Symbol	Description	Age
Trh	Rhyolite	TERTIARY
Td	Dacite	TERTIARY
a	Aplite	LATE CRETACEOUS (?)
qm	Quartz monzonite *(Including granodiorite and quartz diorite)*	LATE CRETACEOUS (?)
an	Andesite and latite breccias, tuffs, and lavas	LATE CRETACEOUS (?)
	Fault	

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE HELENA MINING REGION, MONTANA

Base map from Helena and Fort Logan atlas sheets, U. S. Geological Survey, with additional data from an unpublished map of the Elkhorn Mountains by W. R. Hill.
Surveyed in 1886–88, 1895–99, and 1910

TRUE NORTH / MAGNETIC NORTH 19½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{250000}$
2 0 2 4 6 8 10 Miles
2 0 2 4 6 8 10 Kilometers
Contour interval 200 feet.
Datum is mean sea level.
1913

Geology by Adolph Knopf and Henry G. Ferguson, with additions from Joseph Barrell, R. W. Stone, and W. H. Weed
Surveyed in 1911

House Doc. ; 62d Cong., 3d Sess.

PALEOZOIC ROCKS.

CAMBRIAN AND DEVONIAN SYSTEMS.

The Paleozoic rocks below the Madison limestone (Mississippian, or lower Carboniferous) comprise a conformable series, consisting dominantly of limestones, with some shale and quartzite. The aggregate thickness is estimated to be 2,300 feet and includes rocks of Cambrian and Devonian ages. Owing to the fact that the formations, except the Flathead quartzite, are not readily discriminable throughout the region the Paleozoic rocks below the Madison limestone have been mapped as a unit.

The lowest formation of the Paleozoic is a persistent and easily recognizable series of quartzites, known as the Flathead quartzite. It consists of a highly lithified, vitreous, coarse siliceous quartzite, stratified in beds commonly exceeding 1 foot in thickness. It is normally white, but in weathering takes on characteristically a red tint and in places displays cross-bedding. The thickness of the quartzite ranges from 80 to 180 feet.

The Flathead quartzite forms prominent outcrops and is well exposed. The contact with the underlying Belt series can be traced mile after mile northwest from Helena; it was found that the quartzite rests on the subjacent rocks in strict angular accordance. In some places it overlies the Helena limestone, in others the Marsh shale. The basal portion of the quartzite, nowhere more than a few feet thick, is slightly conglomeratic, the kind of pebbles composing it varying with the character of the underlying rocks. It is believed by Walcott that several thousand feet of strata were removed before the Flathead was laid down, and this is held to prove that a profound unconformity separates the Flathead from the underlying Belt series.

Above the quartzite, which is so prominent a horizon marker, is a great thickness of limestone strata, with interstratified shales of Cambrian and Devonian age. Details concerning these rocks are given in the description of the local geology of Helena (pp. 86–98).

CARBONIFEROUS SYSTEM.

MADISON LIMESTONE.

The Madison limestone is prominently developed in the northern part of the region. Its basal member is a dense dark gray-blue limestone, which contains crinoid remains and other fossils and is pierced by innumerable tremolite needles. This member seems to range in thickness from 100 to 200 feet. Above this comes a heavy succession of thickly bedded, coarsely crystalline limestone, which commonly forms bold outcrops of dazzling whiteness.

The total thickness at Helena, according to Weed, is 2,600 feet. The age is Mississippian (lower Carboniferous).

QUADRANT QUARTZITE.

The Quadrant quartzite overlies the Madison limestone conformably. It consists predominantly of quartzite and ranges in thickness from 190 to 500 feet in the Helena area. The quartzite has a characteristic appearance that distinguishes it readily from the other quartzites of the region. It is a light-gray rock of dense, almost cherty texture and outcrops show typical rough hackly surfaces. As a rule the bedding is neither clearly nor positively recognizable. The age of the formation here correlated with the typical Quadrant is probably Pennsylvanian (upper Carboniferous). To the west, in the Philipsburg quadrangle, Calkins obtained Pennsylvanian fossils from the Quadrant formation. In other areas to the east, however, rocks referred to the Quadrant formation have yielded Mississippian fossils.

Phosphate rock of good grade was found in 1911 by J. T. Pardee, of the Geological Survey, near the top of the Quadrant quartzite in the town of Elliston.

MESOZOIC ROCKS.

JURASSIC AND CRETACEOUS SEDIMENTARY ROCKS.

Rocks definitely determined as of Jurassic age occur at Elliston, where they overlie the Quadrant quartzite in angular concordance.

The beds of determined Jurassic age are buff-weathering arenaceous limestones and some purer limestones, aggregating 50 feet in thickness, referable to the Ellis formation. At the base, as exposed at Elliston, is a sill of diorite porphyry 25 feet in thickness. The basal beds are highly fossiliferous; above them, and possibly a part of the same formation, rests a banded sandstone, as a rule remarkably cross-bedded, with numerous unconformities between the different sets of cross-bedded laminæ. The sandstone is a coarse quartzose rock, carrying numerous minute black chert particles, which impart a speckled appearance to the rock. In places fragments of lignitized vegetal matter, some over a foot long, were found. The section immediately at Elliston shows a thickness of several hundred feet of this sandstone, although there are a few intercalated beds of limestone and of a soft, greenish, conchoidally breaking shale.

The fossils were submitted to T. W. Stanton, who reports:

7242, No. 1. Elliston, Helena quadrangle, Mont.
Pentacrinus asteriscus Meek and Hayden.
Camptonectes pertenuistriatus Hall and Whitfield.
Pseudomonotis (Eumicrotis) curta (Hall).
Undetermined gastropod casts.
Cardioceras ? sp. (small fragment).
This lot is from the marine Jurassic Ellis formation.

Fossils were found, apparently at the same locality, by Lindgren in 1883 and were referred also to the Jurassic by Whitfield.[1]

There is no evidence of unconformity between the Ellis formation and the underlying Carboniferous rocks at Elliston. At Philipsburg, 75 miles to the west, however, the Ellis formation, although resting in angular concordance on the underlying Carboniferous, has a basal conglomerate holding pebbles of Carboniferous and older rocks. An erosion interval is therefore proved.[2] The maximum thickness of the Ellis formation at Philipsburg is 430 feet.

In the region surrounding Elliston there is an extensive development of coarse-grained speckled sandstone lying conformably above the known Jurassic rocks. The sandstone is commonly cross-bedded and semi-quartzitic in appearance. A specimen of dark-gray cross-bedded sandstone from the summit of the 7,000-foot ridge southwest of Elliston was found microscopically to be composed of particles of quartz, black chert, and shale. Considerable secondary quartz in optical continuity with the original grains had grown around the quartz particles. Some few of the quartz grains (0.5 millimeter in diameter) are remarkably perfectly rounded; the chert fragments are subangular.

Limestone, shale, and conglomerate are associated with the cross-bedded sandstone in small amount. Toward the top the rocks apparently grade into the andesite and latite series. Limestones of like appearance and fossil content (obscure fresh-water shells) are interstratified with the volcanic rocks above and the sedimentary rocks below.

These rocks are referred to the Cretaceous, but the line between them and the underlying Jurassic was not determined, and the entire assemblage, Jurassic and Cretaceous, is shown under one symbol on the geologic map.

Rocks of probable Cretaceous age occur at other localities around the margin of the Boulder batholith and even within it, as roof remnants. They occur at Elkhorn, where they are termed by Weed[3] the Crow Ridge series, north of Rimini, south of Helena, and at the head of Basin Creek, where they form part of the cover of the batholith.

IGNEOUS ROCKS.

ANDESITES AND LATITES.

OCCURRENCE.

The remnants of the roof of the Boulder batholith consist principally of andesitic rocks, comprising a bedded series of lavas, breccias, and tuffs, with some interstratified quartzite, shale, and limestone. At most localities the truly volcanic portion predominates.

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[1] Tenth Census, vol. 15, 1886, p. 703.

[2] Emmons, W. H., and Calkins, F. C., Prof. Paper U. S. Geol. Survey No. 78, 1913, p. 75.

[3] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 440.

Rocks of andesitic character are developed also in great volume on both the eastern and western borders of the batholith. As a rule breccias and tuffs form the bulk of the andesite and latite series; they predominate at Elkhorn on the east and form practically the entire series on the west. The breccias are in places rather coarse; at Cliff Mountain, which displays a scarp of stratified breccias (Pl. II *A*), some of the included blocks of andesite are 3 feet long. At this locality beds of hard green and black shales are interstratified with the breccias. Sedimentary rocks are found at other places, as east of Thunderbolt Mountain, where andesite, breccia, banded tuff, and hard shale are interstratified. Fossiliferous limestone carrying fresh-water forms occurs southwest of Elliston.

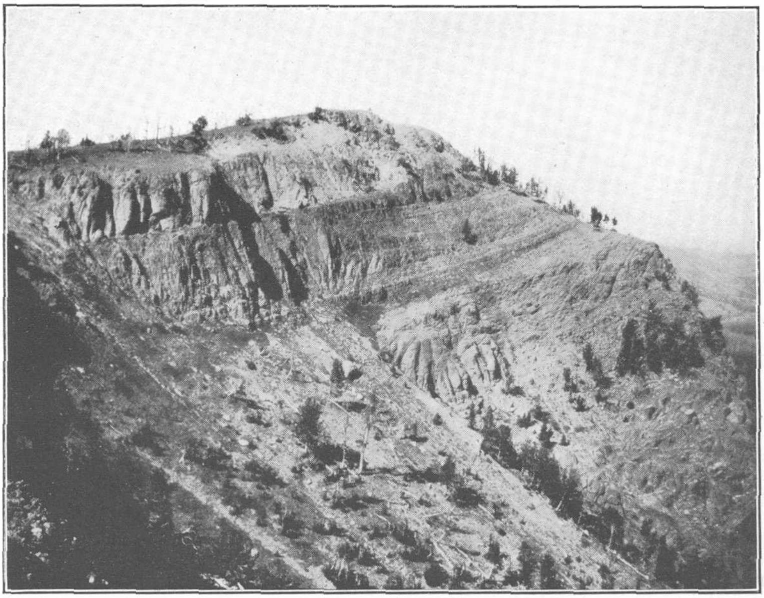
Where the underlying rocks are exposed the andesites rest on them in angular accordance. At one locality only, at the mouth of the canyon of Tenmile Creek, do sedimentary rocks overlie the andesites. These rocks are thermally metamorphosed sediments, mainly of original arenaceous character. Quartzites, some of great purity, are common, but most are partly micaceous. These rocks, as a whole, appear to correspond to Weed's Cretaceous of the Helena district. Near the contact of the andesitic rocks and the overlying sedimentary rocks there is apparently an interstratification of both kinds.

On the eastern side of the batholith, at Elkhorn, the andesitic rocks dip eastward at a gentle angle away from the granite; on the west, at Cliff Mountain, they dip westward at angles of 15° to 20° away from the batholith, passing beneath the soft Tertiary deposits of Deer Lodge Valley. In the areas lying within the batholith steeper dips occur, some reaching 45°, and the strike differs greatly from place to place.

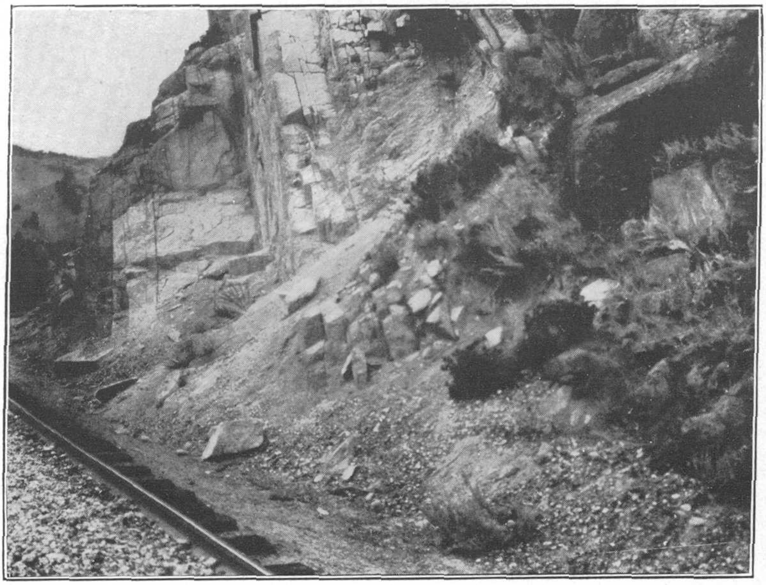
The andesite and latite series is of considerable economic interest, because it forms the country rock at some of the important mines. In fact, the largest producer, the Alta, credited with an output of $32,000,000, is inclosed in rocks of this kind. The favorable factor, however, in the formation of these deposits was certainly not the chemical character of the rock but its position with respect to the sources of mineralization.

GENERAL CHARACTER.

On the steeper declivities the andesites generally form bold outcrops, below which extend long talus slopes of angular fragments. In a broad way they are of similar appearance, fine grain, and dark color. Where, however, the latites prevail, the outcrops weather to a light gray or white, and the exposures resemble those of the rhyolites of the region. On examination at any one locality in detail, the andesites are found to comprise a considerable number of varieties. For example, the andesites at the mouth of the canyon of Tenmile Creek



A. STRATIFIED ANDESITE BRECCIAS FORMING SCARP ON CLIFF MOUNTAIN.



B. JOINTING IN GRANITE SOUTH OF BOULDER.

show the following distinct varieties: (1) With numerous conspicuous feldspar phenocrysts; (2) with pyroxene phenocrysts alone prominent; (3) intermediate between (1) and (2); (4) amygdaloidal phases; (5) flow-banded phases; and (6) breccias, in which highly porphyritic fragments are inclosed in aphyric varieties; also other breccias, probably flow breccias in the main. On the summit of Thunderbolt Mountain thick sheets of lava, strikingly different in appearance, are found in superposition. One variety, a dark bluish black aphanitic rock, carrying small obscure phenocrysts of hornblende and plagioclase, is a fresh-looking lava and shows flow banding but only on the weathered surface. The adjoining lava sheet is of altered appearance and is a bluish-gray rock, carrying numerous conspicuous tabular plagioclase feldspars. It presents, therefore, a strong contrast to the former rock. Glassy porphyries also are prominently developed here.

These rocks are all of typical andesitic appearance. With them, however, are associated other varieties, which exhibit an obvious divergence from the andesitic type. These show small scattered phenocrysts of plagioclase and biotite in a groundmass of flinty texture and commonly display flow streaking. Conspicuously flow-banded varieties, nearly devoid of phenocrysts and of red flinty appearance, are found east of Boulder. North of Thunderbolt Mountain and west of Thunderbolt Creek these rocks, which chemical analysis shows to belong to the latite group, are present in great abundance. Flow banding and streaking is developed in these latites in an extraordinary degree, so that they rival in this respect the Tertiary rhyolites of the region.

PETROGRAPHY.

An andesite from the entrance of the canyon of Tenmile Creek is a dark heavy rock, in which the pyroxene phenocrysts are prominent because weathering in relief. In thin section it is found to contain numerous phenocrysts of calcic plagioclase, ranging up to $Ab_{30}An_{70}$, and of augite, which are surrounded by rims of brown-green amphibole. The groundmass consists of tabular plagioclase and granular amphibole, with some biotite and accessory magnetite bordered by titanite (?) rims. The rock has very probably been modified to some extent by contact metamorphism exerted by the near-by intrusion of quartz monzonite. It corresponds in appearance and mineralogy to the hornblende andesite porphyry, altered from an augite andesite and approaching a basalt in composition, from the southwestern part of the Elkhorn district, which has been described by Barrell and of which an analysis is available.[1]

The bluish-black aphanitic andesite from Thunderbolt Mountain shows a porphyritic hyalopilitic texture. The andesite with the

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 529.

prominent tabular feldspar crystals contains phenocrysts of plagioclase near Ab_1An_1 and of chloritized and epidotized femic minerals in a cryptocrystalline matrix. Both are much poorer in femic minerals than the first-described andesite.

The latites are characterized by the occurrence of plagioclase and biotite phenocrysts in a cryptocrystalline groundmass of salic appearance. Blue, red, and flint-gray are common colors. Streakiness and flow banding are nearly universal.

A specimen from the top of the ridge on the west side of Thunderbolt Creek, near its head, is a porphyry carrying small vitreous plagioclase phenocrysts and bronzy plates of biotite embedded in a dark-red glassy groundmass of dull appearance. It displays a strongly marked eutaxitic structure, especially conspicuous on weathered surfaces, which are of light-gray color. Under the microscope the feldspars, which are well preserved, are found to be andesines near Ab_1An_1, and the biotite plates to be chloritized. The groundmass is glassy, though partly devitrified; flow banding is finely developed, and swirls encircling the feldspars are common, together with a certain amount of breakage of the phenocrysts thus enveloped. Apatite and ilmenite, now altered to leucoxene, are present as accessory minerals.

Analysis of latite from Thunderbolt Creek, Mont.

[J. G. Fairchild, analyst.]

SiO_2	64.45	H_2O+	0.80
Al_2O_3	17.69	TiO_2	.69
Fe_2O_3	1.33	CO_2	.29
FeO	1.93	P_2O_5	.16
MgO	.57	S	.04
CaO	3.73	MnO	.05
Na_2O	3.85	BaO	.19
K_2O	3.68		
H_2O-	.59		100.04

The low magnesia and the relatively high potash, together with the general andesitic composition, are noteworthy. The potash, which, as shown by the mineralogic make-up of the rock, is restricted largely to the groundmass, evidently caused the flowing lava to become stiff and viscous, so that most of these rocks show a highly flow-banded structure.

CONTACT-METAMORPHIC ALTERATION OF THE ANDESITES AND LATITES.

The andesites and latites in proximity to the quartz monzonite intrusion have undergone contact-metamorphic alteration. This has taken one of two forms, either simple recrystallization or recrystallization with addition of material. The former is the more common occurrence.

The contact-metamorphic alteration seems to be most apparent to the eye in the latites or andesites high in potash. Near the contact these rocks lose their dark color and become nearly white; the groundmass takes on obviously a microcrystalline character. Where the latites are flow banded this structure is retained, and the increased light color of the rocks enhances their resemblance to rhyolites. Under the microscope the main change is found to have taken place in the groundmass; whereas before metamorphism it was of cryptocrystalline texture, it is now a clear, well-individualized aggregate, consisting essentially of quartz and orthoclase, with biotite dispersed through it in small flakes. In places tourmaline appears as an accessory.

The most extensive metamorphism of the andesites has taken place on the north side of Elkhorn Peak, extending down to Prickly Pear Creek at 8,000 feet altitude. The rocks are mainly breccias and have been remarkably thoroughly recrystallized. The matrix of the breccias is commonly more coarsely crystalline than the included fragments, and in fact in many localities resembles a fine-grained diorite. The rocks are extensively injected with aplite dikes, many of which carry tourmaline, probably pyrogenetic, and are most thoroughly recrystallized where pierced by numerous aplitic dikelets. In the porphyries the augite phenocrysts have generally been converted to fibrous amphibole, which along with disseminated flakes of biotite, is also common in the groundmass.

The most notable pneumatolytic metamorphism observed in the region is that which has affected the thick stratum of andesitic breccia overlying the large limestone bed on the southwest flank of Elkhorn Peak. The breccia is composed of angular fragments of andesite, the largest 4 inches long; it has obviously been metamorphosed, showing patches of garnet and in places discrete areas composed solidly of fibrous tremolite, with fibers up to 2 inches in length. Thin sections cut from different places naturally show different textures and proportions of the component minerals. Garnet, pyroxene, scapolite, plagioclase, and accessory titanite and apatite, are the minerals present. Remnants of pyroclastic structure remain, as indicated by the presence of unobliterated porphyry fragments; plagioclase phenocrysts or pyroclastic fragments tend to remain intact, but as a rule the new growth of lime silicates has spread throughout the rock. The garnet is not grossularite, but very probably andradite, from the fact that its refractive index is near that of the minimum index of titanite intergrown with it. The pyroxene is a monoclinic variety, suggestive of hedenbergite in part. Scapolite occurs locally in broad plates poikilitically inclosing the other minerals. The plagioclase is mainly residual and is commonly scapolitized. All these features, together with the macroscopic patches of fibrous tremolite, indicate that the breccia was originally calcareous, and was subsequently metamorphosed under the influence of chlorine-bearing solutions.

Northwest of Mullan Pass andesite sills lying between thick beds of coarsely garnetized sedimentary rocks are traversed by small veins carrying calcite and dodecahedral garnet.

AGE OF THE ANDESITES.

The age of the andesites is a matter of considerable interest, inasmuch as they are the youngest rocks into which the Boulder batholith is intrusive. Weed states that an Eocene age is indicated, but the evidence on which this is based is not given.[1] That they are certainly of pre-Oligocene age at least is proved by the fact that Oligocene sediments overlie them west of Cliff Mountain,[2] and at Pipestone Springs, near the southern border of the batholith.[3]

Southwest of Elliston the andesite breccias at the base of the andesite series were found interstratified with the sedimentary rocks, principally cross-bedded semiquartzitic sandstone, that overlie the fossiliferous strata of the marine Jurassic. A certain amount of conglomerate and limestone occurs with the sandstone, and the conglomerate contains some andesite fragments. These facts tend to show that the andesitic eruptions went on contemporaneously with the deposition of the late Mesozoic sediments. In the andesites occur thin intercalated beds of fossiliferous limestone, in appearance like those underlying the andesites. T. W. Stanton reports on the fossils:

7243. From a 7,000-foot mountain southwest of Elliston, Mont. This lot consists of drab fresh-water limestone containing poorly preserved undetermined ostracods and gastropods. The age is probably Cretaceous.

It is known that in eastern Montana volcanic activity commenced in the Montana epoch of the Cretaceous. Formerly it was believed that the eruptions began only after the Laramide orogenic revolution, but this has been disproved both by paleozoologic and paleobotanic evidence.[4]

It will therefore be held, pending the collection of more satisfactory material from the limestones interbedded with the andesites overlying the Boulder batholith, that the andesites are of late Cretaceous age.

The original thickness of the andesitic rocks is unknown. Southeast of Elkhorn, where they are regularly bedded and dip at a low

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[1] Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 29.

[2] Douglass, Earl, Annals Carnegie Mus., Pittsburgh, vol. 5, 1909, p. 263.

[3] Matthew, W. D., Bull. Am. Mus. Nat. Hist., vol. 19, 1903, p. 197.

[4] Stone, R. W., and Calvert, W. R., Stratigraphic relations of the Livingstone formation of Montana: Econ. Geology, vol. 6, 1910, pp. 551-557, 652-669, 741-764.

angle, a thickness of 2,000 feet is indicated,[1] but this figure is obviously a minimum estimate. The high ridges in which the andesites are exposed at Elkhorn have been carved from an area that has been subjected to prolonged and intense erosion ever since the beginning of the Tertiary period. During the same time other parts of the surrounding region, equally subjected to erosion, have been denuded of several thousand feet of rock covering, so that it is highly probable that the andesitic rocks had originally a far greater thickness.

QUARTZ MONZONITE.

GENERAL CHARACTER.

Granite is the predominant rock exposed throughout the region. It is, however, not a true granite, but is accurately designated a quartz monzonite. In local usage the term granite is employed universally and where adopted in this report it is employed in the popular sense. No true granite was found anywhere in the region; such modifications of the quartz monzonite as were noted are toward dioritic rocks.

The granite area of this region is the northern part of the great intrusive mass of granitic rock extending uninterruptedly from the Highland Mountains, 16 miles south of Butte, to Mullan Pass on the north. This large intrusion was named by Weed the Boulder batholith, from the name of the mountains throughout which it is exposed.[2] It occupies an area of about 1,100 square miles, extending 60 miles from north to south and averaging 18 miles in width.

In the mountainous areas the granite weathers in characteristic fashion, forming huge bowldery outcrops and making the country exceedingly rough and nearly impassable.

Locally the granite is traversed by pronounced systems of jointing, as at Rimini and also at Boulder (Pl. II, *B*, p. 24).

The granite has been quarried within the area considered in this report mainly at two points—on the Rimini road 8 miles west of Helena and at a locality north of Clancy. The stone from Clancy is used in the construction of the wings of the State capitol at Helena.

PETROGRAPHY.

The prevailing rock of the Boulder batholith is a coarse granitoid composed in the order named essentially of plagioclase, orthoclase, quartz, biotite, and hornblende. It is remarkably homogeneous in composition over a large area. A widespread feature, extending more or less persistently from Mullan Pass to Butte, is a rough porphyritic habit due to the development of large imperfect phenocrysts of orthoclase.

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[1] Personal communication by R. W. Stone.

[2] Weed, W. H., Granite rocks of Butte, Mont., and vicinity: Jour. Geology, vol. 7, 1899, p. 737.

Toward the margins of the batholith the rock becomes somewhat finer grained and equigranular, as noted south of Helena, east of Boulder, and other localities. The rock apparently becomes more basic and the eye is at a loss to surely distinguish quartz monzonite from such modifications as granodiorite and quartz diorite. At certain localities, as verified by the microscope, the rock becomes dioritic in character.

A considerable number of chemical analyses of rock from widely separated localities on the northern part of the batholith are available, and emphasize the chemical homogeneity suggested by the mineral composition. Two of these analyses were made during the course of the present investigation; the others have been published by Weed.[1]

Analyses of quartz monzonite from northern part of the Boulder batholith.

	1	2	3	4	5	6
SiO_2	65.91	64.49	64.17	67.12	64.31	64.03
Al_2O_3	15.32	15.49	15.25	15 00	15.44	15.58
Fe_2O_3	2.28	1.19	2.16	1.62	2.43	1.96
FeO	2.02	2.71	2.98	2.23	2.58	2.83
MgO	1.52	1.89	2.60	1.74	2.21	2.15
CaO	3.28	4.32	4.24	3.43	4.22	4.20
Na_2O	3.08	3.53	2.62	2.76	2.71	2.76
K_2O	4.80	4.04	4.34	4.52	4.09	4.11
H_2O-	.60	.16	.16	.09	.19	.23
H_2O+	.60	.48	.65	.58	.79	.76
TiO_2	.59	.56	.67	.48	.71	.59
P_2O_5	.18	.19	.16	.15	.22	.18
MnO	Trace.	.07	.04	.06	Trace.	.11
SrO	....	....	Trace.	.03	Trace.	.04
BaO	.10	.06	.07	.07	.07	.07
Li_2O	....	....	Trace.	....	Trace.	....
S	.02	....	....	....	Trace.	....
SO_3	....	....	.07	Trace.	....	....
Cl	....	....	Trace.	....	....	....
FeS_2	....	.13	....	....	....	....
	100.51	99.80	100.18	99.88	99.97	99.86

1. Valley Forge mine, Rimini. J. G. Fairchild, analyst.
2. King Solomon mine, Clancy. J. G. Fairchild, analyst.
3. Frohner mine. H. N. Stokes, analyst.
4. Boulder. H. N. Stokes, analyst.
5. Elkhorn. H. N. Stokes, analyst.
6. Butte, average of four closely similar analyses. H. N. Stokes, analyst.

The average analysis of the quartz monzonite at Butte has been added to show that it does not differ essentially from those of rocks from other parts of the batholith; it is, in fact, practically identical with that of the rock from Elkhorn, which lies on the eastern margin of the batholith, 33 miles northeast of Butte.

Under the microscope rock from different parts of the batholith shows broadly similar features. A zoned plagioclase near labradorite ($Ab_{50}An_{50}$) is found to be the dominant feldspar; the most calcic variety, from Elkhorn, as measured on the core is $Ab_{45}An_{55}$ and the least calcic $Ab_{59}An_{41}$—a remarkably narrow range in composition. Orthoclase and quartz are present in abundance and lie interstitially

[1] Op. cit., pp. 737–750.

between the idiomorphic plagioclase crystals. Biotite and hornblende are the ferromagnesian minerals, and the biotite commonly predominates. At Elkhorn a small amount of augite intergrown with the hornblende is found but none occurs elsewhere. The accessory minerals are magnetite, titanite, apatite, and zircon. The computed mineral composition of the quartz monzonite from Clancy (see p. 56) is 41.58 per cent plagioclase, 18.90 per cent orthoclase, 19.86 per cent quartz, 8.94 per cent biotite, and 7.26 per cent hornblende. At Elkhorn, according to Barrell,[1] it contains by volume 34 per cent labradorite, 22 per cent orthoclase, 25 per cent quartz, 7 per cent biotite, 9 per cent hornblende, and 2 per cent augite.

On Red Rock Creek and extending to Thunderbolt Mountain is a large body of gray diorite of medium grain. Rock from the mouth of the tunnel on the Calendar prospect under the microscope is seen to consist predominantly of plagioclase ($Ab_{55}An_{45}$), with interstitial quartz and orthoclase, each probably under 10 per cent in amount. Hornblende and biotite occur in minor quantities. Whether this diorite is a marginal phase or an earlier or later intrusion than the main batholith was not determined.

CONTACT METAMORPHISM.

The granite batholith and its outliers have invaded a great number of rocks of widely different character. The contact-metamorphic alteration produced by the invasion is correspondingly diverse from place to place, dependent on the original chemical composition of the rocks and on the local accession of material during metamorphism.

The simplest form of the contact metamorphism is the marmarization of the limestones in proximity to the granite contact. This is well shown south of Helena, where the Madison limestone has been coarsely recrystallized, so that it forms conspicuous snow-white outcrops. It is worthy of note that the basal member of the Madison limestone contains a multitude of minute tremolite and tourmaline needles, although the matrix inclosing them has not recrystallized. The tourmaline-tremolite content extends for over a mile from the visible contact. The content of tourmaline and tremolite differs in different beds; some contain much delicately fibrous or bladed tremolite and no tourmaline; others contain much tourmaline, and again others contain both minerals together. Tremolite, however, is by far the more abundant.

Along the contact south of Helena the rocks overlying the Quadrant quartzite have been extensively recrystallized, forming various kinds of biotite hornfels and micaceous quartzite. The metamorphism of the andesites has already been described on pages 26–28.

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 538.

Garnetization has taken place on an extensive scale west and northwest of Mullan Pass at distances of over a mile from the exposed contact. Thick beds of solid garnet rock have been produced, the garnet crystals attaining a maximum diameter of 1 inch. Associated sills of andesite, as already pointed out, are traversed by veinlets carrying calcite and crystalline garnet.

At other localities in the region garnet and other silicate minerals traverse limestones in veins. They occur along the contact west of Nelson Gulch. Here the pure snow-white coarse marble is traversed by masses of lime-silicate minerals breaking across the bedding in

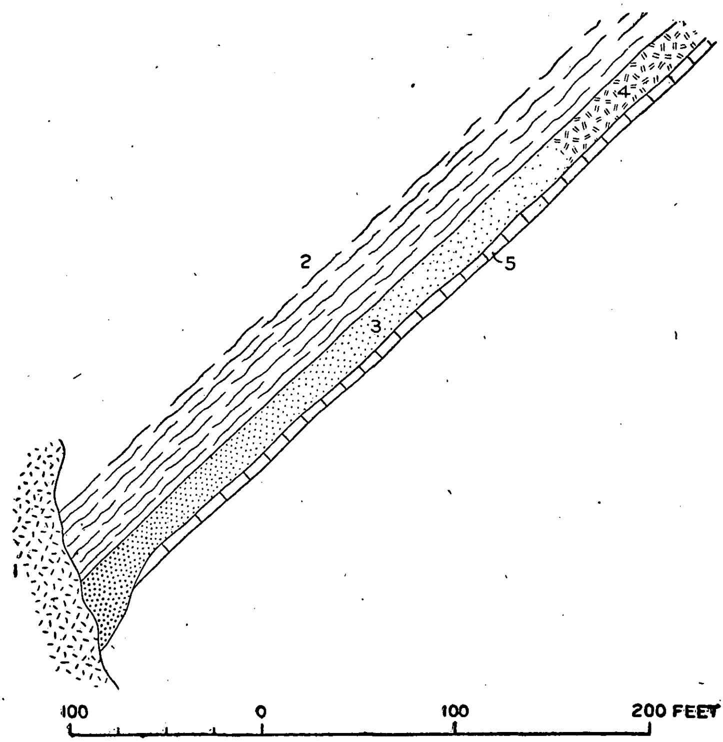


FIGURE 2.—Contact-altered rocks in Colorado Gulch. 1, Quartz monzonite; 2, biotitic quartzite; 3, garnet rock; 4, diopside hornstone; 5, marble stratum.

veinlike fashion. Similarly at the Spring Hill mine metamorphic minerals are developed locally and abruptly across the bedding of thinly stratified limestone.

These facts prove, without the necessity of chemical analyses, that an accession of material has taken place during contact metamorphism.

Near Colorado Gulch, west of Helena, contact-metamorphic rocks are exposed at the granite contact. Garnetization has proceeded continuously to a distance of 350 feet from the granite. At this distance the garnet rock merges into a series of thin-bedded dense diopside hornstones, aggregating 12 feet in thickness. The hornstones are inclosed between a footwall of black micaceous quartzite and a hanging wall of coarse white marble 4 to 5 feet wide. The strike can readily be followed, as the marble on the hanging wall forms a continuous outcrop. Near the granite contact, as shown in figure 2, the garnetization has spread into the marble, forming a mass of brown garnet rock 25 feet thick. The portion of garnet rock that has replaced the limestone is irregularly filled with discontinuous veinlets or blebs of quartz holding large euhedral garnets. A small amount of galena and brilliant black sphalerite is intergrown with the garnet rock, but on the whole seems to favor the quartzose portions of the rock. Enough sulphides are present to have encouraged the prospector to sink an exploratory shaft.

Under the microscope the garnet rock is found to consist essentially of garnet, intergrown with small amounts of diopside, hornblende, calcite, and quartz. The cores of the garnet are generally isotropic, but the margins show zonal structure and optical anomalies. By the immersion method the index of the garnet is found to be 1.77, indicating a variety intermediate between grossularite and andradite. The hornstone into which the garnet rock grades along the strike is seen microscopically to consist of an intergrowth of a finely granular diopside and calcite, with accessory pyrrhotite.

Other examples of contact-metamorphic rocks that carry sulphides and oxides in quantities of economic importance are described under the contact-metamorphic ore bodies.

AGE OF THE QUARTZ MONZONITE.

The first description of the granitic rock from what is now known as the Boulder batholith is given by S. F. Emmons,[1] based on reports and specimens brought in by special agents of the Census. He recognized its unusual character and pointed out that it "proves to be a diorite of somewhat singular character, possessing certain marked characteristics." It was provisionally designated a diorite-granite and was thought to represent an eruptive body of Archean age.

Lindgren, who was a member of the Transcontinental Survey of 1883, termed this intrusive mass the Jefferson granite field, and regarded the great eruption as possibly of Jurassic age. He gave a brief petrographic description of the granite and recognized its resemblance to Zirkel's Jurassic granite from Nevada. The coal-bearing sediments resting on the eroded surface of the granite at Mullan Pass were believed to be probably of Laramie age.[2]

The later work on this problem has been done mainly by Weed, who assigned a post-Cretaceous age to the batholith in 1899.[3] His final view is that the granite is Miocene in age.[4]

[1] Tenth Census, vol. 13, 1885, p. 95.

[2] Idem, vol. 15, 1886, p. 733.

[3] Weed, W. H., Granite rocks of Butte, Mont., and vicinity: Jour. Geology, vol. 7, 1899, p. 737.

[4] Weed, W. H., Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 29.

The evidence at hand is still not as complete or conclusive as is desirable. The youngest rocks into which the granite is intrusive are the andesites and latites, which, as shown earlier in this report, are probably of Cretaceous age and are definitely of later age than the Ellis formation. On the eroded surface of the granite west of Mullan Pass rests a series of unconsolidated lignite-bearing sediments, possibly of White River (lower Oligocene) age. At other localities in this part of Montana beds assigned by Douglass to the White River have been found by him to be slightly lignitiferous. If, as seems most probable, the rocks at Mullan Pass should prove to be the equivalents of either the Lance or the Fort Union, which are common coal-bearing formations in eastern Montana, the period of intrusion of the batholith would be certainly of pre-Tertiary age.

The Boulder batholith, covering an area of 1,100 square miles is in all probability an outlier of the far greater Idaho batholith, which is situated 150 miles to the west and covers an area of 20,000 square miles.[1] Between the two are many similar batholiths, such as those of the Philipsburg quadrangle. These have been found by F. C. Calkins[2] to cut rocks of Colorado (late Cretaceous) age. This fixes the inferior limit, but the superior limit in that area is not known. In view of the foregoing considerations it is concluded that the available evidence points to a late Cretaceous age for the Boulder batholith.

APLITE.

OCCURRENCE AND CHARACTER.

Aplite is a common rock within the area of the Boulder batholith and around its margin. It forms dikes and irregular masses, some of which are measured in square miles. The largest of these masses, east of Corbin, is shown on the geologic map (Pl. I), but other extensive areas of aplite were noted west of Jefferson and on the ridge south of Red Mountain. As estimated roughly, the aplite forms 5 per cent of the surface exposure of the batholith. Although aplite is so abundant, pegmatite is rare.

The border of the granite at many places is fringed with aplite, usually tourmaliniferous, which lies between the normal quartz monzonite and the invaded rock. Dikes of aplite also penetrate the rocks that inclose the batholith. They are particularly abundant near Wickes, where they occur as persistent dikes, up to 200 feet in thickness, traversing the andesites.

The aplites are fine-grained granular white rocks composed essentially of orthoclase and quartz, with minor amounts of biotite. Certain coarsely granular masses show a normal granitic texture and should be designated alaskite. Under the microscope the typical

[1] Umpleby, J. B., An old erosion surface in Idaho: Jour. Geology, vol. 20, 1912, p. 145.
[2] Personal communication.

aplites show a panidiomorphic aggregate of orthoclase, somewhat perthitic, and quartz, with subordinate plagioclase and biotite and accessory magnetite, titanite, and apatite. Two analyses of aplites from Elkhorn are available.

The aplites are commonly tourmaliniferous, but it is usually difficult to determine whether the tourmaline is an original constituent or was subsequently introduced. At a number of localities, however, the tourmaline seems to be clearly of pyrogenetic origin and not connected with fractures or jointing. South of Montana City there occurs a considerable body of aplite carrying nodules composed of tourmaline and quartz, which are scattered throughout the rock with some regularity. The nodules range from a fraction of an inch up to several inches in diameter, and from regular spheroids to most irregular blebs. The aplite is a snow-white rock, completely devoid of biotite, which as a rule is present to the extent of 1 or 2 per cent in the other aplites of the region. Under the microscope the aplite is seen to be of normal composition and texture; in the tourmaliniferous portion the tourmaline, which is an iron-rich variety, is intergrown in poikilitic fashion, mainly with quartz, but also with some orthoclase.

Similar tourmalinic nodules occur in the aplite at Elkhorn and have been described by Barrell.

ORIGIN OF THE APLITES.

Some aplites show intrusive contacts with the inclosing quartz monzonite, but others, especially those occurring along the borders of the batholith as marginal facies, show blended contact. The intrusive contacts, moreover, are welded and the aplite exhibits little evidence of chilling, so that it is clear that the aplite was intruded while the quartz monzonite was still hot.

Despite the great abundance of aplite in the region, there is a noteworthy scarcity of other satellitic intrusions, especially of lamprophyric or so-called complementary rocks, which are practically absent. This fact leads to the conclusion that the aplite was not derived from the splitting up of a single magma into two magmas, one salic and the other femic, but that it originated from the quartz monzonite magma by a process of fractionation during the cooling and consolidation of that magma. During this process tourmaline was concentrated in the aplite magma; by further segregation within the aplite magma the tourmaline formed the tourmaline-quartz nodules.

CENOZOIC ROCKS.

TERTIARY SEDIMENTARY ROCKS.

Stratified deposits which are here referred to the Tertiary period occur at three localities in the region—the Continental Divide west of Mullan Pass, at Helena, and at Elliston. Those deposits exposed at Helena and Elliston belong to the so-called lake beds of western Montana.

The deposit near Mullan Pass consists mainly of clays and poorly indurated shales carrying some thin beds of low-grade lignite. Coarse conglomerate containing limestone and quartzite pebbles occurs, but as natural exposures are poor its relation to the rest of the deposit could not be determined. To the east the sedimentary rocks are apparently overlain by rhyolite. They rest on the eroded surface of the northern end of the Boulder batholith and contrast strongly with the thermally metamorphosed and garnetized older rocks surrounding them.

Some poorly preserved and indeterminable leaves were found near the coal exposures. These rocks were referred to the Laramie by Lindgren,[1] probably on the basis of their lignite content. Coal-bearing rocks of as late age as Fort Union (lower Eocene) having been formerly assigned to the Laramie, it is possible that the rocks at Mullan Pass are of Fort Union age. There is, moreover, a possibility that they may be even younger, inasmuch as Douglass has found beds of White River (lower Oligocene) age to be slightly lignitiferous, although this is uncommon in the so-called lake beds of western Montana.

The deposits near Helena consist of a bedded series of conglomerate, sands, clays, and tuffs, supposedly of Miocene age. West of Elliston is an extensive area of similar rocks, which according to Douglass are very probably of lower Oligocene age.[2] These beds are usually spoken of as lake beds. It is noteworthy that there are two very similar sets of lake beds in western Montana—one of lower Oligocene age and the other upper Miocene—lithologically alike and discriminable only by their mammalian fauna.

IGNEOUS ROCKS.

DACITES.

GENERAL CHARACTER AND DISTRIBUTION.

Dacites, consisting of a bedded succession of lavas, tuffs, and breccias, form a notable accumulation of volcanic rocks in the area immediately west of Wickes, and more especially in the area west of Basin. They are present here in great volume and extend southwestward to Butte, where they form Big Butte, from which that city takes it name. They occur also east of Silver City, in the northern part of the region considered in this report.

Although the dacites, when examined in detail, comprise a number of varieties, they display in general a remarkable uniformity.

[1] Tenth Census, vol. 15, 1886, p. 733.

[2] Douglass, Earl, Fossil Mammalia of the White River beds of Montana: Trans. Am. Philos. Soc., new ser. vol. 20, 1902, p. 244.

The commonest variety of dacite is a porous ash-gray rock carrying a multitude of plagioclase feldspar and quartz phenocrysts interspersed with small brilliant black flakes of biotite. The size and abundance of the feldspar and quartz phenocrysts is the characteristic feature of the dacites. The feldspars, many of which are an inch long, together with the quartzes make up, as a rule, half the bulk of the rock.

The dacites are unusually well exposed along the sides of Boulder Valley west of Bernice to the mouth of Lowland Creek. Tuffs exposed on both sides of the valley prove that the bedding is horizontal. This is the more noteworthy because the flow banding in the lava sheets is commonly vertical and certain lavas show a platy structure standing at a high angle. Swirl structures are common. Lava, otherwise massive, in places contains large irregular inclusions of breccia, which are enwreathed by a platy parting in the lava.

The section west of Bernice shows that here the dacitic rocks attained a thickness of at least 2,400 feet. The surface on which they were erupted was one of considerable relief carved in the granite and andesite. A section of this old surface is well exposed in a railroad cutting near the Great Northern tunnel, south of Wickes. Here at the base of the dacite series occurs a stratum of dacite tuff resting on an old stony soil derived from the underlying andesite. The surface is of moderate but irregular relief, and the tuff bed conforms completely to the underlying topography, proving that the tuff here is a windborne deposit. Locally, as near the Minah mine, conglomerate carrying well-rounded cobbles up to 12 inches long, some of them dacite but most of them andesite and aplite, is associated with tuff and lava sheets and doubtless indicates the operation of fluviatile agencies during the eruption of the dacites.

Dikes of dacite traverse the quartz monzonite and the andesite-latite series. At some localities these dikes are remote from areas of the corresponding surface rocks. Because of their highly porphyritic character such dikes may easily be mistaken for granite porphyry or quartz diorite porphyry dikes. The porphyries that followed closely the great granite irruption, however, are far more granular than the dacites, and they do not resemble the dacites of the region, which have their own characteristic appearance. Certain of the dacite dikes have chilled margins showing a ropy structure, a feature which indicates intrusion comparatively near the surface.

PETROGRAPHY.

As already stated, the dacites are light-colored porphyries inclosing phenocrysts of plagioclase, quartz, and biotite embedded in an aphanitic groundmass. The feldspar is clear and glassy and is visibly striated, so that its plagioclase character is obvious to the eye. The quartz is colorless, differing in this respect from the prevailingly smoky character of the quartz in the rhyolites of the region. It varies in amount in different rocks, being abundant in some and absent in others. Those devoid of quartz would be termed biotite andesites. Although such andesitic phases occur at a number of places, they are comparatively rare. Biotite is universally present, commonly as small thin hexagonal plates, but no other ferromagnesian mineral is found. Under the microscope the rocks, which are ideally fresh, are found to show essentially similar features in specimens from widely separated localities. The ratio of groundmass to phenocrysts approximates 1 to 1. The porphyritic feldspars are andesine, as a rule slightly more calcic than $Ab_{60}An_{40}$. Sanidine is absent from the phenocrysts, as shown by the Becke test on all unstriated feldspar sections. In one specimen only, from Sugarloaf Mountain (examined because of all the dacites it exhibits the nearest resemblance to the rhyolites of the region), were sanidine phenocrysts associated with the andesines. The quartz is generally much fractured and shows corrosion and embayment. Biotite is present in idiomorphic crystals and may be fluidally arranged around the plagioclase phenocrysts. The groundmass ranges in different specimens from glassy to microcrystalline. The microcrystalline form is best developed in those rocks occurring as dikes. Where the constituents of the groundmass are determinable, they appear to consist largely of sanidine and quartz. Apatite and zircon are present as accessory minerals, but magnetite is absent in all specimens examined.

According to the prevailing qualitative classification, the rocks are clearly biotite dacites. It has been pointed out by Rosenbusch [1] that the dacites fall into two rather distinct groups—the liparitic (rhyolitic) dacites and the andesitic dacites. Mineralogically and texturally the first group is closely related to the rhyolites and is characterized by the dominance of biotite and amphibole among the femic phenocrysts. The second is in an analogous way related to the andesites and is characterized by the dominance of pyroxene among the porphyritic minerals. The dacites of the region are rhyolitic in affinity. It is noteworthy perhaps that despite their great development biotite is uniformly the sole ferromagnesian mineral to appear as a porphyritic constituent. In the Butte folio these rocks at Butte were called rhyolites, but subsequently they have been termed rhyolite-dacites.[2] The rock at Big Butte is stated to grade from rhyolite through rhyolite-dacite to dacite. Apparently there is a greater mixture of varieties at Butte than there is farther north. The analysis cited is that of a typical dacite.[3]

[1] Rosenbusch, H., Mikroskopische Physiographie der massigen Gesteine, 4th ed., vol. 2, pt. 2, 1908, p. 999.

[2] Weed, W. H., Geology and ore deposits of the Butte district, Mont.: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 43.

[3] Idem, p. 45.

AGE OF THE DACITES.

No evidence closely fixing the age of the dacites was found within the region. Their general Tertiary age is indicated by the fact that they rest on the deeply eroded surface of the Boulder batholith. Weed, however, has found that the eruptions were contemporaneous with the deposition of lake beds west of Butte. These are of upper Miocene age.[1]

RHYOLITES.

GENERAL CHARACTER AND DISTRIBUTION.

A series of rhyolites rests on the eroded surface of the older rocks. Rhyolites are conspicuously developed near Rimini, where they form the capping of Red Mountain, whose commanding summit is a prominent landmark for many miles around. They crown the summits of many of the neighboring mountains and form the bedrock of the well-known "porphyry dike" country. They occur at Elliston, and on the Continental Divide north of Mullan Pass; they form small scattered patches east of Helena and occur in some abundance in the mountains east of Clancy.

The relief of the surface on which they were erupted has an extreme range of 3,600 feet—from an altitude of 7,600 feet on Red Mountain down to 4,000 feet in Prickly Pear Valley. At Rimini the relief was 2,000 feet in a horizontal distance of less than a mile. Thus it appears that the rhyolites were poured out on a surface as highly accidented as the present surface and whose configuration, as shown by the distribution of the rhyolites, was broadly similar to the existing topography.

The rhyolites are mainly lithoidal lava flows, but include some breccias and obsidians. They display a great variety of textures and colors, including grayish blue, red, pink, and white. Nearly universal features are pronounced streakiness and flow banding, abundant quartz phenocrysts, commonly smoky, and clear glassy sanidine phenocrysts. Dark minerals, such as biotite and hornblende, are not present in most of the rhyolites; some few show a scattering development of biotite. Lithophysæ occur locally in notable abundance and perfection.

A platy or laminated structure parallel to the flow banding is common, causing the rhyolites to break in thin slabs. In places, as west of Elliston and on Minnehaha Creek near Rimini, there is a pronounced columnar structure. The columns are irregular four and five sided prisms up to 6 feet in length. Single columns may show different sets of flow bands, making widely different angles with the same prism edge, a feature proving conclusively that the flow banding is no criterion of the original attitude of the surface on which the

[1] Weed, W. H., op. cit., p. 46.

rhyolites were extruded. In fact, flowage lamination standing at angles ranging from 0° to 90° was found at various places throughout the region.

The thickness of the rhyolite series is not well known, because the bedding or order of superposition of the lava flows is not easily recognizable. On Red Mountain they aggregate at least 600 feet and may be as much as 1,200 feet.

The rhyolite series consists of rhyolites only; neither dacites, quartz latites, nor other transitional rocks are associated with them. They differ notably in appearance from the dacites of the region, which are of general rhyolitic habit, and in fact have been termed rhyolites at Butte. They lack the extraordinarily prominent porphyritic development of the dacites, which is expressed by the abundance of unusually large phenocrysts of quartz and plagioclase. They lack also the biotite, so common in the dacites. Lithophysæ, smoky quartz crystals, and streakiness are restricted to the rhyolites. There is some possibility that the far older latites, which are light colored and show pronounced streakiness, especially those in the country north of Thunderbolt Mountain and at the headwaters of Little Blackfoot River, may be mistaken for rhyolites. However, the latites show no quartz phenocrysts nor do they have the fresh, unaltered appearance that characterizes the rhyolites. West of Elliston some black glistening basalt carrying large amber-colored phenocrysts of plagioclase is found, and this is one of the few exceptions to the rule that the rhyolite series is free from rocks of other types.

PETROGRAPHY.

The rhyolites are light-colored porphyries carrying phenocrysts of quartz and sanidine. The quartz phenocrysts average one-tenth of an inch in length and the sanidine phenocrysts are perhaps twice that size; together they make up between 10 and 20 per cent of the rock. The groundmass of the lithoidal rhyolites ranges from material of rough fracture to that of enamel-like appearance.

Under the microscope the phenocrysts are found to consist of corroded and embayed quartz and idiomorphic sanidine crystals; no plagioclase phenocrysts have been detected. The groundmass commonly shows a microcrystalline development; flow streaking is generally present.

A chemical analysis of a rhyolite from the summit of Red Mountain near Rimini is available[1] and is doubtless typical of the rhyolites generally. This rhyolite shows numerous dark smoky quartz and

[1] Cited by F. W. Clarke in Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880–1908: Bull. U. S. Geol. Survey No. 419, 1910, p. 80; the rock has not hitherto been described.

clear vitreous sanidine phenocrysts inclosed in a groundmass remarkably mottled and streaked. The general color of the rock is gray, diversified by mottlings and bands of various colors, among which dark red is especially prominent. Along some of the flow bands the rock is porous. Microscopically the quartz phenocrysts are seen to be corroded and embayed, whereas the sanidine crystals are comparatively intact. Some of the crystals show that they were broken by flowage movement with the cooling lava. Many of the quartz crystals are surrounded in optical continuity by aureoles of quartz inclosing feldspar. The quartz crystals are commonly much cracked. The sanidine phenocrysts are beautifully clear and fresh; optical tests show that they are nearly uniaxial. The groundmass is holocrystalline and eutaxitic, and in places is considerably pigmented with hydrated iron oxide, which is in part a later infiltration along the flow bands. Mineralogically the groundmass consists of feldspar and quartz; the fabric is different in different flow streaks but is commonly microgranitic and micropoikilitic, with sporadic spherulitic growths. Doubtless the groundmass contains much albite, but it can not be easily differentiated. Zircon is present as a rare accessory.

Analysis of rhyolite from top of Red Mountain, Rimini.

[H. N. Stokes, analyst.]

SiO_2	75.30	H_2O above 110°	0.61
Al_2O_3	11.95	TiO_2	.17
Fe_2O_3, FeO	2.17	P_2O_5, MnO, BaO, Li_2O, Cl	Trace.
MgO	.05	SrO, CO_2	None.
CaO	.62	SO_3	.44
Na_2O	3.09	Organic matter	.45
K_2O	4.96		100.17
H_2O at 110°	.36		

AGE OF THE RHYOLITES.

The rhyolite series seems, because of its general petrographic homogeneity, to represent an outburst of volcanic activity distinct from that of the dacitic eruptions which are known to have taken place in upper Miocene time. However, as the rhyolites have not been found in contact with the dacites, their relation to the dacites is not known. If they were not contemporaneous with the dacites, they probably represent a somewhat younger period of volcanism, as they were erupted upon a surface broadly similar to that of the present.

QUATERNARY SYSTEM.

The Quaternary deposits consist of alluvial gravels, sands, and silts. Patches of high bench gravels occur at many localities, but on account of their small size are not shown on the map (Pl. I). Glacial deposits were noted at Elkhorn, at Red Rock Creek, and on Little Blackfoot River, but because they are of small extent and no special study of them was made they have also not been differentiated.

THE ORE BODIES.

GENERAL CHARACTER.

The ore bodies of the region, classified according to metallic contents, are principally silver-lead and gold-silver deposits. These two classes include practically all the productive deposits of any importance, both past or present.

The silver-lead ore body of the Alta mine, having an accredited output of $32,000,000, has been the largest producer; next in order comes the Drumlummon, the premier gold-silver mine, with an output of $15,000,000.

The deposits, classified according to age of origin, fall into two distinct groups formed during widely separated periods of mineralization. Both groups, based on this age distinction, include silver-lead and gold-silver ores, but heavy lead ores are not common in the lodes of the younger set, which are mainly valuable for their content of the precious metals.

The older group of metalliferous deposits was formed subsequent to the intrusion of the Boulder batholith and prior to the eruption of the rhyolitic and dacitic lavas; the younger group was formed after the extrusion of the volcanic rocks. The older deposits are probably of late Cretaceous or early Eocene age, and the younger are surely of post-Miocene age. A number of the older deposits have been shattered and broken and subsequently recemented by quartz of the second period of mineralization, so that composite ore bodies were produced. Whether any important addition to the metallic contents of the older deposits accompanied the new mineralization could not be determined.

That a long period of time intervened between the formation of the older and the younger deposits is indicated by the geologic history of the region. The rocks covering the granite were largely removed by erosion, the granite was deeply dissected to an uneven surface, and on this surface there was erupted a considerable mass of volcanic rocks—dacitic lavas, tuffs, and breccias—to the thickness, locally at least, of 2,400 feet. Following this volcanic outburst came the second period of mineralization.

Primary minerals of the ore deposits.

	Earlier deposits (Cretaceous).	Later deposits (post-Miocene).	Doubtful.
Adularia		×	
Andradite	×		
Apatite	×		
Aragonite	×		
Argentite		×	
Arsenopyrite	×		
Axinite	×		
Bismuthinite	×		
Bornite			×
Calcite	×	×	
Cassiterite			×
Chalcedony		×	
Chalcopyrite	×	×	
Chlorite		×	
Cosalite	×		
Dolomite	×	×	
Epidote	×		
Fluorite			×
Galena	×	×	
Garnet	×		
Gold	×	×	
Hematite	×		
Magnetite	×		
Molybdenite	×	×	
Opal		×	
Pyrite	×	×	
Pyroxene	×		
Pyrrhotite	×		
Quartz	×	×	
Rhodochrosite			×
Sericite	×	×	
Siderite		×	
Sphalerite	×	×	
Tetradymite	×		
Tetrahedrite	×	×	
Tourmaline	×		

According to the classification of Lindgren,[1] it will be seen that many minerals of the earlier group are characteristic of ore deposits formed under deep-seated conditions, whereas those of the later group belong to those of shallow-zone origin.

OLDER ORE DEPOSITS (LATE CRETACEOUS?).

CLASSIFICATION.

The ore deposits of the first period of mineralization are mainly silver-lead lodes, but include some gold and some copper deposits. They are here classified on a genetic basis, although this has certain practical disadvantages. They are grouped as (1) magmatic deposits, (2) contact-metamorphic deposits, and (3) lodes and veins.

The third group embraces most of the ore bodies of the region. This group may be further subdivided on the basis of the predominant metasomatic process, in accordance with the classification of Lindgren, as tourmalinic lodes and sericitic lodes. The separation of the tourmalinic from the sericitic lodes is somewhat arbitrary, inasmuch

[1] Lindgren, Waldemar, The relation of ore deposition to physical condition: Econ. Geology, vol. 2, 1907, p. 122.

as the tourmalinic lodes are also sericitic and transitional forms occur from highly tourmalinic to nontourmalinic. This subdivision has the disadvantage of separating into different groups ore bodies having similar metallic contents. In the following pages, therefore, the sericitic veins are not accorded extended treatment, because the evidence seems clear that they represent a slightly less energetic phase of the tourmalinic mineralization.

MAGMATIC DEPOSITS.

The single representative of this class found within the region is in the Golden Curry mine at Elkhorn. The ore body, consisting of an intergrowth of pyrrhotite and chalcopyrite with augite, is inclosed in quartz monzonite and represents a local differentiation and segregation in the magma.

CONTACT-METAMORPHIC DEPOSITS.

A number of contact-metamorphic deposits occur throughout the region but as a rule are of small economic importance. They are invariably situated near the contact of limestone with quartz monzonite or a related granitic rock. They consist of a simultaneous intergrowth of the ore minerals with various silicates, among which an iron-bearing garnet, probably andradite, is usually present. In some ore bodies, however, the generation of the ore minerals seems to have persisted somewhat longer than that of the silicate minerals. Deposits valuable for gold, for copper, and for iron have been found.

The largest ore body of this type is the auriferous deposit of the Spring Hill mine, near Helena, which has been worked on an extensive scale. This deposit lies at the contact of a small mass of diorite intrusive into the Madison limestone. The ore minerals are pyrite and pyrrhotite; in places the pyrrhotite forms solid masses several feet in length and width. They are usually associated with a fine-grained aggregate of lime-silicate minerals, forming an exceedingly hard and tough rock, but are also disseminated in grains and blebs through the pure limestone.

Another auriferous deposit of contact-metamorphic origin is the Dolcoath ore stratum at Elkhorn, carrying telluride and sulphide of bismuth and chalcopyrite intergrown with an iron-bearing garnet, diopside, and calcite.

Contact-metamorphic copper ore has been exploited to some extent near Elliston, where an oxidized copper ore intergrown with garnet and calcite was mined.

Bodies of magnetite ore, associated with andradite and lesser amounts of axinite, have been mined as fluxing material at Elkhorn; they carry also minor quantities of copper and gold.

An aberrant type of ore deposit is represented by the Blue Bell mine, near Mullan Pass. This deposit consists of a lode of garnet rock traversing the monzonite and carrying locally chalcopyrite, molybdenite, and pyrite. The contact of the garnet rock with the inclosing monzonite is blurred and shows gradual transition from garnet rock to monzonite. Branch veinlets of garnet break off at right angles to the larger veins. The adjoining monzonite shows unusual metasomatic alteration, apparent even macroscopically. When examined microscopically the most intensely altered monzonite is found to consist of scapolite in broad plates poikilitically inclosing garnet. Other details are given under Elliston.

The deposit is in many respects analogous to that at Mackay, Idaho, described by Kemp,[1] which consists of pipes of cupriferous garnet rock inclosed in quartz porphyry. Whatever explanation is adopted for the Blue Bell deposit, at least the conclusion is incontrovertible that the garnet molecule was able to migrate and form veinlike deposits under the influence of solutions that carried chlorine, as shown by the accompanying scapolitization.

TOURMALINIC LODES.

VARIETIES OF ORES.

A striking feature of many of the ore deposits of the earlier group is their abundant content of tourmaline. This mineral, as is well known, is of comparatively rare occurrence in ore deposits other than tin lodes. It is found associated, to some extent, with gold ores at various localities and with gold-copper ore, notably in Chile. It is therefore a matter of considerable interest that tourmaline is a common gangue and metasomatic mineral in the ores of this region.

The ores include varieties differing widely in mineralogic character and metallic content. On this basis three types can be distinguished—(1) tourmalinic silver-lead; (2) tourmalinic silver-copper; (3) tourmalinic gold.

In connection with the prevalence of tourmaliniferous ore deposits in the region it is worthy of note that cassiterite was frequently found in the gold placers in early days—in Tenmile Creek, in Prickly Pear, and in many others. It has nowhere yet been found in its bedrock source. The cassiterite was commonly in the form of wood tin, a form recognized by German authors as of secondary origin. It is probable therefore that the cassiterite was derived from the erosion of the oxidized croppings of lodes carrying slightly stanniferous sulphides.

[1] Kemp, J. F., The White Knob copper deposits, Mackay, Idaho: Trans. Am. Inst. Min. Eng., vol. 38, 1907, pp. 269-296.

TOURMALINIC SILVER-LEAD DEPOSITS.

DESCRIPTION.

The silver-lead deposits are the most important group of the tourmalinic lodes; they have given rise to the largest number of mines and have yielded the greatest metallic output. This is the more noteworthy in that they constitute a group of ore deposits that is unique so far as shown by the literature of economic geology.

They are developed most strikingly at Rimini, where tourmaline forms the dominant metasomatic mineral of the ore at certain mines, notably the Lee Mountain and the Valley Forge. At Wickes the Alta lode, which has been by far the most productive ore body in the region, shows pronounced tourmalinization. Other lodes in the Wickes district, such as the Comet and Gregory, are probably end members of the same type of deposit, but in which the tourmalinization was feeble. Finally, the tourmalinic silver-lead type is represented at Elkhorn by the Queen mine.

The deposits at Rimini afforded a better opportunity for examination than those at other localities, so their characteristics will be presented in some detail.

The lodes are inclosed in quartz monzonite of uniform composition, which is quite similar to that prevailing throughout the Boulder batholith. A pronounced system of jointing that trends N. 85° E. and dips 80° S. traverses the quartz-monzonite. The joints as a rule are widely spaced and are remarkably plane and parallel. Locally they are closely spaced, as at the falls of Beaver Creek, above the town of Rimini, and the joint faces are coated black with a thin felt of tourmaline fibers.

The ore bodies conform in direction to this system of jointing. The ore occurs in chambers or shoots scattered through a zone which in a few places attains an extreme width of 50 feet. In this zone the granite is profoundly altered by sericitization and is strongly impregnated with metallic sulphides. Commercial ore consists of a heavy sulphide aggregate, composed principally of galena associated with sphalerite and pyrite. Arsenopyrite in small amount is a ubiquitous constituent; tetrahedrite and chalcopyrite occur rarely. The ore is more or less mixed with metasomatically altered granite, but not with vein quartz or other gangue material common in fissure-filled veins.

The ores carry approximately 2 ounces of silver to each 1 per cent of lead, and gold running as high as $11 a ton in high-grade ore.

The characteristic feature that distinguishes these deposits from the usual types of ore body is that they are accompanied along one wall or the other by what is termed locally a ledge of black quartz. This ledge consists of a coal-black rock composed essentially of an intergrowth of quartz and black tourmaline. In places the grain is so dense that the tourmaline is not discriminable and the rock resembles a black jasperoid; in other places the grain is coarser and the radial fibrous structure of the tourmaline is readily apparent. Another phase of the tourmalinic rock shows a mottling due to small patches of vitreous quartz, and is perhaps of interest because of its resemblance to the so-called capel accompanying the cassiterite lodes of Cornwall, as determined by direct comparison with a specimen of capel—a quartz-tourmaline rock—from the 2,800-foot level of the Dolcoath mine.

In places the quartz-tourmaline rock is roughly banded, owing to the presence of intercalated slabs of sericitized granite. This banded phase indicates clearly how the tourmalinic ledge originated. The black tourmalinic bands merge, by diminution in the amount of tourmaline, into sericitized granite. The tourmalinization evidently proceeded from joint planes in the granite; where the jointing was closely spaced or the tourmalinization was intense the granite was altered completely and solidly to a quartz-tourmaline rock. In this way black tourmalinic ledges were formed, extremely dissimilar to the granite from which they were derived, and attained a maximum thickness, so far as observed, of 8 feet. It is noteworthy that the most productive lodes are accompanied by the thickest ledges, although, on the other hand, ore does not occur continuously along these ledges. The tourmalinic rock carries a varied amount of metallic sulphides, among which arsenopyrite predominates, accompanied by pyrite, sphalerite, and galena. Locally it is brecciated and traversed by thin veinlets of quartz and arsenopyrite.

Black jasperoidal tourmaline rock from the Valley Forge mine, as shown by microscopic examination, is composed of quartz and tourmaline in approximately equal amounts. The tourmaline is a brown variety, and is present in granular, columnar, and acicular forms. Other minerals are arsenopyrite, pyrite, sphalerite, galena, sericite, and apatite.

The manner in which the tourmalinization proceeded is clearly indicated in an open cut on the probable eastern extension of the Lee Mountain lode, in the town of Rimini. A sketch of this is given in figure 3. Twenty feet west of the open cut a prospect shaft encountered some heavy galena ore on this tourmalinized zone.

The ore bodies occur in shoots alongside the tourmalinic ledge matter. There is, however, complete though abrupt gradation between the tourmaline rock and the ore material. The ore favors the sericitically altered granite. A certain definite tendency of the sulphides to segregate during deposition is therefore evident, galena-rich ore tending to develop most abundantly in the sericitic phase of alteration. That the development of the sulphides and the tourmalinization were contemporaneous is proved by the intergrowth of the sulphides with the tourmaline. Another line of evidence is the fact that the granite, where traversed by quartz-tourmaline veinlets devoid of metallic sulphides, is tourmalinized, sericitized, and impregnated with arsenopyrite, pyrite, sphalerite, and galena. This indicates beyond question that the same solutions that carried the tourmaline-producing elements carried also the metallic sulphides; it indicates further that there was probably a tendency of the tourmaline to develop slightly ahead of the sulphides.

CHEMICAL PROCESSES.

The chemical processes accompanying the formation of the tourmalinic silver-lead deposits were investigated by a series of analyses of rocks from the Valley Forge mine at Rimini.

The normal country rock, taken at 30 feet from the footwall of the lode at the portal of the main tunnel, is a comparatively fresh quartz monzonite composed of zoned plagioclase near $Ab_{51}An_{49}$, orthoclase,

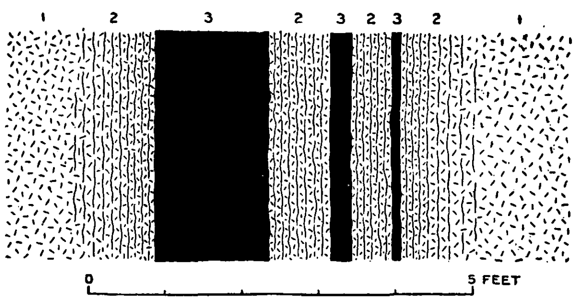


FIGURE 3.—Tourmalinized zone in granite, Rimini. 1, Quartz monzonite; 2, pyritized and sericitized quartz monzonite; 3, black tourmaline-quartz rock.

quartz, micropegmatite, biotite, and hornblende, with accessory magnetite, titanite, apatite, and zircon. Sericite, chlorite, and iron oxide occur in small amounts as secondary minerals. Altered quartz monzonite, taken from rock adjoining the quartz-tourmaline ledge on the hanging wall and selected so as to contain a minimum of tourmaline, is a coarse quartzose rock containing considerable glossy sericite in fine scales and pyrite in deeply striated cubes. Arsenopyrite, sphalerite, and galena are present in lesser quantities. Under the microscope quartz in large optically homogeneous anhedrons is seen to be the dominant constituent; sericite and sulphides are common. A deep-brown iron-rich variety of tourmaline is present in small amount. Arsenopyrite is as a rule sharply crystalline; pyrite is also well crystallized, but the galena and sphalerite are anhedral. Apatite and zircon appear as accessory minerals.

Rock taken from the footwall, and therefore several feet from the tourmalinic ledge, consists of highly sericitized quartz monzonite impregnated with pyrite, galena, arsenopyrite, and sphalerite. The sericite forms translucent waxy patches of light yellowish-green color. The microscope shows that the component minerals are, in order of abundance, quartz, sericite, pyrite, galena, arsenopyrite, and sphalerite and accessory rutile, apatite, and zircon.

Analyses of fresh and altered wall rocks, from Rimini, Mont., and St. Michaels Mount, Cornwall.

	1	2	3	4
SiO_2	65.91	66.70	66.02	69.42
Al_2O_3	15.32	13.25	14.14	15.65
Fe_2O_3	2.28	1.34	1.53	1.25
FeO	2.02	.51	.37	3.30
MgO	1.52	.30	.67	1.02
CaO	3.28	.05	.26	.63
Na_2O	3.08	.39	.39	.27
K_2O	4.80	4.03	4.63	4.06
H_2O-	.60	.08	.10	.06
H_2O+	.60	.37	.48	.54
TiO_2	.59	.20	.56	Trace.
CO_2	.21	.21	.25	
P_2O_5	.18	.12	.17	.40
MnO	Trace.	Trace.	Trace.	.39
BaO	.10	None.	.04	
Li_2O				.81
B_2O_3				.59
F			.02	3.36
PbS		.59	2.02	
ZnS		1.86	.74	
FeAsS		5.09	.72	
FeS_2		4.75	6.73	
	100.51	99.84	99.84	101.75
Less O for F				1.41
				100.34
Specific gravity	2.651		2.893	

1. Quartz monzonite, fresh, from Rimini, Mont. J. G. Fairchild, analyst.
2. Quartz monzonite, altered, from hanging wall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
3. Quartz monzonite, altered, from footwall, Valley Forge mine, Rimini, Mont. J. G. Fairchild, analyst.
4. Greisen (with tourmaline and topaz), from St. Michaels Mount, Cornwall. W. Pollard, analyst.

It is apparent from the analyses that the course of alteration has been essentially similar in both wall rocks; perhaps the fact is noteworthy, however, that the high arsenopyrite and low galena go with the tourmaliniferous phase of alteration. The pronounced removal of all bases other than potash and the low combined water—lower than in the unaltered rock—are striking features. The potash is all present in sericite, but the amount of water is far too low to compute the sericite as $K_2O.2H_2O.3Al_2O_3.6SiO_2$, the formula usually employed. In this respect the alteration of these wall rocks departs from that of most sericitized wall rocks, it being the general experience that water is commonly in excess of the amount required by the formula $K_2O.2H_2O.3Al_2O_3.6SiO_2$. For purposes of comparison an analysis of a greisen from Cornwall has been added, which shows a similar deficiency of water with regard to the content of potash.[1] But such examples are rare.

[1] Reid, Clement, and Flett, J. S., Geology of the Land's End district: Mem. Geol. Survey England and Wales, 1907, p. 59.

To trace the course of alteration more closely the following computations have been made, based upon the assumption of constant volume. They bring out clearly that the net increase of mass, amounting to 9 per cent, has been due chiefly to the introduction of the metallic sulphides; that there has been a notable gain in iron (as pyrite and arsenopyrite), sulphur, lead, arsenic, zinc, and silica; and that there has been a heavy loss in all bases except potash, which has remained practically unchanged in amount.

Alteration of quartz monzonite from Rimini, Mont.

	1	2	1a	2a	3	4	5
SiO_2	65.91	66.02	174.80	191.00	+16.2	+ 9.28	+6.12
Al_2O_3	15.32	14.14	40.60	40.90	+ .3	+ .74	+ .10
Fe_2O_3	2.28	1.53	6.05	4.43	− 1.62	−26.8	− .61
FeO	2.02	.37	5.36	1.07	− 4.29	−80.1	−1.62
MgO	1.52	.67	4.03	1.94	− 2.09	−51.9	− .79
CaO	3.28	.26	8.70	.75	− 7.95	−90.4	−3.00
Na_2O	3.08	.39	8.17	1.13	− 7.04	−86.2	−2.65
K_2O	4.80	4.63	12.72	13.38	+ .66	+ 5.19	+ .20
H_2O-	.60	.10	....	....	....	....	....
H_2O+	.60	.48	1.59	1.39	− .20	....	....
TiO_2	.59	.56	1.56	1.62	+ .06	....	....
CO_2	.21	.25	.56	.72	+ .16	....	....
P_2O_5	.18	.17	.48	.49	+ .01	....	....
BaO	.10	.04	.26	.12	− .14	....	....
PbS	....	2.02	....	5.84	....	....	+2.20
ZnS	....	.74	....	2.14	....	....	+ .81
FeAsS	....	.72	....	2.08	....	....	+ .78
FeS_2	....	6.73	....	19.45	....	....	+7.33
	100.51	99.82	264.88	288.45	....	....	+8.87
Specific gravity	2.651	2.893	....	....	....	....	....

1. Chemical composition of unaltered quartz monzonite.
2. Chemical composition of altered quartz monzonite.
1a. Constituents in grams of 100 cubic centimeters of unaltered rock.
2a. Constituents in grams of 100 cubic centimeters of altered rock.
3. Gain or loss in grams of each constituent during alteration.
4. Gain or loss in percentage of original mass of each constituent.
5. Gain or loss in percentage of original mass of the unaltered rock.

TOURMALINIC SILVER-COPPER DEPOSITS.

The principal representative of the tourmalinic silver-copper type is the Blue Bird mine in the Wickes district. The ore at this mine consists essentially of tetrahedrite and pyrite intergrown with tourmaline. Sphalerite and galena are rare constituents. The ore contains from 10 to 25 ounces of silver, 3 to 5 per cent of copper, and small amounts of gold.

Pockets of ore, composed of columnar arsenopyrite in a matrix of sphalerite and pyrite and carrying 2 ounces of gold to the ton, have been found in highly tourmalinized diorite porphyry near the lode. A shoot of ore formerly worked carried 0.56 ounce of gold and 65 ounces silver a ton, but it probably contained more galena and arsenopyrite than the ore now being extracted, which is an argentiferous tetrahedrite intergrown with tourmaline.

The bearing of these facts is that the tourmalinic silver-copper type of deposit is very probably connected by transitions with the other types of tourmalinic lodes of the region. That the tourmalinic silver-copper deposit of the Blue Bird mine differs from previously described tourmalinic ore bodies, notably from the tourmalinic gold-copper type, has recently been pointed out by the Winchells.[1]

Tourmalinic ore bodies, such as the Eva May and the Bullion, which carry pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and arsenopyrite in variable amounts and are both argentiferous and auriferous, form transitions between all three types of tourmalinic deposits recognized in the region.

TOURMALINIC GOLD DEPOSITS.

The only tourmalinic deposit valuable solely for its gold content is the Big Indian, situated in Jefferson County, 4 miles south of Helena. Most of the other tourmalinic deposits, however, are auriferous to some extent, and in many the gold is an important constituent. In the Evening Star ore, a tourmalinic gold-silver-lead ore, the gold is stated to have run as high as 3 ounces to the ton.

The Big Indian mine is situated in the quartz monzonite one-half mile from the intrusive contact with the sedimentary rocks lying to the north. The ore was taken out from a large pit. In the bottom of this pit it can be seen that the quartz monzonite is in places extremely sheeted by a system of vertical joint cracks. These sheeted zones were loci of tourmalinization and pyritization, and probably of auriferous impregnation. The tourmalinized rock is a medium-grained gray granitoid, which contains about as much tourmaline as the unaltered rock contains ferromagnesian minerals—approximately 10 per cent. The tourmaline aggregates are somewhat porous and contain some yellowish material of undetermined character. Under the microscope the rock is found to consist of plagioclase, orthoclase, micropegmatite, tourmaline in irregular granular aggregates, brown mica in fan-shaped groups, magnetite apparently in part epigenetic, titanite, and apatite.

According to Mr. James Winscott, the discoverer of the deposit, approximately $110,000 in gold was extracted during five years' operations of the old 10-stamp mill formerly on the property. The ore averaged $5 a ton and some clean-ups ran 985 fine. Subsequently the property was sold and a 60-stamp mill was erected, but this is now idle.

ORIGIN OF THE OLDER ORE DEPOSITS.

The ore deposits of the first period of mineralization are closely related to the intrusion of the quartz monzonite, as shown by three features: (1) Their geologic environment, namely, their restriction

[1] Winchell, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, p. 289.

to the vicinity of intrusive contacts of the quartz monzonite; (2) their mineralogy; and (3) the fact that a number of them are cut by Tertiary dacite dikes.

They occur either at the margins of the batholith or in remnants of the roof under which the quartz monzonite was intruded. The largest fragment of the roof that has escaped the erosion and general removal of the rocks formerly covering the batholith—the large remnant of the andesitic roof west of Wickes—has been the great treasure vault of the region. The most productive mines, to name only the Alta, Comet, Gregory, and Minah, were grouped in this fragment of the roof or along its margin.

This geographic restriction of the ore bodies to the intrusive contacts is not of itself conclusive proof that the deposits are genetically related to the intrusion of the quartz monzonite. This is illustrated by the Marysville district, where a series of lodes is massed along the periphery of a boss of quartz diorite but is not connected in origin with the intrusion of the plutonic rock. It is obviously of more importance to show that a close sequence in time exists between intrusion and metallization, but that such a sequence exists can be shown in the broadest sort of a way only. After the granite had consolidated to a considerable depth it was fractured; the ore deposits were formed; subsequently the covering rocks, of unknown thickness, were stripped off and the granite was deeply eroded; and finally in upper Miocene time the dacite lavas were erupted on this surface.

The geographic restriction of the ore deposits considered in connection with their mineralogy is, however, conclusive proof of their genetic dependence on the quartz monzonite intrusion. The third criterion, the intersection of an ore deposit by dacite dikes, is not of great moment, but it establishes the fact that ore deposits so intersected were formed prior to the second period of mineralization.

The ore deposits, as shown by their abundant content of tourmaline, were formed at a high temperature—a condition obviously obtaining near the intrusive contacts at a time shortly after the coming to place of the quartz monzonite magma. That tourmaline is an index of formation at high temperature is regarded as established so firmly that argument in support of the fact is unnecessary.

Although it seems clear, therefore, that the ore deposits are closely linked in origin with the intrusion of the quartz monzonite, this causal connection may ultimately be due either to (1) the heat furnished by the magma, thus stimulating the circulation of meteoric waters and increasing their solvent powers, or (2) to the release of metalliferous solutions from the cooling magma, or (3) to combinations of (1) and (2). The current theory of ore deposits holds that the presence of tourmaline, because of its content of boron and fluorine, is proof that the deposits in which it occurs were formed by direct exhalations from a cooling magma. In the ore deposits here considered, as previously shown, the solutions that carried the elements of the tourmaline carried also those of the metallic sulphides, and the sulphides were formed contemporaneously with the tourmaline. It is therefore probable that the ore-depositing solutions were of magmatic derivation and represent the final manifestation of the intrusive energy of the great quartz monzonite invasion.

The tourmalinization and introduction of the ore took place, however, distinctly later than the intrusion of the aplites, some of which were profoundly altered by the ore-forming solutions. The quartz monzonite magma was therefore not directly the "ore bringer." The release of the metalliferous solutions took place at a more advanced state of magmatic differentiation; in fact, at a stage succeeding the intrusion of the aplite.

The formation of the aplite magma, as pointed out already, was accompanied, as inferred from undoubted facts observed in the field, by an increase in its content of tourmaline to a proportion considerably greater than that in the original quartz monzonite magma. The facts observed in the field suggest a tentative speculation. The concentration of the tourmaline in the aplite magma brought about a further differentiation of which the ultimate product was a highly mobile solution, endowed with great migratory powers. The tourmaline-quartz-orthoclase segregations are regarded as imprisoned and congealed globules of this final differentiate. It is noteworthy that the composition of these tourmalinic segregations is essentially similar to that indicated for the ore-forming solutions by the study of their metasomatic activities. Both contained boron, silicon, aluminum, and potassium. Presumably the increase of tourmaline in the aplite magma was accompanied by a concurrent increase in the concentration of the metallic constituents. But on this point the field evidence fails, for at only one locality was a tourmaline segregation noted to carry a sulphide mineral (pyrite). The phenomena of the ore deposits show that the tourmaline and the metallic sulphides traveled together, but the field evidence does not show how this association was originally brought about.

SYSTEMATIC IMPORTANCE OF TOURMALINIC SILVER-LEAD DEPOSITS.

As is well known, a sharp distinction was drawn by French geologists between the cassiterite-bearing veins and the ordinary sulphide-bearing veins, the so-called "filons plombifères." This division into two classes is recognized by Vogt [1] as valid, only that here, as elsewhere in nature, transitional forms exist. Certain such gradations are pointed out by him, but in conclusion he states that "galena-silver ore veins carrying tourmaline in abundance are not known."

[1] Genesis of ore deposits: Special publication Am. Inst. Min. Eng., 1902, p. 665.

A review by Stutzer in 1906 of all known tourmaline-bearing ore deposits confirms this statement. Eight classes are defined, the limits of which are somewhat arbitrary, owing to transitional forms, but tourmalinic silver-lead ore deposits do not appear among them.[1]

It is therefore a matter of some theoretic interest to find a series of highly tourmalinic galena-silver lodes genetically related to the intrusion of the Boulder batholith. Tourmaline is the most characteristic mineral of the stanniferous deposits; here in Montana it is developed in extreme abundance as an accompaniment of silver-lead deposits. Moreover, the lodes have been important producers; the largest of these, the Alta, credited with a yield of $32,000,000, appears, if the stanniferous lodes are excluded, to outrank in value of output any known ore body of the tourmalinic class of deposits.

YOUNGER ORE DEPOSITS (POST-MIOCENE).

GENERAL CHARACTER.

The ore deposits of the postvolcanic mineralization are essentially precious metal deposits. They include gold, gold-silver, and silver deposits.

Unlike the ore bodies of the older group, the younger ore deposits show no significant geologic distribution. They occur generally throughout the region and are inclosed in rocks of all ages—in the dacites and rhyolites, in the quartz monzonite, and in the sedimentary rocks. At certain localities a considerable number of productive veins are massed together, giving rise to mining districts of economic prominence. Districts whose importance has depended on veins of late Tertiary age are Marysville, Clancy, and Lowland Creek. Besides the veins of these districts there are a large number of widely scattered deposits.

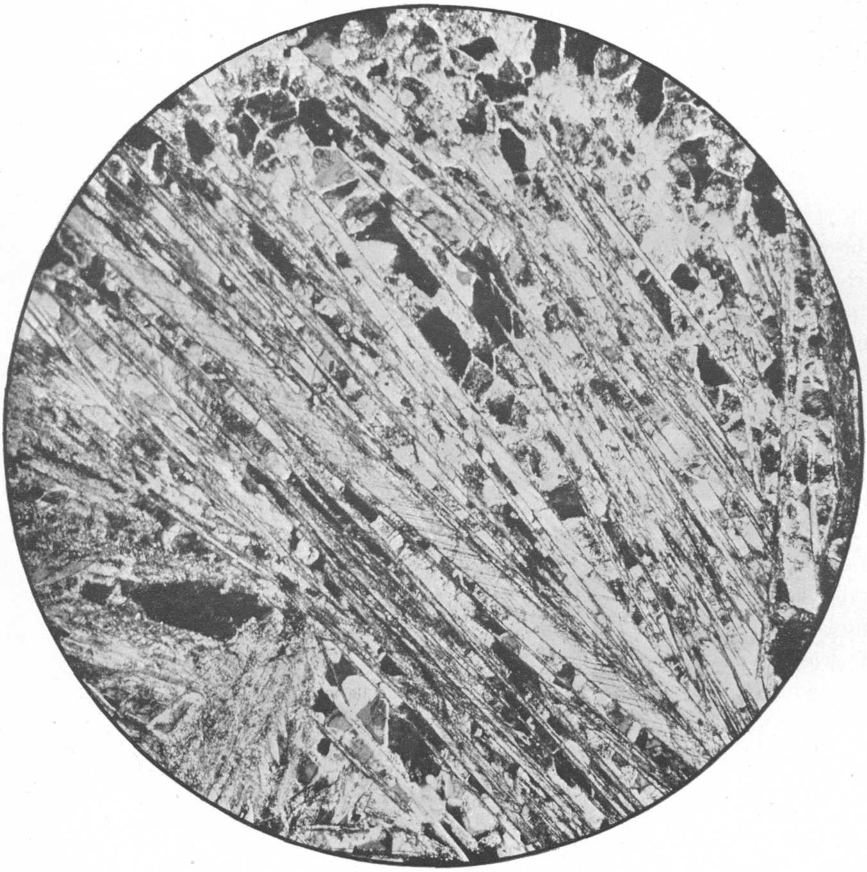
The cause of the localization of the deposits in certain districts is not clearly apparent. The most productive portion of the Clancy district, that of Lump Gulch, is situated in the heart of the quartz monzonite area and at a considerable distance from the nearest accumulation of rhyolites; Lowland Creek, which is 14 miles north of Butte, is situated in the middle of the great dacite area extending southward to Butte; the geologic features do not indicate why there should be a grouping of deposits in these localities. On the other hand, the localization of the deposits at Marysville seems plausibly explicable as due in part to the favoring influence of the contact of dissimilar rocks, inasmuch as the deposits are grouped around the margin of a quartz diorite stock in the Belt series.

Each of the different districts shows a certain degree of individuality, but the general features in common will be pointed out here; the detailed descriptions must be sought under the various districts.

[1] Stutzer, O., Turmalin führende Kobalterzgänge: Zeitschr. prakt. Geologie, vol. 14, 1906, pp. 294–299.

LAMELLAR CALCITE ORE, BELMONT MINE, MARYSVILLE.

Thin section, parallel light; magnified 30 diameters.



LAMELLAR CALCITE ORE, BELMONT MINE, MARYSVILLE.

Thin section, crossed Nicols; magnified 30 diameters.

The ore bodies are mainly fissure veins of branching and irregular character. At Rimini, however, there are some extensive deposits of disseminated low-grade gold ore in the rhyolite. As a rule, the ore bodies carry subordinate quantities of sulphides and are worked for their content of precious metal alone. A prominent feature of the deposits is the prevalence of cryptocrystalline quartz in the gangue material. The cryptocrystalline quartz appears in three varieties: (1) A dark gray-blue flinty variety, (2) a dense-grained white variety resembling porcelain, and (3) chalcedony. These three modifications, however, are likely to be present together in the same deposit, confusedly intergrown and each variety grading into the other. It is not uncommon to find veinlets lined with chalcedonic quartz which toward the central portion of the veinlets grades into drusy crystalline quartz.

In some deposits, notably in some of those inclosed in the dacites on Lowland Creek, the quartz is pseudomorphic after a thinly lamellar calcite. This has given rise to a gangue of characteristic appearance. The arrangement of the quartz plates is commonly such as to inclose irregular pyramidal spaces, which are lined with innumerable small quartz crystals. The plates are also arranged in radiating groups. On fractured surfaces the partial overlapping of thin superposed plates produces an imbricating structure.

The pseudomorphic lamellar quartz is developed in extraordinary perfection in the veins of Marysville, where in fact considerable quantities of unreplaced lamellar calcite still remain. Plates III and IV are photomicrographs of a thin section of calcite ore from the second level of the Belmont mine, Marysville. The lamellar habit of the calcite and the extreme thinness which the plates attain—some under 0.001 of an inch—are well displayed. Plates V and VI show high-grade ore from the same mine. The ore consists wholly of quartz, much of which shows a lamellar structure in the hand specimen; even in parallel light the replacement structure is brought out by the arrangement of inclusions and is confirmed by the behavior between crossed nicols.

METASOMATIC PROCESSES.

The metasomatic alteration of the wall rocks of the late Tertiary veins is principally in the nature of a thorough sericitization, accompanied by the introduction of carbonates and locally by the development of chlorite. The resulting product is as a rule, widely different in appearance to the eye from the altered wall rocks of the older veins. In the wall rocks of the younger veins the feldspars have, as a rule, been reduced to chalky-white spots suggesting kaolin aggregates, but which prove microscopically to consist of microcrystalline sericite; the wall rock of the older veins are of green glossy appearance, due to the development of sericite flakes sufficiently coarse to be distinctly recognizable by the eye.

In order to determine the chemical processes involved in the alterations produced by the late Tertiary vein-forming solutions, analyses of altered and unaltered rocks adjoining the King Solomon lode were obtained. This lode traverses quartz monzonite and consists of parallel veinlets of galena, sphalerite, and tetrahedrite in a chalcedonic gangue, locally carrying some siderite. The late Tertiary age of the vein is proven by the fact that it is younger than the dacites, a dike of which forms the hanging wall of the lode, as described on pages 104–105. As the quartz monzonite is similar to that at Rimini, the alterations produced during the two contrasted periods of mineralization are directly comparable.

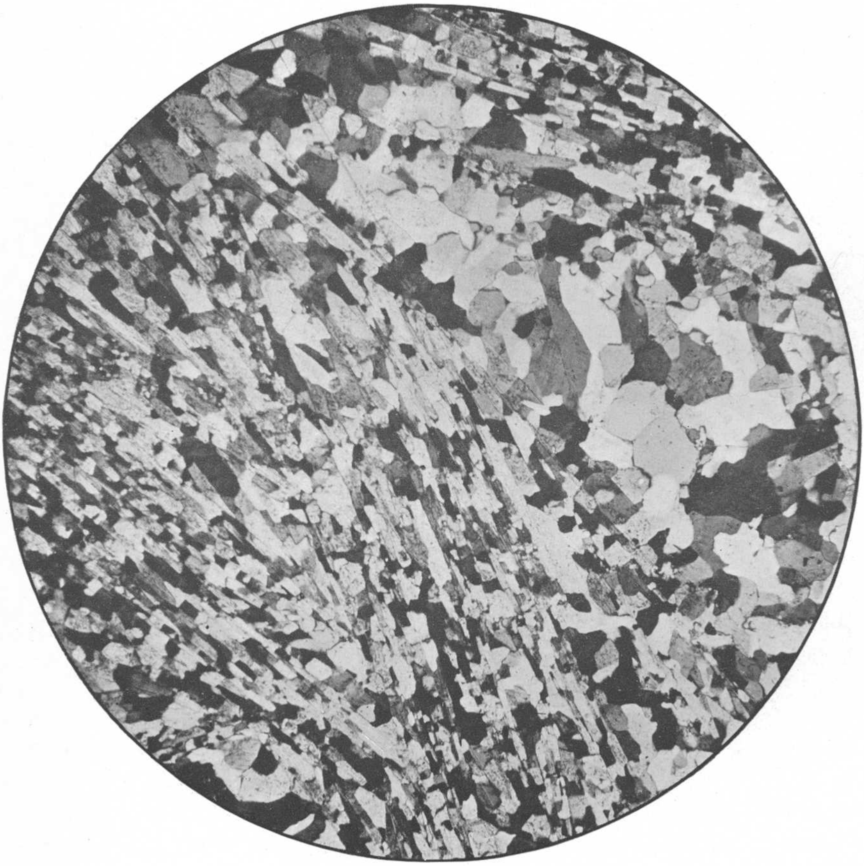
The quartz monzonite is remarkably homogeneous within a radius of several miles of the mine. It is a coarse-grained granitoid of subporphyritic habit, due to the rude development of large sporadic phenocrysts of orthoclase, and consists of plagioclase, orthoclase, quartz, biotite, and hornblende, with a minute amount of finely scattered pyrite. Under the microscope the plagioclase is found to be a zoned andesine near $Ab_{59}An_{41}$, although the periphery is more sodic than this; the orthoclase to be coarse anhedral and somewhat clouded or "watered" from admixed albite; and magnetite, titanite, and apatite to occur as accessories, with a small amount of sericite as secondary mineral.

The altered rock, taken from the lode on the 300-foot level, still shows the original texture of the subporphyritic quartz monzonite; quartz is easily recognizable; the plagioclase is represented by dull waxy aggregates of light yellowish-green color; the dark minerals have altered to silvery sericite, and pyrite is present in small amount. In thin section it can be seen that the rock has undergone profound changes. Quartz is the most abundant constituent. Sericite forms exceedingly fine grained dense aggregates, mainly localized in the former plagioclase feldspars, which have disappeared entirely. Microcline appears as large sporadic phenocrysts, representing dynamically altered orthoclase phenocrysts, and microcline and orthoclase as recrystallization products are present in abundance. In the original rock the orthoclase was mainly in the form of large anhedral plates; here it is finer grained and subhedral. Pyrite in small crystals has developed in the biotite and hornblende and is intimately associated with siderite. Another carbonate, which is present as a minor constituent, is probably magnesite, as indicated by the chemical analysis. Apatite and zircon appear as accessories.

The notable mineralogic feature of this wall-rock alteration is the selective sericitization that has taken place; the soda-lime feldspar has been completely transformed to sericite, whereas the orthoclase,

LAMELLAR QUARTZ PSEUDOMORPHIC AFTER CALCITE, BELMONT MINE, MARYSVILLE.

Thin section, parallel light; magnified 30 diameters.



LAMELLAR QUARTZ PSEUDOMORPHIC AFTER CALCITE, BELMONT MINE, MARYSVILLE.
Thin section, crossed Nicols; magnified 30 diameters.

essentially a potassium feldspar, has remained largely intact, or has been in part recrystallized, although the admixed soda feldspar has been eliminated during the recrystallization.

The mineral composition of the altered and unaltered rocks, computed from the chemical analyses, is as follows:

Mineral composition of fresh and altered quartz monzonite.

	Fresh.	Altered.
Quartz	19.86	42.42
Orthoclase (molecule)	18.90	25.58
Albite (molecule)	28.80	....
Anorthite (molecule)	12.78	....
Biotite	8.94	....
Hornblende	7.26	....
Magnetite	.70	....
Titanite	.59	....
Apatite	.31	.31
Pyrite	.13	.45
Calcite	1.00	....
Siderite	....	2.44
Magnesite	....	.67
Sericite	....	26.86
Water (excess)	.38	.29
	99.65	99.02

The specific gravity of the fresh quartz monzonite as determined on a rock specimen is 2.714; calculated from the computed mineral composition it is approximately 2.712. The porosity is therefore probably very small.

The specific gravity of the altered rock as determined on a rock specimen is 2.599; calculated from the computed mineral composition it is approximately 2.695. The computed porosity is accordingly 3.6 per cent. The alteration of the wall rock by the vein-forming solution has therefore been accompanied by a small increase of porosity.

In the preceding computation the conventional formula of sericite, $K_2O.2H_2O.3Al_2O_3.6SiO_2$, has been used. The result conflicts apparently with the microscopic diagnosis, which indicates a considerably larger quantity of sericite than 26.86 per cent. Probably the use of the formula of a less aluminous mineral, corresponding to Sandberger's lepidomorphite, $K_2O.2H_2O.2Al_2O_3.7\frac{1}{2}SiO_2$, or of an admixture of this mineral would yield a more harmonious result.

The chemical analyses and computations to show the percentage gain or loss of the different constituents during metasomatic alteration follow. These computations are based on the assumption that the volume changes are zero; that this assumption is fully justified is proved by the fact that the altered wall rock still retains the subporphyritic habit and granitic structure of the fresh quartz monzonite.

Comparison of fresh and altered quartz monzonite from the King Solomon mine, Clancy, Mont.

	1	2	1a	2a	3	4	5
SiO_2	64.49	71.22	175.00	185.00	+10.0	+ 6.68	+3.69
Al_2O_3	15.49	15.05	42.00	39.10	− 2.9	− 6.90	−1.07
Fe_2O_3	1.28	Trace.	3.47		− 3.47	−100.0	−1.28
FeO	2.71	1.54	7.35	4.00	− 3.35	− 45.5	−1.23
MgO	1.89	.33	5.13	.86	− 4.27	− 83.3	−1.57
CaO	4.32	Trace.	11.72		−11.72	−100.0	−4.32
Na_2O	3.53	.42	9.58	1.09	− 8.49	− 88.6	−3.13
K_2O	4.04	6.99	10.96	18.16	+ 7.20	+ 65.7	+2.65
H_2O-	.16	− .32					
H_2O+	.48	1.52	1.30	3.95	+ 2.65	+203.8	+ .98
TiO_2	.56	.31	1.52	.81	− .71	− 46.7	− .26
CO_2	.49	1.50	1.33	3.90	+ 2.57	+193.2	+ .95
P_2O_5	.19	.08	.52	.28			
MnO	.07	.05	.19	.13			
BaO	.06	None.	.16				
FeS_2	.13	.45	.35	1.17	+ .82		+ .30
	99.80	99.78	270.58	258.45			−4.23
Specific gravity	2.714	2.599					

1. Chemical composition of fresh quartz monzonite. J. G. Fairchild, analyst.
2. Chemical composition of altered quartz monzonite. J. G. Fairchild, analyst.
1a. Constituents in 100 cubic centimeters of fresh rock.
2a. Constituents in 100 cubic centimeters of altered rock.
3. Gain or loss in grams of each constituent during alteration.
4. Gain or loss in percentage of original mass of each constituent.
5. Gain or loss in percentage of original mass of the fresh rock.

The computations show that there has been a net loss of material amounting to 4.23 per cent. There have been heavy gains in silica and potash and additions of water and carbon dioxide, but these gains are unable to offset the heavy losses in alumina, ferric and ferrous iron, magnesia, lime, and soda.

AGE AND ORIGIN OF THE YOUNGER ORE DEPOSITS.

The ore deposits of this group are post-Miocene in age. This determination is based on the fact that veins of this group are inclosed in dacites on Lowland Creek which are known to be of upper Miocene age. It is a fairly safe presumption that they were formed relatively near the surface, although it is to be noted that if they were formed immediately after the cessation of volcanic activity they may possibly have originated at a depth of 2,400 feet.

The cryptocrystalline and chalcedonic character of the quartz gangue, the content of adularia, and the lamellar calcite and pseudomorphic quartz ally these veins on Lowland Creek with those common in the late Tertiary lavas in the western mining States. Many, such as those at De Lamar, Idaho,[1] and Jarbidge, Nev.,[2] are identical in mineralogy and structure. Furthermore it is perhaps significant that the calcite in the veins from which hot water is trickling at Boulder Hot Springs has a lamellar structure; the silica in the gangue is cryptocrystalline, chalcedonic, and opaline.

[1] Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 106.
[2] Schrader, F. C., A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: Bull. U. S. Geol. Survey No. 497, 1912, pp. 52-56.

Partly because of the striking analogy between the Marysville veins and those of Lowland Creek and other late Tertiary veins throughout the Western States and partly because of other reasons, as detailed under the head of Marysville district, the deposits at Marysville are regarded as of post-Miocene origin, although the evidence from a purely local study of the geology at Marysville strongly favors the idea that the deposits are genetically related to the intrusion of an outlier of the Boulder batholith. It is believed in this connection that one of the more important results of the present investigation is that it shows clearly the necessity of a broad regional study in approaching the problems of ore genesis at any one locality.

The true silver veins of the Clancy and Lump Gulch districts differ somewhat from the preceding deposits, but their late Tertiary age is proved by the fact that they were formed after the intrusion of dacitic dikes. The chalcedonic character of the gangue material is in harmony with their post-Miocene age; in fact this feature is alone sufficient to differentiate them from the older (late Cretaceous) deposits. The study of the wall-rock alterations produced by the ore-forming solutions of this group of deposits shows that the solutions were particularly rich in potassium and silica, and carried carbon dioxide, sulphur, antimony, lead, zinc, copper, and silver. They were strongly reducing and were deficient in iron, calcium, sodium, magnesium, and aluminum. The chemical work which they accomplished shows that they were ascending thermal solutions.

As to the source of these solutions the evidence is as obscure as it is correspondingly clear for the older or batholithic deposits. These deposits were formed from metalliferous solutions expelled from the final differentiate of the quartz monzonite magma. But that the post-Miocene veins are related to the intrusion or extrusion of any igneous rocks is not clear. That they followed the extravasation of the dacites is obvious, but how close this sequence was can not be determined. The distribution of the veins shows no significant relation to the dacites; if the veins are genetically related to the dacites it might confidently be expected that an unusual number of veins would be grouped around old volcanic vents, where communication was most ready with the underlying sources of supply. So far as the geology of the region is now known the Big Butte at Butte is the only recognized vent from which dacites were erupted. Nevertheless the ore deposits at Butte were all formed prior to the eruption of the dacitic lavas, which are said to cover and conceal them.[1]

[1] Weed, W. H., Geology and ore deposits of the Butte district, Montana: Prof. Paper U. S. Geol. Survey No. 74, 1912, p. 43.

COMPARISON OF THE METASOMATIC PROCESSES OF THE TWO PERIODS OF MINERALIZATION.

The ore deposits of the first period of mineralization are clearly of high-temperature origin and belong to the so-called deep-zone group of deposits; those of the second period—the post-Miocene deposits—belong to the shallow-zone group. As the older deposits at Rimini and the younger deposits at Clancy are inclosed in quartz monzonite of nearly similar composition direct comparisons can be instituted between the metasomatic processes operative during the two periods of mineralization.

In the wall-rock alteration of the first period the quartz monzonite has been transformed completely to a quartz-sericite rock carrying abundant metallic sulphides; in extreme phases of alteration the transformed rock is analogous to a fine-grained greisen carrying accessory tourmaline. In the wall-rock alteration of the second period the sericitization has been selective; the plagioclase has been completely altered to sericite, but the orthoclase has been unaffected by this change. In further contrast to the earlier mineralization the introduction of metallic sulphides into the wall rock has been insignificant, but water and carbonates have been introduced in noteworthy amounts.

In order to facilitate the comparison, certain of the analyses and computations are assembled in the table below.

Comparison of fresh and altered quartz monzonite from Rimini and Clancy.

	1	2	1a	2a	1b	2b
SiO_2	65.91	64.49	66.02	71.22	+6.12	+3.69
Al_2O_3	15.32	15.49	14.14	15.05	+ .10	−1.07
Fe_2O_3	2.28	1.28	1.53	Trace.	− .61	−1.28
FeO	2.02	2.71	.37	1.54	−1.62	−1.23
MgO	1.52	1.89	.67	.33	− .79	−1.57
CaO	3.28	4.32	.26	Trace.	−3.00	−4.32
Na_2O	3.08	3.53	.39	.42	−2.65	−3.13
K_2O	4.80	4.03	4.63	6.99	+ .20	+2.65
H_2O+	.60	.16	.10	.32		
H_2O-	.60	.48	.48	1.52		+ .98
TiO_2	.59	.56	.56	.31		− .26
CO_2	.21	.49	.25	1.50		+ .95
P_2O_5	.18	.19	.17	.08		
BaO	.10	06	.04	None.		
MnO		.07		.06		
PbS			2.02		+2.20	
ZnS			.74		+ .81	
FeAsS			.72		+ .78	
FeS_2		.13	6.73	.45	+7.33	+ .30
	100.51	99.80	99.82	99.78	+8.87	−4.23

1. Fresh quartz monzonite, Rimini.
2. Fresh quartz monzonite, Clancy.
1a. Altered quartz monzonite, Rimini.
2a. Altered quartz monzonite, Clancy.
1b. Gain or loss in percentage of original mass of the unaltered rock, Rimini.
2b. Gain or loss in percentage of original mass of the unaltered rock, Clancy.

The difference between the alterations produced during the contrasted periods of mineralization is readily apparent, but its interpretation is an open question, for part of the difference may be due to difference of temperature and part due to difference in the composition of the solutions.

The most striking contrast is that a net increase in mass of 9 per cent has been produced by the earlier mineralization and a net loss of 4 per cent has taken place during the post-Miocene mineralization. So far as the metasomatic record indicates the early or high-temperature alteration might have been produced by anhydrous solutions, for the altered wall rock shows an actual decrease of water content, whereas the late Tertiary, a low-temperature alteration, shows a noteworthy increase. Moreover, during the high-temperature alteration no carbonates were formed, but only during the low-temperature mineralization.

DESCRIPTIONS OF SPECIAL DISTRICTS.

METHOD OF TREATMENT.

In the preceding pages the region has been treated as a unit. The different mining districts, however, differ somewhat among themselves in their geology and in the character of their ore deposits, so that for the sake of definiteness and explicitness descriptions of the special districts are added. These descriptions are generally brief and the broader relations of the geology at any locality and the detailed characterization of the formations must be sought under the preceding systematic treatment.

The districts employed here conform to no political subdivisions. They include the areas easily reached from the natural supply points of the region and their boundaries are accordingly somewhat indefinite. In this respect the scheme accords essentially with local usage.

MARYSVILLE DISTRICT.

LOCATION AND HISTORY.

Marysville is situated in Lewis and Clark County at an elevation of 5,600 feet, 17 miles northwest of Helena. It is the terminal point of a branch from the main line of the Northern Pacific Railway. A number of mining camps now idle, including Bald Butte, Empire, and Gloster, are tributary to Marysville.

The prosperity of Marysville has hinged largely on the fortunes of the Drumlummon mine, the oldest, most steadily operated, and most productive property of the district. The Drumlummon lode was discovered in 1876 by Thomas Cruse, who had been placer mining in Silver Creek, below the present site of Marysville, and the mine was gradually developed by him until 1880, when a 5-stamp mill was erected. In 1882 the property was sold to an English company, known as the Montana Mining Co. (Ltd.), for $1,500,000. During the operations of this property $15,000,000 was extracted. In the early nineties the property became involved in protracted litigation, which extended over some 18 years, and the mine in recent years has been worked only spasmodically. Finally the property was sold in default of payment to satisfy a judgment of $240,000 rendered against the Montana Mining Co. (Ltd.), and was bought in 1911 by the successful litigant, the St. Louis Mining & Milling Co. The new owner has commenced to rehabilitate the milling plant, to open the old workings, which had caved badly, and to search for new bodies of ore.

Other notable mines in the district are the Belmont, Cruse, Penobscot, Bald Butte, Empire, and Piegan-Gloster, but all of these were idle during 1911 except the Cruse or Bald Mountain mine.

The total production of the district has been approximately $30,000,000 in gold and silver.[1] In 1910 the production was $145,663 and in 1911 it was $165,832, distributed as follows: Gold, $143,918, and silver, $21,914.

GEOLOGY.[2]

Geologically, the Marysville district is situated on and around a small stock of quartz diorite intrusive into limestones and shales of the Belt series. This intrusive mass represents without question an outlier of the Boulder batholith, the main body of which appears at Mullan Pass, 7 miles south of Marysville.

The sedimentary rocks surrounding the quartz diorite have been thoroughly metamorphosed to exceedingly hard, tough, and dense-textured rocks termed hornstones by Barrell. These are made up mainly of various silicates, such as diopside, wollastonite, tremolite, and biotite, but these minerals as a rule are not visible or discriminable by the eye. In local parlance the rocks are somewhat vaguely known as slates. They form a zone around the quartz diorite, ranging in width from one-half mile to two miles, and grade outward from the diorite stock into the unaltered siliceous shales and limestones of the Belt series.

The quartz diorite is a medium-grained granitic rock composed essentially of andesine, quartz, orthoclase, biotite, and hornblende. Younger than the quartz diorite are a variety of dikes, some of which seem from their petrographic characters to belong to the intrusive aftereffects of the quartz diorite magma. These minor intrusions comprise aplite, pegmatite, and the Belmont diorite porphyry, so named because of its noteworthy abundance on the slopes of Mount Belmont. The aplites are not important quantitatively and the pegmatites are nearly insignificant, but the diorite porphyry occurs in considerable abundance as persistent dikes.

[1] Weed, W. H., Gold mines of the Marysville district, Mont.: Bull. U. S. Geol. Survey No. 213, 1903, p. 88.

[2] The geology of the district has been carefully described in great detail by Joseph Barrell in Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907.

Among the more prominent of these is the long dike at the Bald Butte mine. The diorite porphyries are rocks of conspicuously porphyritic texture, containing prominent crystals of andesine feldspar, together with prisms of hornblende and flakes of biotite in lesser amounts, in a dark-gray groundmass. The feldspar phenocrysts are more numerous and the groundmass more crystalline in those dikes near the main mass of quartz diorite; in fact, in some of them the feldspar phenocrysts are so thickly massed and the matrix so visibly crystalline that the rock closely resembles the quartz diorite. This assumption of granitoid habit by the dikes within the inner metamorphic zone is believed by the writer to be significant and to indicate that the diorite porphyry dikes were injected soon after the main intrusion of the quartz diorite.

Other dikes whose genetic relations are less obvious are the Drumlummon porphyry and the porphyry sheets of Piegan Gulch. That there is a possibility that these various intrusives, including the diorite porphyries, do not all belong to the same stage of igneous activity was recognized by Barrell,[1] but not much importance was attached to it. The determination of the age of these dikes, however, would afford an independent line of evidence on the question concerning the origin of the Marysville ore deposits.

The Drumlummon porphyry is principally encountered in the workings of the Drumlummon mine, which lies at the contact of the quartz diorite and hornstones. The rock is a grayish porphyry carrying small scattered phenocrysts of plagioclase feldspar inclosed in an aphanitic groundmass. These prove under the microscope to be near andesine in composition; the dark minerals once present are found to have been destroyed by vein-forming solutions, and the groundmass is seen to consist of feldspar and quartz.

The porphyry of Piegan Gulch, so far as is now known, occurs in the Marysville area in three sills, a mile north of Gloster, but is found in great abundance in other parts of the region, as shown in previous pages of this report, where it is termed dacite. The porphyry of Piegan Gulch shows phenocrysts of chalky feldspar, biotite, and quartz in a dense gray groundmass. Under the microscope the feldspars are found to be a plagioclase near andesine, which has been largely altered to calcite. Possibly some sanidine is present. The quartz crystals, which are comparatively rare, show strong magmatic corrosion; the biotite phenocrysts are largely calcitized and sericitized; the groundmass in which the phenocrysts rest is of cryptocrystalline texture. The rock accordingly resembles the dacites from surrounding parts of the general region.

The nearest important development of dacites is east of Silver City, 7 miles east of Marysville; rhyolites, which are closely related

[1] Op. cit., p. 49.

to the dacites, occur south and southwest of Marysville, an especially large area extending north from Mullan Pass, and dacites or rhyolites are associated with the extrusive andesites of Little Prickly Pear Creek, a few miles north of Marysville. It is therefore not surprising that isolated dikes of this character should occur within the district, although, as pointed out elsewhere, it is difficult to distinguish isolated dacite dikes from quartz diorite porphyry dikes, and the study of the local geology would afford no clue to their origin.

The dacites found at Marysville show the hydrothermal alteration characteristically associated with the late Tertiary veins, and this fact suggests, although it does not prove, that the principal mineralization took place in late Tertiary time.

ORE DEPOSITS.

GENERAL FEATURES.

The ore deposits are steeply dipping fissure veins carrying gold and silver. They occur around the border of the quartz diorite, and although some are situated in the marginal portion of the diorite, most of the veins are inclosed in the metamorphic hornstones. None occur in the central part of the diorite area. This massing of a considerable number of productive ore bodies around the diorite is the cause of the economic importance of the Marysville district.

The veins average near 1,000 feet in length; the Drumlummon, which is the longest, was developed for a distance of 3,000 feet along the strike. The maximum width of the ore bodies is 40 feet, but the average is considerably less than this, in most of the veins being probably less than 6 feet. The ore occurred in shoots in which the high-grade ore was found above the 200-foot level; none of the mines, except the Drumlummon, are developed deeper than 500 feet below the surface. Gold is the predominantly valuable metal and the ores range between $10 and $20 a ton.

The gold is finely divided and not visible. In the ore of many mines—the Belmont, Empire, and others—it is unaccompanied by sulphides or by insignificant quantities only. In the Drumlummon it is accompanied mainly by tetrahedrite and chalcopyrite, and in the Bald Butte mine by pyrite, sphalerite, and galena. The gangue material is of highly characteristic composition and structure. It consists of quartz, commonly of lamellar habit, and calcite in broad, thin lamellæ. At the Bald Butte mine fluorite occurs, but this is exceptional, for fluorite has not been noted at any other mine in the district. In many of the typical ores of Marysville the calcite lamellæ attain great breadth and extraordinary thinness, at the Empire mine, for example, the extreme diameter being 6 inches and the thickness only one-fiftieth of an inch. The calcite plates are commonly arranged so as to form rude tetrahedral or other irregular pyramidal forms. The quartz is a sugar-textured white variety, commonly pseudomorphic after lamellar calcite. This gives rise to hollow tetrahedral spaces, which are lined with small clear glassy pyramids of quartz. In places the quartz is pseudomorphic after thin curved lamellæ of calcite, and a foliated or schistose structure results. Rarely the quartz shows a delicate amethystine tint.

The calcite carries some iron and manganese and in consequence the outcrops of some of the veins are highly manganiferous. Probably this prevalence of manganese is in part responsible for the enrichment in gold of the upper zone of the Marysville veins. Impoverishment of the outcrop, however, as demanded by Emmons's theory,[1] has not taken place.

The lamellar quartz and calcite form a striking gangue material. It is identical with the gangue of the gold-silver veins in the Miocene dacites on Lowland Creek and resembles the calcite gangue in the veins from which hot water is oozing at Boulder Hot Springs. Further, it resembles the lamellar quartz ore of the De Lamar mine, Idaho, described by Lindgren in his paper on the gold and silver veins in Idaho, and well illustrated in Plate XXVIII of that report.[2] Similar ore occurs also in many of the late Tertiary veins in Nevada, Utah, Arizona, New Mexico, and Washington.

ORIGIN.

The study of the ore deposits in the area of the Boulder batholith has shown that they fall into two groups, whose age with reference to the rhyolites and dacites resting on the eroded surface of the granite has been determined absolutely. The older group is of prevolcanic origin and is genetically related to the intrusion of the granite; the younger group is of postvolcanic origin. Each group carries a distinctive set of features generally sufficient for the determination of the relative age of a particular ore deposit even where the relation of the ore deposit is not absolutely determinable owing to the absence of the volcanic rocks.

So far as the geology of the Marysville district is now known, the age of the productive ore deposits can not be conclusively established with reference to the Tertiary volcanic rocks. Possibly the productive deposits may prove to be the equivalents of the barren veins north of Little Prickly Pear Creek, which are known from undisputable geologic evidence to be of late Tertiary age,[3] but the matter has not been investigated adequately with this point in view. On the

[1] Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Trans. Am. Inst. Min. Eng., vol. 41, 1910.

[2] Lindgren, Waldemar, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900.

[3] Barrell, Joseph, Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907, pp. 112-113.

other hand, the criteria for the recognition and discrimination of the younger deposits from the older group point unmistakably to the conclusion that the Marysville veins belong to the younger or late Tertiary deposits. This conclusion, following inevitably from a regional study of the ore deposits of the Boulder batholith, is opposed to the conclusion arrived at by Barrell from an intensive study of the local geology.

According to Barrell[1] the Marysville veins—

> as shown by their structural and mineralogical features, are due to contraction effects on the margins of the granite mass, at that time recently solidified and cooling.
>
> The structural evidence consists of the relation of the veins to the vicinity of the contact, or at least to the metamorphic zone; the fact that their courses are either approximately parallel or at high angles to this contact surface; the parallel and branching character of the fissures; the generally shattered and infiltrated character of the walls; the dying out of the vein fissures, many of which are continued in parallel lines offset to one side; and, lastly, the absence of marked throw along the fissure planes.
>
> The mineralogical evidence is found most clearly in the study of the vein fillings and alteration of the walls in the Bald Butte mine, since it is believed that fluorite, which is there a characteristic mineral, is indicative of magmatic emanations, though the deposition may take place under hydrothermal as well as under pneumatolytic conditions. Fluorite is often found in the contact aureole of granitic masses and is presumably given off as acidic vapors in water solutions from solidifying magmas. The probability of this view of the origin of the vein fissures is seen when the effects of such contraction from cooling are considered in some detail. The central portions of a granite intrusion the size of the Marysville batholith would cool slowly and as a whole; the contraction would be equal throughout; and there would be little or no tendency to form wide contraction cracks in any direction. This agrees with the absence of vein fissures in the center of the intrusion. The cooling of the zone of contact metamorphism and of the marginal portions of the batholith, however, would result in a shrinkage away of those portions from the surrounding rocks, producing fissures parallel to the contact; while the lessened circumference of the outer zone, caused by its cooling before the center, would tend to set up another set of fractures more or less radial in nature.

That the veins are massed around the intrusive contact of the quartz diorite is a strong argument in favor of their genetic dependence on the intrusion of the igneous rock. But the argument of itself is not conclusive. The opening of the fissures may have been long posterior to the consolidation of the diorite; it is well known that the contacts of dissimilar rocks are favorable loci for dynamic action and therefore the deposits may have been localized in the brittle hornstones because of their superior frangibility. "The parallel and branching character of the fissures; the generally shattered and infiltrated character of the walls; the dying out of the vein fissures, many of which are continued in parallel lines offset to one side; and, lastly, the absence of marked throw along the fissures planes," can hardly be accepted as proof of the contractional origin of the Marysville fissures. These structural features are of common occurrence in late Tertiary veins which cut surface lava flows and are therefore as indicative of frac-

[1] Op. cit., p. 105.

turing under light load as they are of contraction during the cooling of plutonic rocks. In the region considered in this report all these structural features are found in the post-Miocene veins on Lowland Creek, as is well exemplified in the Ruby mine, described on pages 125-127.

Says S. F. Emmons:[1]

Some writers on ore deposits speak of vein fissures as sometimes resulting from contraction, but I have yet to learn of a well-authenticated instance. I regard a certain amount of movement as necessary to break the cohesion between the respective walls of a joint or fissure sufficiently to make a water channel. This I hold to be true also of eruptive contacts. * * * It is to be noted that a contraction fissure could not extend from one rock into another.

Yet the continuity of the Marysville veins across intrusive contacts, as exemplified in the Belmont, Cruse, and Drumlummon mines, is a salient characteristic of many of the ore bodies. Further, numerous mechanical features, such as brecciation and faulting—all prior to the filling of the veins—indicate considerable movement, even if only of oscillatory character, during the opening of the fissures. These facts would seem to place the burden of proof on one who maintains the contractional origin of the Marysville fissures.

The mineralogic evidence adduced by Barrell seems unfortunately chosen. The Bald Butte mine, the only mine in which fluorite is found, is not characteristic of the mines that have yielded 95 per cent of the production of the Marysville district. Nor is fluorite necessarily indicative of magmatic emanations, and its presence assuredly does not prove that veins containing it are genetically related to plutonic igneous rocks. It occurs in the late Tertiary veins of New Mexico and is even now being deposited by the hot springs at Ojo Caliente.[2] According to Lindgren, fluorite is a persistent mineral and is of little value in determining the genesis of a deposit. Its presence is therefore not incompatible with the late Tertiary origin of the veins at Marysville; nevertheless it can be conceded that the Bald Butte ore is of magmatic derivation without affecting the argument in regard to the origin of the majority of veins of the district.

The characteristic veins of Marysville, comprising those that yielded 95 per cent of the production, have a gangue identical in structure and composition with that of the veins in the dacites of Lowland Creek; that is with the veins of proved post-Miocene age. This striking gangue, the lamellar calcite and pseudomorphic lamellar quartz, is of wide occurrence in the late Tertiary deposits of the Western States, and this circumstance indicates that peculiar conditions were responsible for this type of ore. The widespread condition common to all the deposits was probably deposition near the surface. For De Lamar, Idaho, Lindgren has estimated that the deepest ore bodies

[1] Suggestions for field observations of ore deposits: Min. and Sci. Press, vol. 95, 1907, p. 18.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol Survey No. 68, 1910, pp. 70-73.

were formed at a depth of 700 feet.[1] Further confirmatory evidence is the fact that the Marysville quartz is in general exceedingly dense or porcelainoid in texture, agreeing thus with the younger veins rather than the older, which are characterized by coarse-grained quartz. Then, too, the metasomatically altered wall rocks, when directly comparable, resemble those accompanying the younger deposits. Tourmaline, which is so conspicuously developed in most of the older deposits of the Boulder batholith, is entirely absent; so also, is that coarse sericitization which yields a macroscopic sericite of glossy habit. On the other hand, the feldspars have been reduced to chalky spots of cryptocrystalline sericite, and chloritization and calcitization, both of which are absent from the older deposits, are common alterations. In short, the Marysville deposits are in no way like those of the older group; on the other hand, they closely resemble those of the younger group.

It may, perhaps, be argued that the Marysville veins are nevertheless genetically related to the intrusion of the quartz diorite, but represent a later phase of the same mineralization to which the older group of deposits belongs. A strong objection to this argument from a theoretical standpoint is the fact that the Marysville veins were first filled with lamellar calcite and that this was subsequently replaced by quartz. This sequence of mineralization is in direct contravention of the sequence of magmatic emanations, according to which the carbonate stage should come last and not first.[2] The veins show internal evidence of two phases of mineralization, both similar to those shown by the late Tertiary veins, but neither is analogous to any phase of mineralization of the older deposits, and this objection, based upon field evidence, seems conclusive against the argument that the Marysville veins represent a final stage of the older mineralization.

DESCRIPTIONS OF MINES.

DRUMLUMMON MINE.

The Drumlummon mine is worked principally through the Maskelyne tunnel, a 1,200-foot crosscut intersecting the lode at a depth of 400 feet. At the intersection a shaft was sunk to the 1,600-foot level, but it is now filled with water. The vein has been developed along the strike for a distance of 3,000 feet, but because of caved stopes most of this part of the vein was inaccessible during 1911.

Much of the material filling the caved stopes is said to constitute low-grade milling ore, and it is now being drawn off and sent to the mill. Twenty stamps of the old 60-stamp mill have been put in working condition by the new owner, the St. Louis Mining & Milling Co., and

[1] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 165.

[2] Clarke, F. W., The data of geochemistry, 2d ed.: Bull. U. S. Geol. Survey No. 491, 1911, p. 275.

the crushing of ore was commenced again in July, 1911. In addition to the ore taken out through the Maskelyne tunnel, surface ore was being mined through the Roadside tunnel on the Nine-Hour claim, which is situated on the southwest end of the Drumlummon vein. This ore is stated to carry from $35 to $80 a ton and constitutes, therefore, shipping ore, which is sent to the smelter at East Helena.

The total production of the mine has been $15,000,000, of which 60 per cent was in gold. The surface ores were of high grade, probably comparable to that now taken from the Nine-Hour claim, but the ore mined during the later years of the operations of the Montana Mining Co. was of medium grade only, containing one-half ounce of gold and from 7 to 12 ounces of silver a ton.[1]

The Drumlummon vein parallels the contact of the granite and hornstones, having a general trend of N. 15° E. and steep easterly dip. Extensive pits due to caving mark the course of the vein on the surface and show clearly that the wall rocks consist mainly of dense-grained banded hornstones, which are cut irregularly by granitic dikes and by small aplite dikes. The aplite dikes are shattered and in places are mixed with the general country rock. The hornstones are the metamorphic equivalents of the banded phase of the Helena limestone of Algonkian age, and when examined microscopically are found to consist essentially of diopside and wollastonite, which explains why these so-called slates prove so extraordinarily difficult to drill. Porphyry dikes are also encountered in the mine, as discussed by Barrell.[2]

As seen on the 400-foot level, the Drumlummon vein has a well-defined footwall, strongly wavy and heavily corrugated. The corrugations trend vertically, and the striæ and surface protuberances show that the hanging wall moved downward on the footwall. In places a layer of attrition product 1 to 1½ feet thick rests on the footwall; in places there are a number of superposed false walls above what may be termed the real or ultimate footwall. The hanging wall of the vein consists of a well-defined plane, but the country rock, as shown by a short crosscut south of the shaft, is more or less interlaced with quartz-calcite veinlets to a distance of at least 10 feet. In places the fissure continues, but the filling of the vein consists of barren detritus from the wall rocks. In the south end of the vein, according to J. E. Clayton,[3] "the quartz gangue gives out entirely and the filling between the walls is nothing but crushed shale and abraded material from the walls of the fissure." This feature is particularly well shown on the Nine-Hour claim, where numerous open cuts have been made during the progress of litigation to show the

[1] Bayliss, R. T., Trans. Am. Inst. Min. Eng., vol. 26, 1897, p. 33.
[2] Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 108.
[3] Eng. and Min. Jour., vol. 46, 1888, p. 106.

continuity of the vein. The fissure, which is some 25 feet wide, is barren here—that is, devoid of quartz—and the filling consists of broken country rock, more or less stained with iron oxide. The footwall is marked by a strongly slickensided plane. All these features indicate that powerful forces were operative during the formation of

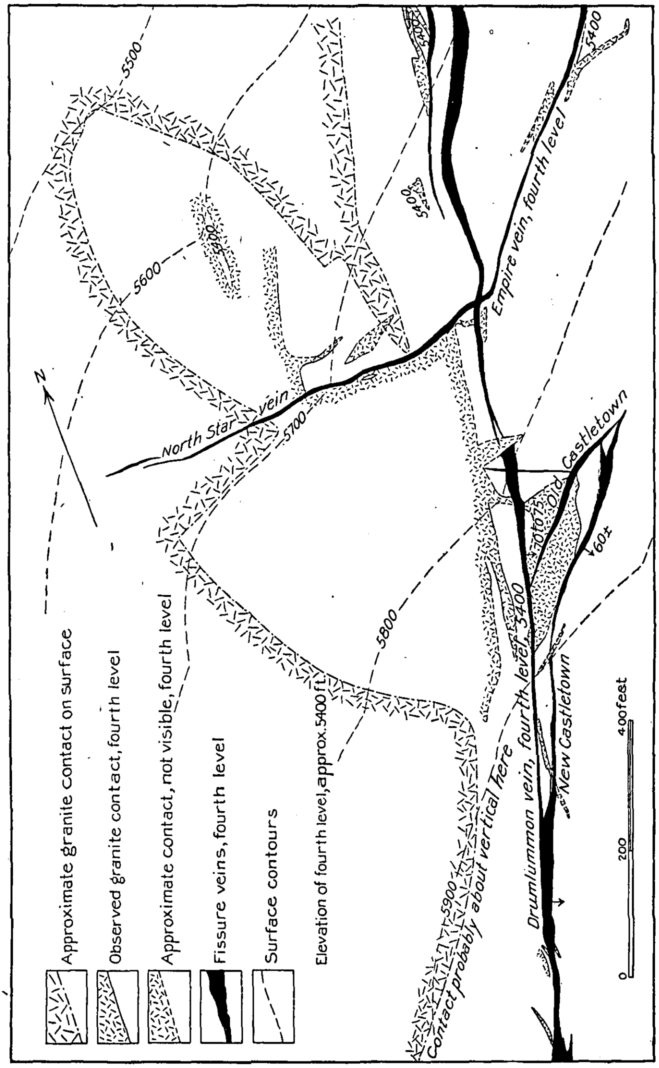


FIGURE 4.—Drumlummon vein system on the level of the Maskelyne adit (from Barrell).

the Drumlummon fissure and prove beyond question that its opening was not due to contraction produced by the cooling of the surrounding rocks after the intrusion of the granite.

The New Castletown and Old Castletown veins are branches of the Drumlummon vein, as shown in figure 4. The North Star is an intersecting vein. According to Clayton it is older than the Drumlummon; according to Barrell it is younger.

The ore occurred in pay shoots, which in places expanded to a maximum width of 40 feet, but on the whole averaged 20 feet in width. The shoots pitched obliquely to the south within the plane of the vein, the direction being determined by the structural features of the vein. The wavy character of the walls causes the vein to swell and pinch along the strike and on the dip, and the expanded portions of the vein are found farther south on successively lower levels. The cause of this southward pitch of the ore shoots is clearly explained by Clayton:[1]

The shifting of the hanging wall has been nearly straight down the slope of the underlie, and the curvatures, or wave lines of the fissure, pitch down obliquely to the south, corresponding generally with the pitch of the ore shoots in that direction.

The rich ore of the mine occurred mainly above the 200-foot level, and an impoverishment of the ore shoots began to be noticed below the 400-foot level. Good ore, however, was found down to the 1,000-foot level, but none, according to Weed, occurred below that level. The data at hand are insufficient to prove whether this decrease in the grade of the ore in depth is due to secondary enrichment or to primary vertical distribution; the facts seem to point to a combination of both processes.

The surface ore now being taken out on the Nine Hour claim is thoroughly oxidized. It shows considerable azurite, together with oxides of iron and manganese in a quartz gangue, and is rich in fine gold, although this is not visible. The primary sulphides in the Drumlummon ore are tetrahedrite and chalcopyrite in rather sparse amounts. Pyrite, galena, and sphalerite are rare. The bonanza ore formerly worked doubtless contained silver sulphantimonides, such as pyrargyrite, but tetrahedrite (variety freibergite) appears to have been the most important constituent. The gangue material is a fine-grained saccharoidal white quartz, in places so dense as to resemble porcelain. The texture is rather drusy and vuggy, and the vugs are lined with quartz, calcite, and dolomite crystals. Fragments of altered wall rock are common in the quartz. For example, good ore from the 1,000-foot level consists essentially of angular fragments of wall rock cemented by calcitic quartz of drusy structure; sparse chalcopyrite is the only visible metallic mineral. Calcite, somewhat ferriferous and manganiferous, is prominent in various parts of the mine, and shows the lamellar habit and tetrahedral arrangement of the lamellæ so characteristic of the Marysville ores. Quartz that is pseudomorphic after calcite is found, but appears not to be as common as in other mines of the district.

Primary ore was seen in place on the 400-foot level, 50 feet south of the shaft. This ore is a somewhat calcitic quartz carrying tetrahedrite and chalcopyrite; the adjoining hanging-wall rock is a firm,

[1] Op. cit., p. 107.

hard granite (or, accurately, quartz monzonite), which under the microscope proves to be highly calcitized and chloritized. At 150 feet north of the shaft the wall rock, which is here the banded hornstone, is extensively shattered by postmineral fracturing and leached by sulphate solutions. So thorough has this leaching been in places that all the bases have been removed, leaving a white rock of low specific gravity which consists essentially of silica. These altered wall rocks show an abundant development of manganese dendrites.

The calcitic nature of the primary ore of the Drumlummon vein precludes the possibility that secondary enrichment, whether of gold, silver, or copper, has extended downward to any considerable depth.

CRUSE MINE.

The Cruse or Bald Mountain mine, as it is known locally, together with the West Belmont mine, which is worked through the Bald Mountain adit, was the most active property at Marysville in 1911. Seventy men were employed until July 1, when a considerable reduction of the force took place. A 20-stamp mill is on the property; 70 per cent of the gold and silver is recovered on the plates, and the tailings go directly to a cyanide plant.

The mine is situated at the contact of the granite and hornstones, which form a capping resting horizontally on the intrusive granite. It is developed by three tunnels drifted on the vein; tunnel No. 1 is the working adit of the mine. The maximum depth reached anywhere in the mine is 500 feet. The vein trends east and west at right angles to the contact and dips 70° S. The two tunnels above No. 1 are in the hornstones; No. 1 commences in granite but encounters solid hornstone at 1,000 feet from the portal, although some minor masses of hornstones are inclosed in granite at some distance from the main contact. The 100-foot level below tunnel No. 1 is entirely in granite. The main ore shoot of the mine was in granite and was from 5 to 30 feet wide and 500 feet long. Along the strike, as seen in tunnel No. 1, the vein becomes abruptly narrow on entering the hornstone and tends to split and fork. The upper portion of the vein was inclosed in hornstones, which show pronounced evidence of oxidation and leaching by downward-moving solutions. The ore shoot did not come to the surface through this highly altered zone, and this fact, together with the decrease in value of the ore in depth, suggests that a secondary enrichment of gold has taken place.

The West Belmont vein, which is worked through the Bald Mountain adit, resembles the Bald Mountain vein. The ore consists of quartz intergrown with manganiferous calcite in large thin plates. The quartz in part is pseudomorphic after lamellar calcite; black oxide of manganese is more or less common, and the ore is therefore like that characteristic of the Marysville district.

BELMONT MINE.

The Belmont mine, situated on the east slope of Mount Belmont, has been one of the largest producers, but was idle during 1911 and not accessible. According to Barrell,[1] the mine—

> has been developed on a system of veins running in general at a high angle to the contact surface. What is known as the main or south vein, running from west to northwest, forks to the west into two main branches which diverge at a slight angle, and the southern of these branches splits again. The north vein begins at a point about 100 feet north of the main vein, bearing at first northwest and then nearly north. This vein, as shown on the map of the second level, tapers out into a fork at the east end and passes into a barren fault to the northwest. The dip of the vein is toward the main vein at an angle of 70° to 75° The veins are very short, and the ores are found only from the fourth level to the surface. They do not continue across the large dike or porphyritic hornblende-quartz diorite which separates this arm of hornstones from the main sedimentary body, but, as mentioned above, show a disposition to branch and taper out. Where the branches separate the country rock near the junction shows considerable brecciation with infiltration of quartz veinlets, and many such parallel quartz seams may be noted in the granite in association with the main vein, even where the latter does not branch. In the hornstones the vein matter is more sharply limited to the principal fissures, but these have an aggregate width as great as in the granite, indicating no greater opening of one than of the other. Within the mineralized zone the average aggregate width of vein quartz is estimated at about 3 feet per 100 feet of granite. On the fifth level the vein quartz shows widths of 3 to 5 feet but contains many opening vugs and is almost barren.
>
> A series of east-west normal faults with dips to the south, later than the veins, in some places follow the strike and in others cut across the veins. These ore deposits have probably received considerable secondary enrichment in which the fault fissures have taken part.

Exceptional ore from the main level consists of fine-grained quartz which shows traces of lamellar structure and is traversed by manganiferous films. Some gangue material consists almost entirely of white lamellar calcite; other specimens show an equal admixture of calcite and quartz, and such material under the microscope reveals the remarkably perfect replacement of calcite by quartz. Comby amethystine quartz is also found.

BALD BUTTE MINE.

The Bald Butte mine is on the northwest slope of Bald Butte near the head of Dog Creek. A mill of 20 stamps belongs to the property, but is situated 1 mile downstream from the mine, necessitating haulage of the ore by teams.

The mine was operated continuously from 1890 to 1902, intermittently since that time, and was idle during 1911. The total production is two and three-fourths million dollars, of which approximately 90 per cent was recovered in the bullion and 10 per cent in the concentrates. The average yield on the plates was $10.11 a ton and the

[1] Geology of the Marysville mining district, Mont.: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 109.

average fineness of the bullion was 753. The concentrates carried about 4 ounces of silver to each ounce of gold and averaged roughly 10 per cent of lead.

The workings comprised a number of surface pits and a series of tunnels, of which No. 2 has been the main working level in recent years. The extreme depth thus attained is 500 feet. Many of the drifts are inaccessible and no ore in place was seen. The workings are associated with a diorite porphyry dike, nearly vertical in attitude, and 60 feet wide, as shown in crosscuts. In places the dike is cut by a closely spaced system of veinlets, but this mineralized porphyry does not constitute ore, at least upon the lowermost level, where it assays under $1. The veinlets are dense-textured aggregates of quartz and fluorite, showing a faintly banded structure, and commonly containing a small amount of fine flaky molybdenite. Shoots of ore were found alongside the dike in places and in the adjoining hornstone country rock on its northeast side. Here was found a highly irregular system of short narrow fissure veins. The "Knifeblade," so named because of its extreme narrowness, was extraordinarily rich in free gold. Associated metallic minerals were pyrite, galena, and sphalerite.

PENOBSCOT MINE.

The Penobscot mine, which is one of the best-known mines in the history of Montana on account of the extraordinary richness of its surface ore, lies near the head of Penobscot Gulch 2 miles southwest of the town of Marysville. The Penobscot vein as seen from the surface had a remarkably well defined hanging wall; the ore body, which swells and pinches, averaged 3 to 4 feet in width. The country rock inclosing the vein consists of the metamorphic hornstones of the Helena limestone cut by intrusions of diorite porphyry. Two parallel veins, known as the Eagle and the Leopard veins, which like the Penobscot dip 65°–80° NW., lie in the footwall of the Penobscot vein; the Eagle at 250 feet, and the Leopard at 600 feet.

As shown on the stope map, ore was extracted from the Penobscot vein for 1,000 feet along the strike at the surface. The mine was developed to a depth of 500 feet, but the ore came principally from above the 300-foot level and largely from above the 200-foot level. The production was one and one-fourth million dollars. The ore rock is a porous manganiferous quartz, which in places carries lamellar calcite.

On the Eagle vein an incline was sunk 70 feet; the ore shoot yielded $10,000, but gave out at 50 feet depth.

The present attempts to find ore in the Penobscot vein, which have continued in a small way during the last 10 years, consist of a tunnel 300 feet long (mainly along the vein) attaining a depth of 90 feet.

The face of this tunnel shows a lode of highly manganiferous and iron-stained porous quartz, which is said on competent authority to resemble the ore formerly found in the productive part of the Penobscot vein, but this material contains no gold. Another tunnel, which like the preceding is situated on the west end of the property, aims to tap the vein on the 300-foot level. The evidence from the history of the mine seems unfavorable to the probability of finding ore in depth; the geologic evidence, based on the presence of a highly manganiferous leached quartz, suggests that the gold may have been dissolved and carried to a lower level, and that therefore there is a possibility, at least worth testing, that ore may be found on the downward extension of the vein.

EMPIRE MINE.

The Empire mine and mill of 60 stamps, now idle, are situated on the west slope of Mount Belmont. The vein is said to be stoped out above the principal haulage level for a length of 1,500 feet, the extreme depth thus attained being approximately 400 feet. The country rock consists of the metamorphic phase of the Empire shale, which dips here 10° W. The vein trends N. 60° W. and stands vertical. The Whippoorwill is a parallel vein several hundred feet northeast of the Empire.

The ore now available is a sugar-textured white quartz full of vugs and devoid of metallic sulphides. It contains as a rule much lamellar calcite, which commonly forms plates of extraordinary thinness and diameter, some plates attaining a diameter of 6 inches.

PIEGAN-GLOSTER MINE.

The Piegan-Gloster, a consolidation of two adjoining properties, is situated 3 miles northwest of Marysville. The mine is opened by two tunnels on the vein, the upper one of which is now inaccessible. The lower tunnel, trending N. 25° E., is 1,200 feet long.

The mine is situated near the northwestern margin of the Marysville stock and the country rock is quartz diorite, but the contact-metamorphic hornstones are found near by. The vein as seen in the lower tunnel dips 60° E. and averages 3 feet in width. Some post-mineral movement has taken place along the walls, but the ore is generally frozen to the quartz diorite. The gangue is mainly quartz with some calcite. The quartz, which in places is amethystine, commonly shows large vugs lined with coarse crystals; in places also it displays the lamellar structure and tetrahedral habit so characteristic of the replacement of the calcite of the district. At the face of the tunnel the vein narrows to 1 foot of massive quartz containing small streaks of pyrite. Fragments of the diorite wall rock up to 6 inches in diameter are common in the vein.

The Gloster is stated to have yielded a considerable output in former years, the ore having been derived from a shoot 800 feet long, 600 feet deep, and from 3 to 12 feet wide.[1] The Piegan part of the property was systematically explored during 1906, and a winze 750 feet from the portal of the lower tunnel was sunk to a depth of 750 feet, but the mine was idle during 1911.

STRAWBERRY MINE.

The Strawberry mine lies 3 miles southeast of the town of Bald Butte and near the head of the gulch on the east side of Greenhorn Mountain. The developments consist of an inclined shaft sunk on the vein, a drift at 120 feet vertical depth, and a crosscut tunnel from the surface on the mill level. A 10-stamp mill stands on the property.

The vein, which strikes north and south and dips 60° W., is situated along the faulted contact of diorite and dark Marsh shale. It ranges in width from 3 to 15 inches. On the hanging-wall side it is separated from the diorite by a narrow seam of gouge, but is frozen to the footwall. The vein filling consists of quartz and calcite, both of which are lamellar in habit, forming a gangue material entirely similar to that of the veins at Marysville. The quartz is commonly of a delicate amethystine tint, and the lamellæ are so disposed as to form hollow tetrahedrons, which are incrusted internally with small quartz crystals. Small pieces of slate inclosed in the vein are surrounded by a radiating growth of quartz crystals.

The ore is said to yield upon the plates between $30 and $70 a ton in gold.

ELLISTON DISTRICT.

LOCATION.

Elliston is the first town on the Northern Pacific Railway west of the Continental Divide and is situated on Little Blackfoot River at an altitude of 5,000 feet. It is the shipping point of a large territory, but during 1911 little mining was in progress throughout this region.

The lime plant of the Elliston Lime Co. is situated 1 mile east of the town, the kilns standing alongside the railroad right of way. The raw material is quarried from the Madison limestone, which outcrops prominently here. The seasonal output of lime is reported to be 125,000 bushels of 80 pounds.

GEOLOGY.

The rocks in the immediate vicinity of Elliston consist of an apparently conformable succession of limestone, quartzite, and sandstone, striking north and south and dipping westward at an angle of 20°. They range in age from Carboniferous to Cretaceous. The lowest

[1] Rept. Montana State Inspector of Mines, for 1905-6, p. 109.

formation is the Madison limestone, well exposed 1 mile east of Elliston. This is overlain by the Quadrant quartzite, consisting predominantly of a dense massive quartzite, near the top of which occurs a bed of high-grade phosphate rock. The Quadrant quartzite is succeeded concordantly by the Ellis formation of Jurassic age, which is highly fossiliferous through a thickness of 50 feet. Above these rocks come several hundred, possibly a thousand, feet of cross-bedded sandstone, the upper portion of which is doubtless of Cretaceous age. Near the west end of the town the quartzite of the Quadrant formation is brought up again by a fault, but disappears within a short distance beneath the rhyolites that are prominent along the valley of Little Blackfoot River west of Elliston.

Rhyolites are present in considerable volume southwest of Elliston and persist on the flanks of the mountains up to an altitude of 6,200 feet. Some of these rhyolites differ considerably from the rhyolites common throughout the rest of the region; one of these is especially noteworthy because of its marked characteristics. It is a snow-white porphyry carrying as its sole porphyritic constituent large scattered phenocrysts of smoky quartz. Breccias of this rock are common. With the rhyolites are associated various basaltic rocks, among which a black glistening variety carrying large amber-colored phenocrysts of plagioclase is most prominent.

Tertiary lake beds underlie an extensive area west and northwest of Elliston. According to Douglass the lake beds north of Avon, which is 9 miles west of Elliston, are very probably of lower Oligocene age. At the mouth of Snowshoe Creek auriferous gravels rest on an eroded surface of lake beds.

Well-rounded gravels, presumably of Pleistocene age, occur 600 feet above the river in the vicinity of Elliston, but their origin was not investigated. A few miles southeast of the town extensive morainal deposits, as indicated by the pitted plain structure, are spread over the broad valley of Little Blackfoot River. These deposits, lying at an altitude of 5,000 feet, are the lowest glacial deposits found anywhere in the region considered in this report.

DESCRIPTIONS OF MINES.

JULIA MINE.

The Julia mine, the property of the Montana-Clinton Copper Mining Co., is situated 8 miles south of Elliston at an altitude of 6,600 feet on the west side of Telegraph Creek. This is a comparatively recently discovered property. It is developed by a shaft 210 feet deep. The vein is inclosed in granite and as a rule lies between exceedingly well defined walls, although the ore does not, except in a few places, fill the entire vein. The course of the vein is slightly south of east and the dip is 80° S. As seen on the 200-foot level, which is 150 feet long, the vein swells and constricts abruptly, ranging in thickness from 6 inches to a maximum of 5 feet. The sulphides reach 2 or 3 feet in thickness. The granite or quartz monzonite inclosing the vein is firm and unaltered up to the walls, being only slightly pyritized for about 1 foot from the vein; that within the vein is greatly altered and along the walls there is considerable soft sticky gouge due to postmineral movement.

The ore consists of a heavy sulphide mixture of galena, sphalerite, pyrite, and tetrahedrite, associated with subordinate quartz. The texture in places is rather drusy, vugs lined with quartz crystals being common. Tetrahedrite indicates a high content in silver. Sulphides consisting predominantly of pyrite, which commonly occurs in large well-crystallized pentagonal dodecahedrons, are discarded as valueless. The ore is stated to carry 60 ounces in silver with small amounts of lead and copper.

The surface ore is said to carry much gold, but the amount has decreased with increasing depth. The silver is said to have increased. As a rule, however, there is little evidence of oxidation or enrichment.

EVENING STAR MINE.

The Evening Star mine, better known as the Big Dick, lies 6 miles due south of Elliston on the summit of the mountain on the south side of Little Blackfoot River. The altitude is 7,000 feet. This property was idle during 1911.

The country rock is a coarse andesitic breccia, apparently bedded; the strike is N. 50° E. and the dip 20° NW. It is much jointed so that determinations of strike and dip of bedding are likely to be unsafe. The ore deposit is said to be a blanket vein developed by a shaft 300 feet deep and is said to dip north at a low angle. The ore carries galena, pyrite, sphalerite, and arsenopyrite in a quartz gangue; some of the quartz contains numerous large columns of black tourmaline intergrown with pyrite. The ore is reported to have been high grade, carrying as much as 3 ounces of gold a ton. During 1906 a gold-silver-lead ore was shipped to the East Helena smelter and a production was maintained until 1910. The deposit was worked out to the west end line; during 1911 the lessees were engaged in sinking a shaft near this end line on the adjoining claim, which is one of a group known as the Finnish or Weston group. It was expected that the Big Dick vein would be struck at a depth of 150 feet.

TWIN CITY MINING & MILLING CO.'S MINE.

The Twin City Mining & Milling Co.'s property is situated 8 miles south of Elliston, at an altitude of 6,800 feet, on the east side of Telegraph Creek. It is developed by a shaft 85 feet deep with a crosscut at the bottom 21 feet long, but these were under water at the time of visit. The vein is inclosed in granite, trends N. 70° E., and is 18 feet wide. It is reported that 8 feet of the lode adjoining the footwall averages $3.60 a ton, the product being gold, silver, copper, and lead. The material on the dump resembles in part the ore at Rimini, being a black tourmaline-bearing quartz ore. Some strong tourmalinic lodes have been uncovered in the vicinity of the shaft, but they have not been found to carry any valuable constituents.

ONTARIO MINE.

The Ontario mine, which has the reputation of having been one of the largest producers in the Rimini district, is situated near the head of Ontario Creek, a branch of Little Blackfoot River. The main developments consist of a crosscut tunnel 800 feet long, from which is sunk a shaft 320 feet deep. These workings were inaccessible during 1911. The country rock is granite, and the ore, as shown on the dumps, consists of pyrite, sphalerite, and galena, inclosed in quartz.

MONARCH MINE.

The Monarch mine lies on the north flank of Bison Mountain at an elevation of 7,250 feet. Geologically it is situated near the intrusive contact of the quartz monzonite and the overlying andesites. The ore minerals are galena, blende, pyrite, and arsenopyrite in quartz.

BLUE BELL MINE.

The Blue Bell mine, although long idle, is worthy of description here on account of its unusually interesting geologic features. The mine is situated 1 mile southeast of the west portal of the Mullan tunnel. The developments consist of a shaft, a number of surface cuts, and a tunnel about 175 feet below the collar of the shaft. It is reported that some rich copper ore was shipped from the mine.

The country rock is a monzonite containing numerous large porphyritic orthoclase crystals. The nearest intruded rock is a mile distant and consists of Madison limestone. The ore material is mainly fine-grained garnet rock carrying disseminated molybdenite and pyrite. There is also much porous rock composed of large euhedral garnets coated with secondary minerals. An open cut 200 feet from the shaft shows clearly the geologic relations of the ore to the inclosing country rock. In this open cut the lode is about 12 feet wide, and the filling consists of garnet rock inclosing a few irregular thin masses of monzonite. These horses are in fact ungarnetized residuals of monzonite. Veinlets of garnet traverse the monzonite exactly as veinlets of quartz and tourmaline do in the ordinary forms of mineralization throughout the region. In the vicinity of fine cracks near the garnetized zone the plagioclase feldspars of the monzonite have been converted solidly to brilliant yellowish-green aggregates of epidote, and the rock is thus rendered strikingly porphyritic. The thin veinlets of garnet are commonly bordered by a white band of altered monzonite, contrasting markedly with the normal dark-gray color of the monzonite. When examined microscopically, the white rock adjoining the garnet veins is found to consist essentially of garnet and scapolite, with subordinate amounts of epidote, orthoclase, plagioclase, pyroxene, quartz, and apatite. Some of the massive garnet rock is found under the microscope to consist predominantly of garnet, with which is associated some monoclinic pyroxene, suggestive of hedenbergite, and a small amount of sericite. The garnet is a dark-brown variety, whose index of refraction exceeds 1.79.

All the features of this deposit suggest that it is a vein of garnet in the monzonite. It is possible that it represents a highly metamorphosed inclusion of limestone from the roof of the batholith, but the field evidence seems to be against this supposition. Whatever explanation is adopted, the phenomena here show conclusively that the garnet molecule is able to migrate and form veinlike deposits under the influence of chlorine-bearing solutions.

RIMINI DISTRICT.

LOCATION.

Rimini lies at an altitude of 5,200 feet, 14 miles by air line southwest of Helena. It is situated on Tenmile Creek, which flows in a deep gorge just above the town, between Red Mountain on the east and Lee Mountain on the west. The surrounding country is of high relief, so that mine development is favored to an unusual extent by the ease and advantage with which adit tunnels can be constructed.

Rimini is the terminal point of a branch of the Northern Pacific Railway from Helena; owing to the present low state of the mining industry a semiweekly service only is maintained. A considerable mining territory is tributary to Rimini; this was formerly, and is occasionally now, known as the Vaughn mining district.

GEOLOGY.

The prevailing country rock is coarse-grained granite, technically a quartz monzonite, composed of plagioclase, orthoclase, quartz, biotite, and hornblende. It is of uniform appearance and, as shown by chemical analysis of material from the Frohner and Valley Forge mines, coincides in composition with the general rock of the Boulder batholith. A considerable body of aplite extends along the ridge from the Peerless Jennie mine to Red Mountain, where it is covered by rhyolite.

Pregranitic rocks, represented by the andesite-latite series, occur 2 miles below Rimini and extend westward across the Continental

Divide. On the summit a flow-streaked biotite latite is well exposed, and masses of diorite porphyry are common. Farther south on the divide is a small patch of profoundly tourmalinized andesite. The distribution of these pregranitic rocks suggests that although bare granite is the dominant surface rock in the Rimini district, the present surface is neither far removed nor much below the under surface of the cover beneath which the granite was intruded. The greatest depth is indicated at Rimini, possibly 2,000 feet.

Rhyolites are a conspicuous element in the geology of the district. They form the capping of Red Mountain and of Lee Mountain, extend southward along the high summits, and form the bedrock of the well-known "porphyry dike" country. Those of Red Mountain display a great variety of color and texture, but nearly universal features are flow streaking, abundant phenocrysts of smoky quartz, and phenocrysts of sanidine, commonly opalescent. The rhyolites are mainly lithoidal porphyries but include some obsidian and some breccias.

ORE DEPOSITS.

Two periods of mineralization are recognizable at Rimini: An older or late Cretaceous and a younger or late Tertiary period. The ore bodies of the first period are auriferous silver-lead deposits inclosed in granite. The principal ore mineral is galena, accompanied by sphalerite and pyrite. Most of the lodes are notably tourmaline-bearing, and the characteristics of these deposits have been described on pages 46–51 under the heading "Tourmalinic silver-lead deposits." It is to be noted that at Rimini tourmaline is usually called hornblende.

Among the deposits of this kind may be enumerated the Lee Mountain, Valley Forge, East Pacific, Lady Washington, John McGrew, and Armstrong on Minnehaha Creek. Others, such as the Election, show only feeble tourmalinization, and still others, such as the Eureka, show no tourmalinization, so far as this study was able to determine. These probably represent the nontourmalinic phase of the same mineralization, comparable in its effects to that which has altered the footwall of the Valley Forge mine.

Sulphide ore is encountered at shallow depths beneath the carbonate zone; in the Valley Forge mine, for example, at 40 feet. Although the relief of the district is large and abrupt, water stands near the surface. At an altitude of 6,250 feet water stands in the East Pacific shaft at 50 feet depth, although the bed of Tenmile Creek, less than a mile away, is 1,000 feet lower.

Mining activity was at a low ebb during 1911. Yet it seems probable that at least some of the mines which have been important producers in the past may again become productive upon systematic exploration and development. There seems to be no reason against the possibility that as good bodies of ore may be encountered in depth as have been found on the upper levels. Further, as has already been pointed out, the ore occurs in chambers scattered through zones of tourmalinized and sericitized granite; it follows, therefore, that any such zone of profound alteration should be explored thoroughly along the strike and equally thoroughly across the strike by crosscuts driven across the full width of the ore-bearing zone.

The Tertiary deposits consist of low-grade disseminated gold ore inclosed in the rhyolites resting on the eroded surface of the granite. The most prominent is the "porphyry dike" property, near the head of Tenmile Creek. The "dike," however, is not a dike but a series of surface flows of rhyolite lying on the granite. The practical importance of this distinction is of course obvious: A dike has an indefinite extension downward, whereas the rhyolite flows form a capping of definite thickness, being terminated in depth by the granite floor on which they rest. The rhyolites are altered and impregnated with gold along small fractures, the whole mass constituting a low-grade ore said to carry several dollars to the ton. More details are given in the special descriptions.

DESCRIPTIONS OF MINES.

VALLEY FORGE MINE.

The Valley Forge mine is situated on the flank of the mountain just east of the town of Rimini. It is developed by a series of drift tunnels, the lowest of which is at an altitude of 5,800 feet; in this a winze was sunk 100 feet deep. The ore bins at the mouth of the lowest tunnel are connected with the Northern Pacific Railway by an aerial tramway. The extreme depth attained below the surface is approximately 325 feet. A tunnel was commenced from the level of the town of Rimini which will give an additional depth of 600 feet on the lode; the length required is estimated to be 1,385 feet, but as yet only 300 feet have been completed.

All ore above the main tunnel has been stoped out. During the early part of 1911 three men were employed getting out carbonate ore from the outcrops. This was shipped to the East Helena smelter and is stated to have carried $6 in gold, 12 ounces in silver, and 7 per cent lead, but this is low-grade ore. Higher-grade material is said to carry as much as $11 in gold.

The total production of the mine is about $200,000, the ore ranging in value from $15 to $30 a ton in gold, silver, and lead. The gold exceeded the silver in value and the lead ran as high as 40 per cent.

The general country rock at the mine is granite, although just to the north across the gulch is a small patch of flow-streaked rhyolite.

The lode trends east and west and dips 80° S., thus conforming with the general trend of the veins at Rimini. It averages 4 feet in width. The footwall is commonly well defined and consists of sericitized granite impregnated with pyrite, galena, sphalerite, and arsenopyrite, as described elsewhere in detail in this report. The hanging wall consists of quartz-tourmaline rock or so-called black quartz, which in places reaches 6 feet in thickness. This carries a small amount of pyrite, some sphalerite, and galena; locally all three of these sulphides are intergrown.

The commercial ore consists of an aggregate of galena and pyrite which is associated with some sphalerite and rarely some chalcopyrite. The ore occurs in shoots lying beneath the hanging wall of black quartz-tourmaline rock. The shoot on the lowermost tunnel, No. 3, was 350 feet long, but for 450 feet from the portal the lode or mineralized zone, although well defined, was barren.

Two hundred feet south of the Valley Forge lode is a vein of heavy jasperoid which has been opened by prospect pits to some extent. It is said to carry gold in places. The ledge is formed along a brecciated zone of tourmalinized granite. Analysis by J. G. Fairchild of the heavy red jasperoid material shows that it contains 43.60 per cent ferric oxide, representing total iron, 49.06 per cent silica, and 6.38 per cent water.

LEE MOUNTAIN MINE.

The Lee Mountain mine is situated on the west bank of Tenmile Creek at Rimini. The lode was discovered in 1864 by John Caplice and the claim was staked under the old Montana law that allowed the preemption of claims 2,200 feet long and 100 feet wide. The mine was opened by a series of drift tunnels, the lowest of which, driven 30 years ago, is approximately 850 feet long and attains a depth of 600 feet. The present lessees contemplate sinking a shaft to a depth of 200 feet below the level of this tunnel and drifting eastward under the bed of the creek, where, according to report, a good body of ore was exposed before the stream bed was covered with rock débris.

The production of the Lee Mountain mine is conservatively estimated as $1,500,000, of which $750,000 is authenticated by smelter returns.

The ore occurs in chambers distributed through a zone about 50 feet wide. The general trend of the ore-bearing zone is N. 85° E. and the dip 80° S. A ledge of black tourmaline-quartz rock, ranging up to 8 feet in thickness, accompanies the ore-bearing zone. The ore makes in the adjoining highly sericitized granite and consists of a mixture of galena, sphalerite, pyrite, and subordinate arsenopyrite, with some tetrahedrite. More or less altered granite is mixed with the sulphides. Considerable postmineral movement has affected the ore bodies and in consequence much soft sericitic gouge is present.

Ore recently developed at the face of the lowest tunnel yielded, as shipped, $2 to $4 in gold, 20 ounces of silver, and 10 per cent lead; it also carried 8 per cent zinc. This ore is a mixture of primary sulphides and indicates that the unoxidized ore of the deeper workings is of payable grade. It is probable that the ore worked formerly consisted largely of oxidized material, from which, as shown by some sacked ore still remaining, the zinc had been entirely leached out.

JOHN McGREW PROSPECT.

The John McGrew claim was being developed under bond during the summer of 1911. It is an old property, having been located over 30 years ago. Developments consist of a drift tunnel within which a winze was sunk 35 feet; at the bottom of this a drift along the vein was being driven.

The lode is inclosed in granite and the ore makes abruptly and capriciously along a ledge of black quartz-tourmaline rock. In the bottom drift the lode is 18 inches wide and shows a banded structure. Along the hanging wall there is 3 inches of barren black tourmaline; this merges toward the footwall into a low-grade pyrite galena ore and becomes quartzose on the footwall. Barren gray quartz, 3 inches wide, rests directly on the footwall. A small amount of iron-stained gouge is found along the walls.

PEERLESS JENNIE MINE.

The Peerless Jennie mine is situated near the divide at the head of Tenmile Creek at an altitude of 7,500 feet. It was formerly a considerable producer of silver-lead ore, but has been idle for many years. The vein consists of a crushed zone in granite about 6 feet wide and dipping 70° N. The underground workings comprise a crosscut tunnel 240 feet long and several hundred feet of drift along the vein. The adit level attains a depth of approximately 200 feet from the surface and the ore is stoped out to the shaft level above. At the face the vein consists of crushed granite, containing locally small seams of quartz. The granite adjoining the vein is thoroughly sericitized and impregnated with cubical pyrite. The ore on the dump is chiefly pyrite embedded in quartz, associated with sphalerite and in places with cerusite. The richest ore is said to have occurred in pockets of galena.

According to R. W. Raymond [1] the surface ores were extraordinarily rich; 50 tons averaged 900 ounces of silver to the ton and 200 tons averaged nearly 500 ounces.

PORPHYRY DIKE.

The summits of the mountains between Ruby and Monitor creeks at the head of Tenmile are capped by a series of rhyolite flows and

[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1874, p. 362.

interbedded tuffs and breccias. This rhyolite capping is known as the porphyry dike, and the whole area throughout which it occurs has been covered by mining claims. That this rhyolite is auriferous is indicated by the fact that old placer workings extend to the very summit of the range, where the streams flowed on a rhyolite bedrock.

At 7,500 feet altitude is a large pit about 50 feet in diameter and averaging 40 feet deep, from which ore was taken out and treated in a 10-stamp mill until the work was stopped by the water company that furnishes the municipal supply for Helena. A tunnel has been driven approximately 125 feet below the pit and is said to be 1,400 feet long. It commences in the granite on which the rhyolites rest.

The country rock as exposed at the pit from which the ore was quarried is a strongly flow-banded and laminated rhyolite; the flow bands are steeply tilted at angles ranging from 60° to 90° and are convoluted and irregular in direction. The rhyolite is remarkably full of lithophysæ (stone roses), ranging in size from a fraction of an inch to several inches. At one place there is a width of 20 feet of lithophysal rhyolite. The walls of the lithophysæ are coated with quartz crystals, as are also the pores and cavities in the flow bands of the rhyolites. In places the quartz has grown exceedingly coarse, some prisms an inch in diameter having been formed. The rhyolites are generally of white chalky appearance and in places are interlaced with quartz veinlets one-tenth of an inch in thickness. They are considerably less porphyritic than the varieties of rhyolite prevailing in the surrounding region, but carry sporadic phenocrysts of quartz. Under the microscope they exhibit the usual features of rhyolites, except that they have been considerably sericitized and that much kaolin is present.

The rhyolites show some limonite derived from the oxidation of pyrite crystals. They are traversed also by limonite-stained fractures, which are said to be particularly favorable places for the occurrence of gold. As a rule, however, gold is not visible to the eye. The deposits have been extensively sampled, both by surface work and by diamond drilling, and are said to show a gold tenor of several dollars to the ton.

In addition to the ore taken at the pit described above, considerable ore was mined at the pits on the property known as the Pauper's Dream. The rock exposed in these pits consists of rhyolite tuff-breccia of kaolinized appearance; this ore is reported to have milled $2 a ton in gold.

HELENA DISTRICT.

HISTORICAL SKETCH.

Helena, the capital of Montana, is a city of 12,515 population, situated in Lewis and Clark County at an elevation of 4,100 feet. It was founded in 1864 as a result of the discovery of the Last Chance placer by a party of prospectors who had turned back from the Kootenai stampede. In the fall of the same year lode gold was discovered on the divide between Oro Fino and Grizzly gulches, 5 miles south of Helena. This was the famous Whitlatch-Union lode which, according to report, has produced $6,000,000 to date.

The gold placers were soon exhausted, but a considerable quartz mining industry sprang up south of Helena, at Park and Unionville. The earliest estimate on record concerning the output of the Last Chance placer is that by Vom Rath in 1883, who gives the output as over $10,000,000;[1] succeeding estimates, by Bancroft in 1889, place the output at $16,000,000;[2] by Swallow in 1890, at $30,000,000,[3] and by recent writers at $35,000,000. The estimates have thus increased enormously, although placer mining had long ceased to exist previous to 1883.

During 1911 little mining of any kind was in progress. The production of precious metals, mainly gold, in 1910 was about $15,000.

GEOLOGY.

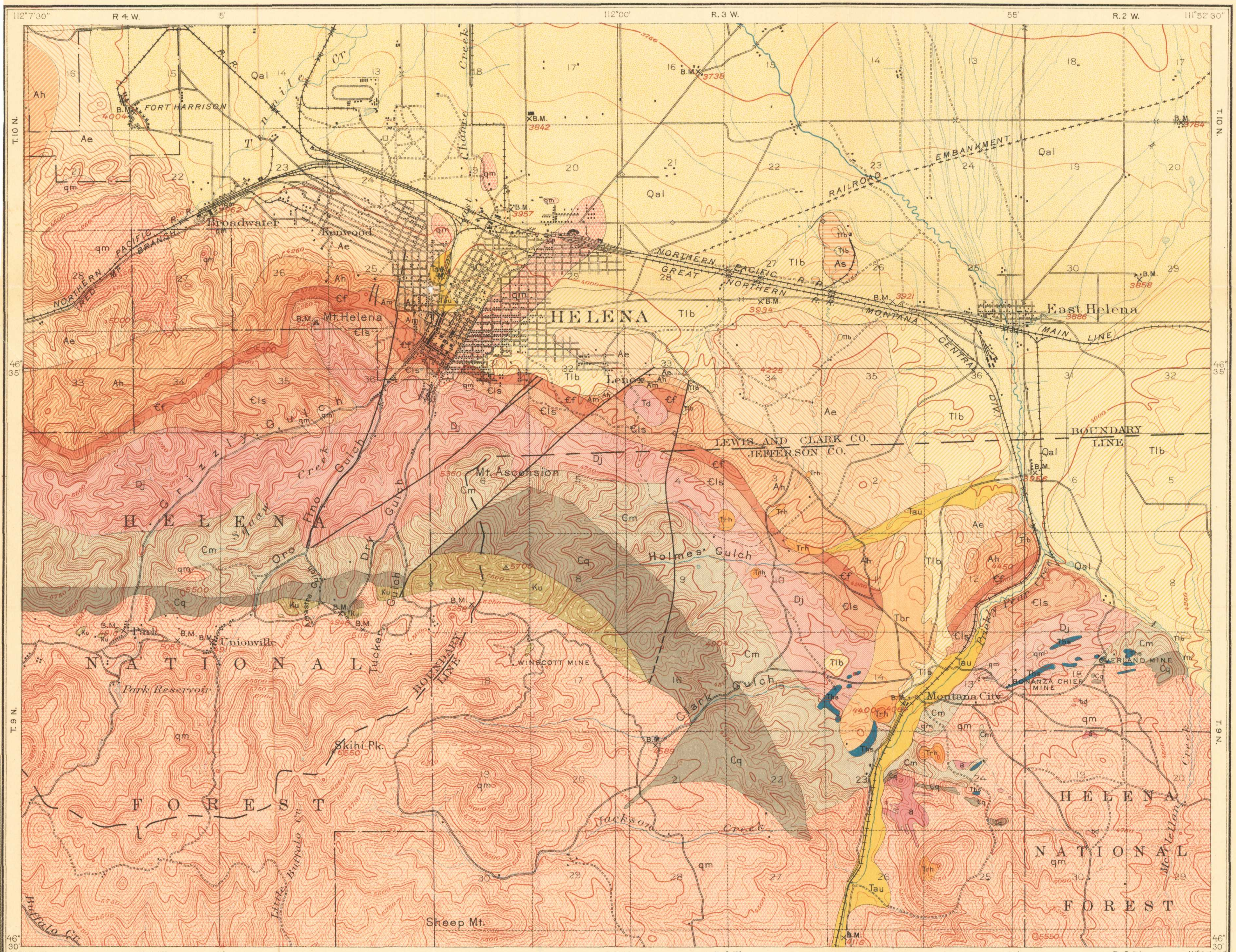
The distribution of the geologic formations in the vicinity of Helena is shown on the accompanying map (Pl. VII) on the scale of approximately 1 mile to the inch. This map was prepared by W. H. Weed and his assistants and shows the geology of the area in far greater detail than is shown on Plate I.[4] The following text (pp. 86 to 98) is taken, with few changes, from an unpublished report by Mr. Weed.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

The various sedimentary formations recognized in the Little Belt Mountains and in the ranges near Livingston can in a general way be correlated with the sedimentary series at Helena. The series differs, however, somewhat in detail and no sharp discrimination of the formations by means of fossil remains is as yet possible, owing to lack of evidence. Fossils are not abundant. The Cambrian and the Carboniferous limestones usually carry shell remains, but in general the rocks are barren and over a considerable area are altered, the limestones being marmarized by contact metamorphism due to the granite intrusion. This contact metamorphism is especially notable in the Mesozoic rocks, whose determination as such is based on

[1] Zeitschr. Deutsch. geol. Gesell., vol. 36, 1884, p. 630.
[2] History of Washington, Idaho, and Montana, 1890, p. 721.
[3] Rept. Montana State Inspector of Mines for 1890, Helena, 1891, p. 37.
[4] In preparing the drawing of this map for publication here, the areas originally shown as quartz monzonite, granite, granite porphyry, and diorite have been given the general symbol of quartz monzonite; the area of igneous rock east of Lenox, originally shown on the map as granite porphyry and described in the text as rhyolite porphyry, has been marked with the dacite symbol, in conformity with the results of the present investigation.



LEGEND

SEDIMENTARY ROCKS

- Qal — Alluvium (Quaternary)
- Tau — Auriferous gravels (Pliocene; Tertiary)
- Ths — Hot-spring deposits (Miocene or Pliocene; Tertiary)
- Tlb — Lake beds (Miocene or Pliocene; Tertiary)
- Ku — Contact-metamorphosed sandstone and shale (Cretaceous and Jurassic (?))
- Cq — Quadrant quartzite (Pennsylvanian (?); Carboniferous)
- Cm — Madison limestone (Mississippian; Carboniferous)
- Dj — Three Forks shale and Jefferson limestone (Devonian)
- €ls — Yogo limestone, Dry Creek shale, Pilgrim limestone, Park shale, Meagher limestone, and Wolsey shale (Cambrian)
- €f — Flathead quartzite (Cambrian)
- Am — Marsh shale (Belt series; Algonkian)
- Ah — Helena limestone (Belt series; Algonkian)
- Ae — Empire shale (Belt series; Algonkian)
- As — Spokane shale (Belt series; Algonkian)

IGNEOUS ROCKS

- Tbr — Rhyolite breccia (Tertiary)
- Trh — Rhyolite (Tertiary)
- Td — Dacite (Tertiary)
- a — Aplite (Late Cretaceous (?))
- qm — Quartz monzonite (Late Cretaceous (?))
- bd — Basic dikes
- Fault

DETAILED GEOLOGIC MAP OF HELENA, MONT., AND VICINITY

E. M. Douglas, Geographer in charge.
Triangulation by Gilbert Thompson and R. H. Chapman.
Topography by Gilbert Thompson and W. J. Lloyd.
Surveyed in 1897-98.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 50 feet.
Datum is mean sea level.

1913

Geology by Walter Harvey Weed
Assisted by Joseph Barrell
and L. S. Griswold
Surveyed in 1901-1906

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

House Doc. ; 62d Cong., 3d Sess.

stratigraphic sequence and character—fortunately satisfactory evidence in this case. The formations are mapped according to the detailed tracing of distinctive and easily recognizable beds by L. S. Griswold. The boundaries adopted for intervening formations are somewhat arbitrary but have been checked up or connected at several points and are substantially correct.

Great difficulty was experienced in attempting to define the subdivisions of the Algonkian. The various formations of the Belt series are as a whole individualized, but they are extremely difficult to define in mapping and the boundaries on the map are not closely accurate.

Thicknesses were determined by two carefully measured sections, one on Mount Helena and in its vicinity and the other near Unionville, many partial sections being measured elsewhere. No place was found where the whole sequence of beds was satisfactorily exposed, but the section is correct so far as determinable along the line measured, additional information being derived from work near by.

For the reasons already stated no distinction could be made in the Mesozoic. The Jurassic is believed to be present, as it is well developed at various points not far distant on every side, but careful examination furnished no satisfactory proof of its presence here. The same reason explains the lack of subdivision in the Cretaceous.

ALGONKIAN SYSTEM.

Distribution and subdivision.—The oldest rocks of the Helena district are those of the Belt series, of Algonkian age. The series, where fully developed, consists of eight formations, each well defined as a whole, but grading into one another, so that the subdivisions are not sharp and can not be adequately separated in mapping in this region. The series is named from its occurrence in the Big Belt Mountains, where it is typically developed and forms the core of the range. The rocks cover a large area in northwest Montana, extending northward into Canada. The following formations have been established by Walcott, who gives the thicknesses here stated:

	Feet.
Marsh shale	300
Helena limestone	2,400
Empire shale	600
Spokane shale	1,500
Greyson shale	3,000
Newland limestone	2,000
Chamberlain shale	1,500
Neihart quartzite	700

In the Helena district only the four uppermost formations are found, and the top of the Marsh shale has been eroded before the deposition of the Cambrian, so that the upper limit of the formation and its entire thickness are not known.

Spokane shale.—The oldest rock of the Helena district is the Spokane shale. It consists of massive and thinly bedded siliceous shales, usually of a deep-red color but passing in places into green and gray rocks, containing arenaceous beds which merge at times into sandstone. The formation is named from the Spokane Hills, 15 miles east of Helena, where it is finely developed. The rocks form low hills bordering the Prickly Pear Valley on the north and west.

Empire shale.—The Empire shale is a formation composed of massive-bedded, greenish-gray, well-banded, siliceous shales, showing color bandings of light and dark material and locally a marked knotty structure. The thickness is estimated by Walcott at 600 feet. The rocks are seen in the hills near the railroad from 2 to 3 miles west of East Helena. At this locality they consist of pale greenish-gray slates, with characteristic purple spots.

Helena limestone.—The Helena limestone is a formation composed predominantly of impure bluish-gray or gray noncrystalline limestone. The limestones occur in beds 1 foot to 6 feet thick and contain thin interbedded bands of gray siliceous shale, more rarely of green to purple clay shales. The limestones are ordinarily dark blue on fresh fracture but show a characteristic buff-colored velvety appearing surface on weathering. The upper beds have a rough surface, with a pale or blue-gray color, and resemble Cambrian rocks. These beds alternate with shale and form the ridges on the northwest foot slopes of Mount Helena.

The formation has no distinctive physiographic expression within the district, but its relatively massive bedding gives the limestone prominence on the slopes about the city.

The name was given the formation by Walcott from its typical occurrence about the city of Helena.

The formation is barren of fossils, though the oolitic character and the local presence of carbonaceous markings has led to the belief that they will ultimately be found. The estimated thickness of 2,400 feet in this vicinity is based on rough measurements, as it is impossible to find a satisfactory exposure of the entire formation for exact measurement. The formation covers a large part of the district, especially about the borders of the Prickly Pear Valley. So far as known the rocks are conformable to the formations above and below, and grade into them by intercalations of shale. The upper and lower limits are therefore not sharply definable. About a mile east of Helena the Marsh shale is wanting and the Cambrian quartzite rests directly on the eroded surface of the Helena limestone. Good outcrops are seen near the high school within the city limits.

On the north face of Mount Helena the Cambrian quartzite rests on dark-blue and dense limestones, weathering buff, and these rocks in turn rest on pink and buff-colored shales, which appear red in most exposures and are included as part of the Helena limestone. These reddish shales contain numerous massive beds of white cherty limestone, forming reefs running obliquely across the slopes and extending downward within a few yards of the streets of Kenwood. The beds of limestone are 6 to 10 feet thick and in weathering and character resemble those of Paleozoic rocks. The same pink and buff-colored shales, with interbedded limestones, are seen in the gulch east of Lenox, the 4,350-foot knoll at that locality showing light-gray fine oolitic limestone with black grains in a white matrix.

Marsh shale.—The Marsh shale consists of red and yellowish-green shales and thin-bedded sandstones. According to Walcott, it is 250 feet thick east of Helena; on the north slope of Mount Helena it is reduced to 75 feet; and to the northwest it increases in thickness to 300 feet. The formation is cut out 1 mile southeast of Helena, but the shales reappear at a point 2 miles southeast of the city. The name is derived from Marsh Creek, in the vicinity of Marysville, Mont., where the formation is typically developed. It is also the predominant formation on the slopes of Greenhorn Mountain, near Marysville. It is seen underlying the Flathead quartzite on upper Main Street in the city of Helena, 165 feet of beds being exposed

CAMBRIAN SYSTEM.

Subdivisions and character.—The Cambrian rocks of the Helena region, as in the Little Belt Mountain region to the east, are divisible into seven formations. All these formations except the uppermost—the Yogo limestone—are of Middle Cambrian age; the Yogo limestone is of Middle Cambrian and Upper Cambrian age, according to Walcott. The Helena region shows the same alternations of quartzite, limestone, and shale recognized in the mountains to the east of the Little Belt region and southward to the Yellowstone Park; the formation names adopted for the Little Belt region will therefore be used in this report. These names are, from the basal formation upward, Flathead quartzite, Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, Dry Creek shale, and Yogo limestone. On the map the Flathead quartzite is discriminated and the rest of the Cambrian formations are shown undivided.

The line between the Cambrian and Devonian rocks was originally supposed to be the upper limit of a well-marked shale belt. This shale belt is persistent and well recognized and was in mapping regarded as the upper limit of the Cambrian. Later work, however, showed that the limestones lying above this shale also belong to the Cambrian, and it became necessary to draw a new line, based on stratigraphic evidence and the topographic relief but not checked by field observations; this line is not, therefore, free from error.

Flathead quartzite.—The Flathead quartzite, the lowest formation of the Cambrian system, consists of a hard, fine-grained, massive quartzite varying to grayish-yellow to gray sandstone. The lowest stratum in places is pebbly, grading into a conglomerate at the base. The bedding planes range from a few inches to a few feet apart and faint lines of sedimentation are seen. The rock is jointed by sharply cut planes. Higher up in the formation thin beds of gray-brown mottled and green micaceous shale are found locally, increasing in thickness toward the top. The pebbles in the basal bed vary in character from place to place and consist predominantly of the material derived from the immediately underlying beds. As mentioned elsewhere, this quartzite is in most places apparently conformable to the Algonkian, but there is a slight angular unconformity observable east of Helena, and the Marsh shale is in places cut out, so that the quartzite rests directly upon the Helena limestone. The only fossils recognized are scolithus borings. The total thickness of the Flathead quartzite in the Helena district is 300 feet. The formation is easily recognized in the topography of the area, as the resistant nature of the beds causes them to form low foothill ridges, which are prominent on the slopes of Mount Helena, and as the cap reef on the mountain ridge running southward from that peak.

Wolsey shale.—The Wolsey shale consists of micaceous and calcareous gray to greenish shales, which contain small oval and flat concretions of limestone, grading in places into thin and very irregular plates of limestone. Trilobite and shell remains of Cambrian types occur abundantly along the contact between these shales and limestones. The rocks are in few places well exposed, owing to their soft and crumbly nature, but their position is recognizable by the ravines cut in them or, on the mountain slopes, by their forming a more gentle angle between the limestone bluffs above and the quartzite ridges below. They have a thickness of about 420 feet.

Meagher limestone.—The Meagher limestone is composed of light-gray to bluish limestones, which are shaly near the base but grade into alternating beds of massive dark-colored and flaggy white limestones, and these into thinly-bedded dark-purple to blue fossiliferous limestones, forming the top of the series. In other regions the rocks are pebbly, but this character is not conspicuous in the Helena district. The rocks have an estimated thickness of 400 feet. They form the characteristic bluffs on the north face of Mount Helena, extending from the gentle slopes formed by the Wolsey shale upward almost to the very summit of the mountain. The rocks are also seen in the bold cliffs below the east side reservoir. Fossil remains occur, but no collections were made.

Park shale.—The Park shale consists of earthy and micaceous dark-gray to green or purple shales. The rocks are not well indurated and crumble readily, so that very few good exposures are seen. A partial section is exposed in the quarry near the upper part of the city of Helena, and shows the formation to contain lavender or pinkish beds, grading through green shales to a grayish earthy shale carrying an abundance of small fossil shells, identified as Obolella. The upper portion contains limestone lenses in a jaspery shale, which grades downward into a dense cherty rock resembling hornstone. This shale has an estimated thickness of 150 feet. It forms the flat bench on the summit of Mount Helena, between the apex and the northern cliffs, and covers the ridge followed by the trail.

Pilgrim limestone.—The Pilgrim limestone consists of massive beds of bluish to dark-gray limestones. The lowest bed is a dark-colored crystalline rock, mottled with yellow and dark-gray spots; its peculiar coloration and massive character are characteristic of the limestone throughout Montana. This bed of mottled limestone is overlain by light-gray to white noncrystalline limestone, used for making quicklime in the Grizzly Gulch kilns. No fossils have been found in the mottled limestone, but its position and lithologic character correlate it with the "Mottled" limestone of the Yellowstone Park folio. This formation occurs on the very summit of Mount Helena, where it forms the uppermost bed of the gentle syncline sweeping down the southeastern side of the mountain. It is also seen in bluffs above the East Side reservoir, and forms a low cliff extending up Oro Fino Gulch for 2 miles above the city, the relief being due to the crumbly nature of the Park shale in which the gulch is being eroded. The mottled beds are 150 feet thick and are overlain by white limestone, which is included in the formation. The total thickness of the formation is 317 feet.

Dry Creek shale.—The Dry Creek shale consists of light-colored brownish-yellow, red, and pink shales and calcareous sandstones. The formation is well exposed in few places but can be recognized by its topographic relief, as it forms sags in the high ridges and ravines on the mountain flanks. No fossils have been found in the shale. It is correlated on the basis of lithology and stratigraphic position with the Dry Creek shale of the Threeforks and Little Belt regions. The thickness is estimated at 40 feet.

Yogo limestone.—The Yogo limestone consists of light-colored, thin-bedded limestones, with crinkly bands and films of jasper, in many places composed of limestone pebbles held in a glauconitic matrix. The formation corresponds to the so-called "Pebbly" limestone of the Threeforks folio. It has a thickness of 175 to 450 feet. The jaspery flaggy limestone forms prominent buttress exposures along the east side of Oro Fino Gulch above the city.

DEVONIAN SYSTEM.

The Devonian period is represented by two formations, the Jefferson limestone at the base and the Threeforks shale at the top. On the map these formations are not separated.

Jefferson limestone.—The Jefferson limestone, the lower of the Devonian formations, consists of a series of limestones, characteristically dark colored, but includes also some light-colored beds. The dark beds have a characteristic granular structure, are commonly mottled by light-colored patches due to metamorphosed corals, and are quite fetid when struck with a hammer. The assignment to the Devonian is based on fossil remains found in other areas, as the rocks within the Helena district have not yielded any identifiable fossils. The lowest beds are dark colored, almost steely in luster and texture, and usually form a bluff or ledge that rises abruptly above the more fissile Yogo limestone. The buff-colored argillaceous shales which overlie the limestones have been included in the Jefferson, but they may belong to the Threeforks shale. The total estimated thickness of the Jefferson limestone is 243 feet.

Threeforks shale.—The Threeforks shale varies somewhat in the different parts of the Helena district. It is essentially composed of black shale and alternating beds of limestone; it contains brachiopod remains, which correspond to those identifiable elsewhere as Devonian species. It corresponds in position to the formation in the Threeforks quadrangle known by this name. The uppermost bed of the formation is 15 feet thick, consisting of fine-grained black carbonaceous shale. This rests on light-colored fossiliferous calcareous shales that grade downward into earthy shales with interbedded bands of quartzite, the total thickness being 270 feet. The rocks are seen on the ridge west of Grizzly Gulch about 1½ miles from Park. At this locality there is a basal bed of shale 40 feet thick, capped by 186 feet of calcareous argillite overlain by 56 feet of black shale. The formation is well exposed only on the high ridges, where it forms low saddles between limestone knobs. In the gulches cut in these rocks exposures are poor and more than a few feet of the beds can be found at but few places.

CARBONIFEROUS SYSTEM.

Distribution and character.—The Carboniferous system is represented in this region by a basal formation consisting of a mass of limestones characterized by lower Carboniferous or Mississippian fossils, to which the name Madison limestone has been applied. This limestone is overlain by a formation, essentially quartzitic, which is correlated with the Quadrant formation of the Yellowstone Park, Threeforks quadrangle, and other areas in Montana. The rocks are well exposed and cover a considerable portion of the mountain area in the southern part of the district. As a rule they are readily distinguished from the soft Mesozoic rocks which overlie them, but in this region contact metamorphism has so altered the Mesozoic rocks that they are as hard and resistant as those of the Carboniferous period.

Madison limestone.—The Madison limestone in the eastern ranges of the State has been subdivided by Weed into three members, to the lowest of which he gave the name Paine shale, to the middle the name Woodhurst limestone, and to the upper the name Castle limestone. All these subdivisions can be recognized in a general way in the Helena district. The lowest member consists of thin-bedded impure bluish limestones, which carry crinoid stems and other fragmentary fossil remains. A very persistent bed is characterized by black needles of tourmaline, and as this bed occurs near the base of the formation it is quite useful in mapping the limits of the Madison. This member grades upward into the well-bedded limestones of the middle member, which forms the steep slopes and well-marked cliffs throughout the southern part of the district. The rock is light gray to dark gray and the beds are separated by partings of impure shaly material, which break into angular splintery fragments; much of it is cherty.

The upper member consists of very massive white or light-colored limestones showing no bedding planes, and in the Helena region they are commonly altered to white marble. The total thickness of the Madison is 2,600 feet.

Quadrant quartzite.—The Quadrant quartzite consists, as its name implies, chiefly of quartzite with sandstones and some interbedded white limestone. Throughout the area the rocks are much altered by contact metamorphism and their distinctive characters obliterated. The formation is named from Quadrant Mountain, in the Yellowstone Park, with which the rocks in this area are correlated. The formation composes the high hills adjoining the granite contact in the south part of the district. The thickness is estimated at from 190 to 500 feet. To the west, in the Philipsburg quadrangle, Calkins obtained from the Quadrant formation fossils which were pronounced by Girty to be of Pennsylvanian age. In other areas to the east in Montana, however, rocks referred to the Quadrant formation have yielded Mississippian fossils.

CRETACEOUS SYSTEM.

Rocks which are referred to the Cretaceous because of their stratigraphic position, and which possibly include some of Jurassic age, occur in the southern part of the area. They form a belt lying along the great granite mass which has invaded them and which in a number of places has broken the continuity of the belt. They consisted originally of sandstones and shales but have been subjected to intense contact metamorphism, so that now they consist of biotite hornfels and allied varieties of rocks.

TERTIARY SYSTEM.

Lake beds.—The Tertiary lake beds cover a far greater area than any other formation within the Helena district. The rocks vary in character from point to point according to the composition of the underlying formation. In general they consist of well-bedded sands, gravels, and conglomerates composed of the underlying country rock, together with a large amount of rhyolite. In the center of Prickly Pear Valley, where the rocks have been penetrated by boring, several sheets of rhyolite have been found. In the hills to the east the beds are well exposed, and the indurated tuffs forming a part of the series are quarried in the vicinity of Lenox. As a rule, however, the rocks crumble on weathering, and good exposures are rare. These lake beds undoubtedly underlie the entire Prickly Pear Valley, but have been covered by detritus washed from the surrounding slopes and the alluvium brought in by the streams, so that although a thickness of over 1,200 feet is known from the bore holes put down in seeking artesian waters, the bottom of the formation has not yet been found. The rocks are nearly everywhere distinctly bedded, but as a rule they show little persistence in character. The pebbles are normally rounded but in part subangular, and as the material is mostly of local origin the color and composition vary from point to point. The beds are regarded as of Miocene or Pliocene age.

Hot spring deposits.—The hot spring deposits shown on the map (Pl. VII, p. 86) consist mainly of large masses of chalcedony.

Auriferous gravels.—The auriferous gravels of the Helena district are regarded as of Pliocene age, as the remains of the mammoth and other vertebrates believed to be of that age have been found in the vicinity of Helena and of Montana City. The gravels are composed of the harder, more resistant material from the drainage basins of the streams and naturally vary at different points. In the Montana City area there is a large proportion of andesite brought down from the headwaters of Prickly Pear Creek, together with much vein quartz and granite. In the Last Chance placer gravels, which underlie the city of Helena, the material has been derived from the various tributary gulches draining the granite contact and therefore consists of pebbles, cobbles, and well-bedded sands, composed largely of quartz monzonite, with varying proportions of limestone. Invariably the gravels are auriferous when the streams drain the contact region, and the source of the gold is to be found in the veins which follow the granite contact.

QUATERNARY SYSTEM.

The Quaternary deposits of the district consist of alluvial silts and gravels and are developed most extensively in the great plain north of the city of Helena.

IGNEOUS ROCKS.

Distribution and character.—Igneous rocks cover about one-fourth of the area of the district, forming high mountains to the south and the isolated peaks known as the Scratch Gravel Hills, as well as numerous lesser elevations. The oldest rocks occur only as intruded sheets or sills in the Cambrian sediments and have been folded with them. They are of unknown age but are certainly pre-Tertiary. The most abundant rock is granitic in character and forms part of the Boulder batholith. The Miocene rocks occur as intrusive dikes and masses of rhyolite and as lava flows and tuff beds of the same rock. They also enter into the composition of the lake beds.

Basic dikes and sheets.—The basic dikes and sheets shown on Plate VII consist mainly of dark-greenish to steely-gray rocks of dense texture and commonly marked by rusty spots or the holes resulting from the alteration of augite and olivine crystals. Sometimes fresh augite is recognizable in the specimens. The commonest rock may be called a greenstone of diabasic character. It occurs intrusive in the Wolsey shale on the west side of Mount Helena and at the same horizon about a mile south of Lenox. Another dike of this material cuts the Flathead quartzite in the northwest portion of the city.

An augite porphyry, a tough and dense green rock containing white porphyritic crystals of plagioclase, occurs as a sheet 40 feet thick intrusive in a belt of black shale in the upper part of the Cambrian. This rock is exposed on the slopes east of Oro Fino Gulch, a short distance above the city, and it follows this shaly belt for a distance of several miles, outcropping at intervals.

A hornblende porphyry, a dark-green, fine-grained rock carrying stellate clusters of hornblende, occurs intrusive in the Helena limestone east of the Broadwater hotel. It forms a sheet 6 feet thick and outcrops for several hundred yards.

Acidic sheets.—A porphyry that contains altered feldspar phenocrysts but that is too thoroughly decomposed for specific identification occurs as a persistent sheet from 10 to 20 feet thick intrusive in the Wolsey shale close to the Flathead quartzite. It is exposed on the northeast side of Mount Helena and is traceable for several miles westward. A second sheet of similar nature occurs 30 to 40 feet higher in the shale.

Meta-andesite.—This name is applied to andesites which have undergone distinct alteration but whose original structure and composition are still recognizable. Patches of these rocks occur east of Montana City and at one or two other places in the Helena district. They are mostly fragmental in origin, being old volcanic tuffs and breccias baked and altered by contact metamorphism. A few intrusives are doubtfully referred to this type. They are older than the granitic rocks and in the region south of Helena form the cover to the granite. Fragments torn off by the granite intrusion occur in places in the later rock near its contact with the andesite.

Granitic rocks.—The coarse-grained rocks composed of feldspar and quartz, with lesser amounts of mica and hornblende, are conveniently called granite, as it is not usually possible to determine the species of feldspar in the field. A more precise definition, based on a study of thin sections of the rock under the microscope, enables us to classify the material more exactly. In the granitic region extending southward from Helena to Butte the prevailing form of rock is a coarse-grained quartz monzonite, called the Butte quartz monzonite, which under the new quantitative system of classification is designated amiatose. A rock corresponding to this is seen in the Scratch Gravel Hills, at the south end, and also occurs in a small area near Holmes Gulch. The greater part of the granite of the Helena district is, however, a finer grained rock of slightly more basic composition.

Rhyolites.—The rhyolites are all of Miocene age and occur as intrusives, extrusives, and fragmentary rocks.

The rhyolite breccia covers a considerable area in the southeast part of the district. It is a mass that varies in character from place to place but is composed essentially of both rounded and angular fragments of rhyolite, lying without stratification and at all angles in a fine-grained stony matrix which is speckled with minute flakes of biotite and carries a few fragments of feldspar and quartz. The rock is generally light colored, varying from pale red and purple to buff color and white. Much of the fragmentary material composing the rock is a white, porous, pumice-like rhyolite. A good exposure is found in the quarry on Holmes Gulch 1½ miles west of Montana City. At this place the breccia is a light, porous, somewhat friable rock, made up mainly of white rhyolite pumice, with small rounded pebbles of granite, jasper, and other rocks. It is regarded as a mud flow composed essentially of volcanic dust and ejectamenta which fell on the granitic slopes and was washed down to fill the hollows of the lower ground.

The rhyolite flows are readily distinguished from the intrusive rocks by their porosity and flow structure and as readily from the breccias by their compact nature. The rocks are prevailingly reddish to purple colored and contain phenocrysts of quartz, biotite, and in some specimens feldspar in a dense lithoidal groundmass. The chief exposures of this rock are in the vicinity of Montana City, one flow forming the cap to the highest hill in the region. The rock on this summit has a platy parting with a dip of 45° and forms extensive areas of slide rock on the west side of the hill but none on the east. It is evident that it was a lava flow covering a surface which has been much tilted since the consolidation of the lava.

Rhyolite intrusives are exposed in the vicinity of Lenox, where a patch one-fourth of a mile across and three-fourths of a mile long is intrusive in the Algonkian slates and has broken up and thrown over the Flathead quartzite. The rock is a normal rhyolite porphyry, showing phenocrysts of biotite, feldspar, and quartz in a stony groundmass.[1]

[1] The present investigation shows that the rock is more accurately termed a dacite, and it is therefore so designated on Plate VII.

STRUCTURE.

The Helena district lies on the south side of a great dome-shaped uplift some 25 miles in diameter, whose center lies north of the Scratch Gravel Hills. This dome extends from the mountain ridge west of Marysville eastward to York, on the west side of the Big Belt Mountains. The city of Helena and the mountains south of it lie on the south side of the dome. Although the general structure is that of a simple anticline, the dome is not perfectly regular but shows secondary crumpling. Within the Helena district the dome shape is well shown. Subsequent to the folding which formed this great dome the granitic rocks broke through and faulted the south flank of this anticline.

Broadly considered, Prickly Pear Valley is a basin deeply eroded in the dome-shaped uplift noted above, an arch whose summit has been worn away and cut down into the soft shales of the Belt series that form its nucleus, so that the sheets of white limestone and other rocks that once covered it are now only seen on Mount Helena and the hills south of the city, in the Spokane Hills to the east, and the flanks of the Belt Mountains north of the district. This broad arch involved the entire sedimentary series of the region from Algonkian to Cretaceous. The simplicity of structure has been, however, modified by the granite intrusion and faulting.

The granite area in the southern part of the district (see Pl. VII), which forms a rugged mountainous tract, mostly unfit for agriculture and largely denuded of valuable timber, is the extreme northern part of a granite area extending 75 miles southward, a great mass of intrusive igneous rock designated the Boulder batholith. A part of this batholith extends northward under the sedimentary rocks, and, as already stated, the latter are highly altered and commonly crystalline, as a result of the heat and vapor given off by this once molten material. The upper contact between the granite mass and the bedded rocks is uneven, and arms and offshoots of the former rock extend upward. Some of these, bared by erosion, are seen as dikes and bosses, as, for example, the granite area near the Broadwater Hot Springs, that north of Helena, and a smaller area east of the city.

In the adjustment of the rocks following the violent intrusion of this great body of granitic rock, with its initial uplifting force and subsequent settling as cooling progressed, faulting occurred and the irregularly triangular blocks of the limestone series and their accompanying rocks were dislocated. These faults are not of very great magnitude. To the east, however, the bedded rocks were not clearly cut off, but broken into small blocks by the force of the intrusion, and a very complicated mosaic of sediments and igneous rock is shown on the map.

FAULTS.

The Helena area has a number of faults, which cross the stratified rocks at approximately right angles to their strike and which may be regarded as radial faults of the great anticline. Owing to the fact that the faults are marked by more or less crushed matter, which is easily eroded, they are followed by the stream gulches.

The West Side Reservoir fault shows an upthrow on the east with a horizontal offset of 500 feet and 290 feet vertical. This fault is indistinguishable where it passes through the massive beds of the Madison limestone, and in the Algonkian rocks the exposures are too few to determine it correctly. There are two small subsidiary parallel faults near-by, at the north base of Mount Helena. These faults have offshoots of 60 and 40 feet respectively, corresponding to 30 and 20 feet vertical, and have a downthrow on the east. On Montana Avenue, the north-south street separating sections 19 and 20, and 29 and 30, where the Flathead quartzite crosses, there are two small faults; one has a throw of 30 feet and the other, 100 yards farther east, has a throw of 15 feet.

A long northeast fault passing through Lenox splits at the north end into two faults 300 feet apart. The upthrow is on the west, and the fault displacements are 110 feet and 230 feet.

One-half mile farther east occurs the Mount Ascension fault. This is a big fault, having an offset of 850 feet (as the strata dips 40° this corresponds to 765 feet vertical). A half mile farther east is another fault of like magnitude. The wedge between these faults has sunk at least 765 feet, forming a trough or "graben."

These faults have been actually observed and measured, but it is probable that there are many faults of small displacement which have not been recognized, for the great block of altered sediments that rested on the granite while it was cooling must have suffered considerable contraction, with consequent fracturing and readjustment.

Strike faults due to slipping of the beds on one another probably accompanied the uplifting of the sediments. One was recognized southeast of Lena, where the Meagher limestone rests against Pilgrim limestone, the intervening shale being cut out.

In general the faults just noted can not be recognized in the relief of the region. A gulch marks the line of the Lenox fault (northeast-southwest) toward Unionville. The north-south fault on the east side of the depressed triangular block already noted seems to break into smaller faults and is strongly marked in the landscape. Several mine and quarry openings disclose its nature. The fault walls are smooth or polished and show well-marked striæ. Between these vertical walls, which vary from 5 to 40 feet apart, the fissure is filled by friction breccia, ground up wall rock, showing angular and partly rounded rock fragments in a clayey matrix.[1]

[1] Up to this point the text follows the manuscript of Mr. Weed.

ORE DEPOSITS OF HELENA DISTRICT.

LOCATION.

The ore deposits of the Helena district, using this term in its broad sense, are mainly located south of Helena along the heads of Oro Fino, Grizzly, and Nelson Gulches. Geologically they are situated mainly along the contact of the granite with the invaded sedimentary rocks—hornfels, quartzite, and limestone.

Opportunities for examination of the ore deposits were unfavorable during 1911. The properties were idle and most were inaccessible. The systematic position of certain of the deposits has already been pointed out—the Big Indian on page 51 and the Spring Hill on page 44—so that repetition is unnecessary here.

DESCRIPTIONS OF MINES.

WHITLATCH-UNION MINE.

The Whitlatch-Union lode, discovered by James W. Whitlatch in September, 1864, is the oldest quartz discovery in the region. The lode was rapidly developed by several different mining companies, each of which owned but a short length, the longest piece being the 500 feet held by the Whitlatch-Union Mining Co. By 1872 the mine had produced $3,500,000, when it was shut down because of litigation. It has been operated intermittently since that time and is stated to have yielded to date $6,000,000 in gold.

The mine was originally opened by a number of inclines, but with the exception of the Owyhee and McIntyre they are all caved near the surface. Later a vertical shaft was put down to a depth of 500 feet. During 1911 some of the upper levels were accessible through the Owyhee incline, from which in recent years lessees have been getting out small shipments of ore.

The lode is situated 4 miles south of Helena on the summit of the low divide between Grizzly and Oro Fino gulches. It lies in the granite just south of the contact with the Quadrant quartzite. There occur scattered in the granite near the contact some huge blocks of highly metamorphosed sedimentary rocks, probably belonging to the Cretaceous formation shown on Weed's map.

The general course of the vein is N. 84° W.; the dip averages 45° N., but is subject to remarkable and abrupt changes, ranging from nearly horizontal to vertical. In width the vein ranged from a thin seam up to 15 feet, averaging about 4 feet. The ore taken out in early days averaged from $20 to $25 a ton in gold.[1]

As seen in the Owyhee incline the Whitlatch-Union vein is partly inclosed in hornfels and partly in granite. Abrupt changes in dip accompany the passage of the vein from the one rock to the other.

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[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1869, p. 147.

A specimen taken from the footwall of the vein in the end of a drift driven west from the Owyhee incline is a dark heavy rock showing numerous small lustrous black flakes of biotite. When examined microscopically it is found to consist of a confused intergrowth of brown-green amphibole, biotite, and andesine, with accessory quartz. It is evidently a thermally metamorphosed rock, but further than this its origin is not apparent. It is possibly a recrystallized igneous rock.

The locality from which this rock was taken is in the newest workings of the mine. The vein here is narrow, averaging 4 inches, and dips at a low angle to the north. The ore consists of pyrite and some quartz and is slightly oxidized. A small shipment running $70 a ton in gold was taken out; unmixed with waste the ore runs $130 a ton.

BIG INDIAN MINE.

The Big Indian mine is situated 4 miles south of Helena. The two main claims, the Alabama and the Gold Hill, were located in 1875. The ore was taken out from a large quarry, and a 10-stamp mill was operated at a profit for a number of years. During the operation of this mill $110,000 was produced, the ore averaging $5 a ton in gold. According to James Winscott, the original locator of the property, some clean-ups ran 985 fine. Later the property was taken over by a corporation and a 60-stamp mill was erected and put in commission in 1902. This mill was operated by electric power from the Missouri River Power Co.'s plant at Canyon Ferry on Missouri River, and it was estimated that the ore could be mined and milled at a cost of 60 cents a ton. During 1903 and 1904 the Big Indian mine was the leading gold producer in Jefferson County, but soon afterwards it was shut down and has remained idle since that time.

The mine is situated half a mile south of the main contact of the granite with the sedimentary rocks on the north. The country rock is a gray medium-grained quartz monzonite. Under the last management the mine was worked by the glory-hole method, the glory hole being at the level of the top of the mill. The pit is several hundred feet in length and breadth and 50 to 75 feet deep. Near the surface the rock is soft and incoherent and crumbles easily, but toward the bottom of the pit it apparently grows hard. Near the bottom the granite is traversed by a close-spaced system of vertical jointing, along which considerable tourmalinization has taken place. About as much tourmaline was developed in the granite as the biotite and hornblende originally present. In addition to the tourmalinization there was a slight introduction of pyrite. Noteworthy is the fact that there are no quartz veinlets anywhere in the ore body.

The granite is cut by a few aplite dikes and also by some dark-colored diorite porphyry dikes. The tourmalinization ensued after the intrusion of the aplite dikes and probably after the intrusion of the porphyry dikes, which are somewhat pyritized.

SPRING HILL MINE.

The Spring Hill mine is situated 4 miles northwest of Helena in Grizzly Gulch. It is developed mainly by an adit tunnel and by levels below this tunnel. A 3,000-foot crosscut was driven to connect with the 500-foot level of the Whitlatch-Union mine in order to give the ore of the Spring Hill mine an easy outlet to the mill at Unionville.

The general country rock is the Madison limestone, which strikes N. 5° E. and dips 67° E., as shown on the surface near the large open cut. The ore deposit is located near the contact of a dark fine-grained gray granitoid, in which biotite is the most prominently recognizable constituent. As determined microscopically this rock is a diorite composed essentially of plagioclase, hornblende, and biotite, with subordinate interstitial quartz and orthoclase. The limestone is a white dense saccharoidal variety and shows selective metamorphism, for certain narrow bands from 2 to 3 inches wide show silication; that is, the development of pyroxene and garnet. At 50 feet from the contact some of these silicate bands fray out gradually into unaltered white limestone. Another open cut shows even more clearly that the development of silicate minerals is independent of the composition of the limestone, for metamorphic minerals are formed locally and abruptly across the bedding of thinly stratified limestone.

As seen on the main level the deposit consisted of a large body of contact-metamorphic ore which was stoped out in large high galleries, thick pillars of ore being left as supports. The ore minerals are pyrite and pyrrhotite; in places the pyrrhotite forms solid masses several feet in length and width. The sulphides are usually associated with a fine-grained aggregate of lime-silicate minerals that form an exceedingly hard and tough rock. They are also disseminated in grains and blebs through pure limestone. A notable feature of the deposit is the lack of oxidation exhibited, contrasting in this respect with other deposits in the region, The deposit is, as it were, doubly protected against the effects of enrichment, namely, by calcite[1] and by pyrrhotite,[2] both of which are effective precipitants for downward-moving solutions. The gold tenor is stated to run as high as $30 a ton, but the average value makes this a low-grade ore.

DUTRO MINE.

The Old Dominion or Dutro mine, as it is known locally, is situated 7 miles west of Helena and 1 mile north of the Rimini road. During 1911 two men were employed here in getting out ore by means of a small gasoline hoist from an incline extending down 150 feet.

[1] Bard, D. C., Econ. Geology, vol. 5, 1910, pp. 59-61.
[2] Emmons, W. H., Public presentation before Geological Society of Washington, April, 1912.

The general country rock consists of a series of Paleozoic limestone and dolomite standing on edge and trending north and south. The mine is situated near the end of an intrusion of fine-grained diorite, whose longer axis, about one-fourth of a mile long, lies parallel to the strike of the inclosing rocks. The limestones are generally saccharoidal in texture and in places show abundant needles of tremolite. At the main working is a small boss of black fine-grained diorite about 150 feet in diameter.

The ore, occurring in irregular masses in the dolomite, consists of jasper and opal and usually contains much iron oxide. On account of the oxidized condition the original character of the ore is rather obscure. The prevailing ore is a jaspery quartz commonly showing specks of free gold. Locally it contains an iron-gray metallic mineral, which has been determined in the laboratory of the Geological Survey to be bismuth sulphide. The oxidation of this mineral seems to be the cause of the chrome-yellow color apparent in some of the ore. Under the microscope the ore is seen to consist of microcrystalline and cryptocrystalline silica, which forms a replacement of the dolomite. In addition to the minerals already noted, some cassiterite was detected. This is the only occurrence of cassiterite in its bedrock source yet discovered here, although it has been known to occur in the placer deposits of the region; the quantity is very small and the mineral could not be detected in hand specimens of the ore.

The ore is shipped to the East Helena smelter and is reported to average $75 a ton in gold.

CLANCY DISTRICT.

Clancy is a small town in Prickly Pear Valley, 14 miles southeast of Helena. It was settled in 1865 and was formerly a thriving mining center, but is now chiefly dependent on agriculture and on the railroad, being a division point on the Havre-Butte branch of the Great Northern Railway.

GEOLOGY.

The prevailing rock is the typical quartz monzonite of the Boulder batholith. The abundance of aplite in dikes and large masses is noteworthy; some of the larger masses attain an area of several square miles, but they were not separately mapped. Intrusions of pegmatite and granite porphyry also are common.

Of the younger rocks, rhyolites are present in considerable quantity in the area east and northeast of Clancy. They were erupted on a surface whose relief was much like that of the present topography. Those east of Clancy are light-colored porphyries and include flow-banded, lithophysal, and breccia varieties. They are true rhyolites, consisting essentially of phenocrysts of quartz and sanidine inclosed in a microcrystalline groundmass of quartz and sanidine. Most of them are devoid of dark minerals, but some contain scattered hexagonal plates of biotite. The rhyolite forming the butte at the mouth of Clark Gulch, north of Clancy, is strongly flow-banded; in places the banding, as a result of movement in the following lava, is contorted and stands vertical. Locally the rhyolite is filled with lithophysæ or "stone roses." The walls or petals of the lithophysæ are extremely thin and delicate and weather out readily, so that such rhyolites yield honeycombed outcrops.

Some dikes of rhyolite cutting the quartz monzonite occur locally; noteworthy among them are those paralleling the veins at the head of Warm Spring Creek. They commonly show margins several feet thick consisting of dark obsidian glass. West of Clancy, in the valley of Clancy Creek, a few dikes of dacite have been noted.

ORE DEPOSITS.

The mines in the vicinity of Clancy were founded on true silver ores; that is, ores valuable principally for their silver content. A considerable number of such mines were grouped in Lump Gulch, a few miles northwest of Clancy, and gave rise to a once flourishing mining camp called Lump Gulch City. All, however, are now idle. Of the mines of the Lump Gulch district, the Liverpool, credited with a production of over a million dollars, was the deepest and most productive. It attained a depth of 750 feet.

The veins were inclosed in quartz monzonite and carried rich argentiferous sulphides—galena, sphalerite, and tetrahedrite—in a chalcedonic quartz gangue. The only mine operating in 1911 on a vein of this type was the King Solomon mine, a description of which is given in some detail on pages 104–105. In its essentials this description doubtless applies to all the other mines. Dikes of dacite porphyry like that accompanying the King Solomon lode, however, were not noted at the Little Nell, Free Coinage, and Legal Tender mines.

The ore at the King Solomon mine is clearly of primary origin and is unaffected by enrichment; possibly, as suggested by the following description of the Legal Tender vein, the surface ores of the veins of this type were enriched to a certain extent by oxidation and the removal, by leaching, of some of the constituents.

A feature of the Clancy district is the abundance of iron-stained chalcedonic reefs, which form large, prominent outcrops. Some of these reefs carry a small amount of tetrahedrite. Their relation to the productive veins is not entirely clear; they are possibly somewhat younger or they may be merely the large barren equivalents.

The ore deposits at the head of Warm Spring Creek, a tributary entering Prickly Pear at Alhambra, 1 mile above Clancy, are of a different type than the foregoing and probably belong to the older mineralization. They are quartz veins, carrying mainly pyrite with subordinate galena, sphalerite, and arsenopyrite, and yield a smelting ore running from $15 to $30 a ton, mainly in gold. They were inaccessible during 1911, although preparations were being made to reopen the Fleming, or Bell, mine, which has been the principal producer. These mines have recently been described in brief by R. W. Stone.[1]

DESCRIPTIONS OF MINES.

KING SOLOMON MINE.

The King Solomon mine is situated on the north side of the valley of Clancy Creek, 2 miles west of Clancy. The property was located in 1889 but has been worked only intermittently since that time. The output has been $100,000, mainly by lessees. In 1901 the mine was bought by Mr. I. S. Moreland, who organized the King Solomon Mining Co. During 1911 siliceous silver ore was being extracted and shipped to the smelter at Butte.

The mine is opened by an inclined shaft sunk on the lode to a depth of 300 feet. Development and exploitation is at present proceeding on the 300-foot level, west of the shaft.

The country rock at the mine is a coarse granite, the chemical and mineralogic features of which are described in detail on pages 56–58. Some dikes of fine-grained white aplite cut the granite but are of small importance. Of considerably more importance is a thick porphyry dike, which forms the hanging wall of the King Solomon lode. The dike trends slightly south of west and dips 60° to 70° S.; as shown by a crosscut on the 200-foot level it is 85 feet wide and the walls are rather wavy. In appearance the dike strongly resembles a granite porphyry, but familiarity with the rocks of the region suggests that it is allied to the highly porphyritic dacites so abundant at Wickes and elsewhere. It is an ash-gray porphyry, holding abundant crystals of feldspar and quartz, and numberless small brilliant black flakes of biotite, the phenocrysts forming half of the rock. Under the microscope the feldspar phenocrysts are found to be crystals of glassy andesine ($Ab_{56}An_{44}$) and are seen to be embedded in a groundmass of cryptocrystalline texture. The identity of the rock as a dacite is thus established. The ore body, being younger than the dike, is therefore of late Tertiary age, a fact immediately suggested by the prevalence of chalcedonic quartz in the gangue matter of the lode.

The lode consists of a wide shear zone, traversing mainly granite but in places aplite also. It trends parallel to the dacite dike, which forms, as it were, a hanging wall to the ore deposit, the course of the dike, as already pointed out, being somewhat wavy, but the lode pursues a straighter course than the dike and touches the footwall of

[1] Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, pp. 87–88.

the dike at the crests of the waves only. At such points the dike is generally much sheared and altered. The granite adjoining the lode for a distance of at least 20 feet is softened and has been greatly altered through the action of the ore-forming solutions, as described in detail on pages 56–58.

The lode, or ore-bearing zone, measured normal to the dike, is 25 feet or more wide, but of this width the ore aggregates a few feet at most. The ore consists of narrow slabs of high-grade material trending parallel to the structure. In rich places along the lode the ore forms a series of imbricating slabs of nearly solid sulphides 1½ to 3 inches thick, constituting short ore shoots aggregating from 1 to 2 feet in thickness. The metallic minerals are essentially galena, sphalerite, and tetrahedrite; pyrite is rare, but molybdenite has locally been found in some abundance. The sulphides are irregularly intergrown and are of contemporaneous and primary origin. Ore high in tetrahedrite is rich in silver. The sphalerite is mainly the resin-colored variety. The gangue of the ore-bearing veinlets is principally chalcedonic quartz. Some of the ore, however, is highly brecciated and angular fragments of chalcedony and of sulphide aggregates have been recemented by fine-grained curved siderite.

The ore is carefully sorted, and a product high in silver is obtained, carrying between 100 and 200 ounces a ton.

On the 200-foot level, east, the dacite dike was crosscut and much gouge and shattered granite, in places 4 feet wide, was found on the hanging wall of the dike. Streaks of rich ore were encountered here, and a ribbon of ore 1½ to 8 inches wide, consisting essentially of resinous sphalerite intergrown with tetrahedrite in a quartz gangue, was found; this constituted 400-ounce rock.

LITTLE NELL MINE.

The Little Nell was the only mine of the Lump Gulch mines at which there was some activity during 1911. The main operations consisted in reworking the old dumps, but some underground work was also done. The mine was partly unwatered and a tunnel was run westward on the 150-foot level in the expectancy of reaching an ore shoot.

The old workings attained an extreme depth of 500 feet and smelter returns show a production of $400,000. The geologic and mineralogic features are similar to those of the King Solomon lode, namely, an argentiferous galena-sphalerite ore in a chalcedonic quartz gangue. As a rule, ore high in zinc is also high in silver.

YELLOWSTONE PROSPECT.

The Yellowstone group, comprising 10 or 11 claims, is situated on a small stream tributary to Clancy Creek, 5 miles west of Clancy. A 90-foot shaft had been sunk on the prospect by former owners and had been abandoned, but the property was relocated in 1908 by the present owners. A drift tunnel, which is now 200 feet long, was commenced by the new owners 150 feet below the collar of the shaft.

The country rock is quartz monzonite, carrying large porphyritic orthoclase crystals and abundant biotite in hexagonal plates. The lode is considered to be 25 feet wide; the footwall is not well defined, but toward the hanging wall there are a number of good walls which show considerable gouge and horizontal corrugation. The 25-foot ore-bearing zone contains a number of thin and widely spaced veinlets; the ore minerals are principally chalcopyrite and galena, with minor amounts of sphalerite and pyrite. The gangue is mainly quartz, grading in places into chalcedony. Azurite in small quantity and a little malachite are found on the surface. The lode, which strikes east and west and dips 65° S., apparently cuts across a dacite dike 90 feet wide and trending nearly north and south.

KENNEDY OR JACKSON CREEK MINE.

The Kennedy mine is one of the old mines of the district that has been recently reopened. The former workings are said to have attained a depth of 250 feet. The ore consisted of rich silver sulphides, which, in 1872, were hand sorted and hauled to Fort Benton by ox teams and shipped to Swansea, Wales. The old workings are no longer accessible. An incline of 69° has recently been sunk to a depth of 115 feet and a crosscut back to the ledge on the 100-foot level was commenced.

The country rock is a coarse granite, consisting of orthoclase, plagioclase, quartz, and biotite. At the surface this has been disintegrated to a sand through which project a few hard fresh aplite dikes. Three parallel ledges occur on the property, trending east and west. One that is being prospected by pits shows an overburden of disintegrated granite 10 feet thick. In places the ledge is represented by oxidized sheared granite.

LEGAL TENDER MINE.

The Legal Tender mine is situated a short distance east of Clancy. According to Raymond,[1] writing in 1873:

> This lode is a true fissure vein, cutting through granite, and is considered the richest and best developed silver property in the Territory. The ore and vein matter varies in thickness from 1 to 3 feet, increasing gradually in width as depth is obtained. A portion of the ore in the vein is a very rich argentiferous galena, carrying a larger or smaller quantity of dark-brown zinc blende, sulphurets, and carbonates of lead, oxide of manganese, iron, copper, and antimony, with streaks in which native wire, flake, sheet, and ruby silver occur abundantly. The heaviest galena ores contain black and gray sulphurets of silver, and yield from $2,000 to $4,000 per ton. A fine blue quartzose ore predominates, in which occurs very frequently native and ruby silver. A

[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1873, p. 230.

small portion of these ores can be successfully reduced by the smelting process, as has been demonstrated in the works at Helena and Jefferson City; but the larger portion of the ore from this mine can be most profitably reduced by the milling (roasting, chloridizing, and amalgamating) process. The lode was first discovered by Joseph Fultz in 1866, but no work of development was accomplished until 1872, under the management of its present owners, who came into possession in the winter of 1871–72. Up to May 1, 1872, a shaft was sunk only to the depth of 60 feet, which, however, demonstrated the existence of a true vein and a body of very rich ore. Since that time work has been prosecuted with vigor, and large and commodious whim, shaft, and ore houses have been erected, with company office, assay office, and other necessary buildings.

The mine is developed to the depth of 160 feet, showing an increasing width of vein with depth. At the depth of 80 feet levels were run 140 feet east and 90 feet west, and at the depth of 160 feet the east level is out 130 feet. Some stoping has been done east of the main shaft. An air shaft 60 feet west of main shaft extends down to the 80-foot level.

From the commencement of work by the present owners up to January 1, 1873, the mine has produced 7 tons of ore yielding $6,090 coin value, or at the rate of $870 per ton; also 130 tons of ore yielding $54,000 coin value, or at the rate of $417.78½ per ton; and 240 tons yielding $31,607 coin value, in lots, at rates varying from $128.42 to $202.49 per ton. About 175 tons of second-class ore are now on hand.

* * * * * * *

The first-class ores have mostly been shipped out of the Territory in wagons to Corinne, thence to San Francisco and Europe.

The mine has long been idle and dismantled. The preceding description has been thus fully quoted because the facts therein presented, taken together with the present condition of the mine, give an accurate picture of what has happened to so many other mines throughout this same region.

From what can now be seen on the surface, the vein ranged from 4 to 6 feet in width, trended N. 80° E., and dipped vertically. It belonged to the same type of ore body as the King Solomon. The fine blue quartzose ore of Raymond's report is the fine-grained flinty or chalcedonic quartz of this report. Ninety feet south of the Legal Tender shaft are huge iron-stained outcrops of one of the chalcedonic reefs so common in this part of the district. The Legal Tender vein is either cut off by this reef or converges with it at a narrow angle approximately 200 feet west of the shaft.

WICKES DISTRICT.

LOCATION AND HISTORY.

The Wickes district has been the largest producer of silver-lead ore in Jefferson County. Within the district as designated in this report, are included the towns of Wickes, Corbin, and Jefferson, and the deserted mining camps of Gregory and Comet. Jefferson was settled in 1864 and Wickes in 1877. Corbin is considerably more recent.

Wickes is situated 20 miles south of Helena on the Great Northern Railway. Formerly it was served also by a branch of the Northern

Pacific Railway, extending from Helena, but this line was abandoned about 1900. The large smelting plant of the Helena Mining & Reduction Co. was situated here and was operated until 1893, when it was shut down. It has never been started again and is now a wreck. This blow, together with the cessation of mining at many of the properties in the vicinity, destroyed the prosperity of Wickes. Corbin, situated 2 miles below Wickes, has in recent years enjoyed a copper boom on account of the large bodies of ore believed to exist there, but since the panic of 1907 the boom has largely collapsed.

Although the district contains an array of mines noteworthy for their output—the yield of the Alta, Comet, Gregory, and Minah mines aggregating over $50,000,000—only one property was shipping ore in 1911. This was the Blue Bird mine, which produces a copper-silver ore. Extensive development work, however, was in progress at the properties of the Boston & Corbin Gold & Silver Mining Co., Corbin Copper Co., and Corbin Metals Mining Co.

GEOLOGY.

The oldest rocks in the Wickes district belong to the series of andesites and latites. They form the largest remnant of the cover under which the granite of the Boulder batholith cooled. Massive lavas, breccias, and an unusual proportion of fine-grained tuff and argillaceous rocks are found. In places the andesites, or more probably latites, display conspicuous flow streaking, as near the summit outcrops of the Alta lode and along the road from Wickes to Gregory. The prevalence of banded tuffs allows the dip and strike to be determined more readily than is generally possible in the andesite-latite series. Measurements show that, although flat dips are of general occurrence, steep dips up to 45° are common. These dips are steeper than those obtaining along the margins of the batholith; furthermore, the strike of the beds is inconstant in direction. This structural complexity suggests a possibility that the roof remnant has suffered partial foundering and collapse during the intrusion of the quartz monzonite.

The granitic rock of the Wickes area is the normal quartz monzonite of the Boulder batholith. It is intruded, however, by unusually large masses of aplite, the largest of which is shown on the geologic map (Pl. I, p. 20). Another large area, probably approaching in size that east of Corbin and Wickes, lies west and southwest of Jefferson. Dikes of aplite also are common in the quartz monzonite and in the andesites.

West of Wickes is a considerable area of dacites that form a series of prominent white and light-gray porphyries. These rocks rest on the eroded surface of the andesites and granite and are therefore considerably younger. Dikes of dacite pierce the older rocks; some of these that carry few or no quartz phenocrysts are, strictly speaking, biotite andesites and are not easily distinguishable from diorite porphyries.

DESCRIPTIONS OF MINES.

ALTA MINE.

The Alta mine, whose output of $32,000,000 is by far the largest of the mines in the region, is situated on Alta Mountain, 2 miles southwest of Corbin. It was developed by a series of tunnels, the lowest of which is known as the 800-foot tunnel, although it is considerably less than 800 feet vertically below the summit of Alta Mountain. The property, together with many others in the vicinity of Wickes, was acquired in 1883 by the Helena Mining & Reduction Co. A smelter, which was for some years the largest reduction plant in Montana, was built at Wickes, and regular mining operations continued until 1893. Since then an intermittent production has been maintained by lessees. In 1909, however, the property was taken over by the Boston & Alta Mining Co. and a shaft, situated near the mouth of tunnel No. 8, was sunk to a depth of 600 feet. Drifting was commenced to intercept the vein below the old levels, but operations were suspended in August, 1910. Lessees were engaged during 1911 in extracting carbonate ore from shallow surface workings and grass-root tunnels near the summit of Alta Mountain.

The production of the mine previous to 1893 is stated to have been 1,250,000 tons of ore, aggregating $32,000,000, mainly in lead and silver, and up to that time only the highest grade ore was shipped.[1]

The prevailing rock in the vicinity of the Alta mine is a latitic andesite. The rock at the summit of the mountain shows a pronounced streaky and flow-banded structure. The intrusive granite occurs several hundred yards east of tunnel No. 8; on the wagon road below the mine a dike of coarse aplite and two dikes of dacite 50 or 100 feet wide are exposed, penetrating the andesites.

The underground workings being inaccessible, only surface observations could be made. These show that the ore body, trending slightly south of west, was inclosed in the andesites and that the ore minerals consisted of galena, sphalerite, and pyrite. The introduction of the ore, as shown by material on the dumps at 6,100 feet altitude, was accompanied by intense tourmalinization, so that radial aggregates of black tourmaline are common in the altered andesite. In places the andesite was fractured and netted with quartz tourmaline veinlets and impregnated with pyrite. Such rock examined microscopically proves to be composed of quartz and sericite in nearly equal abundance, tourmaline, and pyrite.

[1] Mineral Resources U. S. for 1909, U. S. Geol. Survey, 1910, p. 374.

The output of $32,000,000 of lead-silver ore entitles the Alta lode to rank among the world's most notable deposits of lead-silver ore occurring in noncalcareous rocks. Further, this great yield would seem to give it foremost place in the class of tourmalinic ore deposits.

BERTHA MINE.

The Bertha mine, the property of the Boston & Corbin Copper & Silver Mining Co., is situated 1 mile west of Corbin. The company was organized in 1907 and the main work done on the property has been accomplished since that time. A 2-compartment shaft, operated by a balanced electric hoist, was sunk to a depth of 900 feet, which was the bottom level of the mine at the time of visit. This level, however, is called the 1,200-foot level, owing to the fact that the discovery croppings are situated 300 feet above the collar of the shaft. It is planned to erect a 300-ton concentrator on the property.

The country rock is a coarse gray granite or quartz monzonite. The vein trends northeast-southwest and dips steeply northwest, commonly in excess of 80°. Drifts have been run along the vein southwest from the shaft on various levels and a considerable tonnage of ore has been blocked out. The vein ranges in thickness from a few inches to a maximum of 10 feet and on the 700-foot level averages about 4 feet; on the 900 and 1,200 foot levels it is somewhat narrower. The vein on the 700-foot level has a well-marked ribbon structure, where undisturbed, but much postmineral movement has taken place and the quartz is brecciated along the footwall. This postmineral movement was mainly horizontal, as shown by corrugations on the walls, and took place chiefly along the footwall, which is overlain by a layer of gouge in places 1½ feet thick. Locally this gouge is somewhat stained with iron oxide. The granite adjoining the vein on the 700-foot level shows white chalky feldspars, which give it a porphyritic appearance; it slacks and crumbles readily. In this phase the biotite plates have remained unattached and lustrous; in other phases both feldspar and biotite are sericitized and the rock is more highly pyritized.

The ore is a coarse white quartz, carrying chalcopyrite and pyrite, and is stated to average from 2 to 3 per cent copper, with small values in silver and gold. Some of the ore carries small amounts of a lead-gray mineral, locally known as gray copper, but which, on qualitative chemical analysis, proves to be a sulphide of lead and bismuth answering to the description of cosalite. It would probably be a matter of some metallurgical interest to determine whether this mineral carries any silver, as it will undoubtedly slime during concentration. Some bornite occurs in small amount on the 700-foot level, but is not found above or below this level. It may represent local enrichment, but this is doubtful. Other than the occurrence of this bornite, there is no evidence of sulphide enrichment, and the bulk of the ore is clearly of primary origin.

According to a recent report,[1] a carload shipment of average ore for testing purposes sampled 3.6 per cent copper, 7.1 ounces of silver, and 20 cents in gold to the ton.

BLIZZARD MINE.

The Blizzard mine is situated 3 miles west of Wickes. It was operated by a company from 1888 to 1896 and by lessees from 1899 to 1906. In 1911 three men were engaged in exploring the property with a view to opening it up again. The old workings produced about $150,000, smelter returns showing that the ore carried from 0.1 to 0.8 ounce of gold and 10 to 60 ounces of silver to the ton and 6 to 20 per cent of lead. There are two veins on the property, and of these only the northern vein carries ore. The northern vein occurs in a shear zone in andesite and ranges in thickness from a few inches to 6 feet. The joint planes in the andesite near the vein are at many places heavily pyritized; rarely slight tourmalinization occurs along the joints in the andesite, but occurs nowhere in connection with the ore. The ore consists principally of pyrite and arsenopyrite, in places with small bands and patches of galena, sphalerite, and blende, rarely chalcopyrite. Practically no quartz is present.

The smelter returns show that this ore carries 0.3 ounce of gold and 14 ounces of silver to the ton, 8.5 per cent of lead, and 1.3 per cent of copper. The southern vein, which is said to fault the northern vein, occupies a fault plane in the andesite and dips 45° N., except at the east end near the fault, where it dips 85°. The filling of this vein consists of pyrite, rhodochrosite, pyrolusite, calcite, and quartz.

BLUE BIRD MINE.

GENERAL FEATURES.

The Blue Bird mine is situated at an altitude of 7,000 feet, 4 miles west of Wickes. It is one of the old mines of the district, and the property, recently enlarged by the purchase of the adjoining Penn Yan claim on the west, was taken over in 1911 by a new company, which is proceeding to develop the mine systematically.

The authenticated production is $175,000, but the amounts taken out by lessees from time to time are believed to bring the total up to $250,000.

The main haulage way, whose portal is situated 400 feet below the highest point on the outcrop of the lode, consists of a crosscut tunnel 648 feet long bearing S. 45° W., and a tunnel following the trend of

[1] Eng. and Min. Jour. vol. 93, 1912, p. 668.

the lode for 1,600 feet in the general direction N. 80° W. The tunnel, which is of somewhat devious course, though considerably straightened by the present management, will eventually undercut the lode beneath a shoot of ore known to have been exploited in the summit workings. This shoot was 350 feet long and has been stoped out from the 120-foot level to the surface. The ore averaged 0.56 ounce in gold and 65 ounces in silver to the ton,[1] being considerably higher in precious metals than the ore now mined.

Geologically the Blue Bird mine is situated on the western margin of a large andesitic area that constitutes a remnant of the roof under which the quartz monzonite was intruded. It lies at the head of a long embayment of the quartz monzonite extending into the andesites, an embayment sufficiently pronounced to be apparent on the geologic map, even with the small scale employed. On account of this proximity to the intrusive contact, various granitic dikes, comprising quartz monzonite, aplite, and diorite porphyry, penetrate the general country rock at the mine. Contact-metamorphic alteration also has affected the rocks, especially those on the west end of the property.

The rocks at the Blue Bird mine consist principally of andesitic tuffs grading into hard shales. They are known locally as "slates,"[2] but none show slaty cleavage. Such local terms are apt to be misleading in a general report, so the term will not be used here; it need but be pointed out that the "slates" at the Blue Bird mine are in no respect similar to the rocks locally called "slates" at Marysville. A specimen taken 100 feet south of the lode line at the summit of the hill is a massive fine-grained greenish-gray rock of andesitic appearance. Under the microscope its tuffaceous character becomes apparent. It is seen to be composed of plagioclase fragments with numerous epidote aggregates and chlorite scales embedded in a cryptocrystalline matrix. Some of the coarser-grained rocks are clearly of pyroclastic origin, but the finer-grained rocks are less easily discriminable, and it is of course impossible to draw any hard and fast line between argillaceous tuffs and pure shales. Here, as elsewhere in the region, as shown under the systematic treatment of the geology (pp. 23–29), lava, tuff, and argillaceous rocks occur interstratified. Undoubted massive porphyritic andesite, possibly latitic like that on Alta Mountain, is found in the mine; it was specially noted in drift No. 812. The bedded andesitic tuffs, as shown in a cutting near the superintendent's house, strike north and south and dip 40° E.

Diorite porphyry forms extensive outcrops 800 feet north of the lode line, and similar rock has been encountered on the main haulage

[1] Winchell, H. V. and A. N., Notes on the Blue Bird mine: Econ. Geology, vol. 7, 1912, p. 287.
[2] They are so termed by H. V. and A. N. Winchell, op. cit., p. 292.

level of the mine. The relation of this rock to the surrounding rocks has not been determined, and it is not known whether the diorite porphyry preceded or followed the quartz monzonite intrusion. Diorite porphyry from crosscut No. 605, locally termed granite, is a highly porphyritic rock containing numerous plagioclase phenocrysts and hornblende inclosed in a microcrystalline matrix. Under the microscope the plagioclase phenocrysts are found to be labradorite near Ab_1An_1 and remarkably clear and well preserved, in view of the altered condition of the rest of the rock. The porphyritic hornblendes are largely changed to confused intergrowths of actinolite. The groundmass is composed essentially of a microgranitic aggregate of orthoclase and quartz, with accessory magnetite. Common secondary minerals are chlorite, epidote, and pyrite. The diorite porphyry mass in drift No. 605 shows various phases; where pyritized and sericitized it is light colored, and where mainly tourmalinized it is nearly black. Such kinds of alteration took place concurrently with the formation of the lode, and a small pocket of 2-ounce gold ore, consisting of columnar arsenopyrite embedded in a matrix of sphalerite and pyrite, was encountered in this altered diorite porphyry, which is therefore clearly older than the ore body.

Dacite is the youngest igneous rock at the mine. It forms a 50-foot dike lying in the footwall of the lode and dipping 70° S. The dike is apparently several thousand feet long, having been noted at the Penn Yan shaft on the west and at the Abe tunnel on the east. The dacite is a light-gray porphyry holding phenocrysts of quartz, plagioclase, and biotite in numerous small hexagonal plates. The characteristic features of this rock are sufficient to establish its identity with the extrusive dacites of the region, which are so well developed a few miles east of the mine. The dacite dike was therefore injected long after the main mineralization at the Blue Bird mine had taken place. Some brecciation of the footwall of the dike has occurred, followed by a slight introduction of pyrite, but this mineralization was of no economic importance.

THE ORE.

The ore occurs in shoots along a profoundly tourmalinized zone trending approximately east and west. On the 200-foot level of the Blue Bird shaft a crosscut into the hanging wall shows 40 feet of tourmalinic rock. This rock is of striking appearance and shows, contrasted against a light-colored matrix, a great number of radial groups of black columnar tourmaline, the largest several inches in diameter. Arborescent growths are common. Microscopically the rock is seen to be composed of tourmaline, quartz, sericite, pyrite, and apatite. The tourmaline ranges from broad columns of brown-green color to long colorless ultramicroscopic needles traversing a succession of consecutively adjoining quartz grains. Apatite, although ranking as an accessory mineral only, was probably introduced with the tourmaline and pyrite. The rock as a whole has been so thoroughly recrystallized that its original character is no longer recognizable. The ore is found in rock of this kind. Along the lode some remarkably thorough postmineral brecciation and crushing has taken place, producing rounded fragments of ore embedded in a clayey matrix.

In the workings on the main haulage way and in the two levels below it, the features of the ore-bearing zone are somewhat different. A tourmalinic breccia occurs on both sides of a granitic dike, which is 10 to 15 feet thick and dips 70° S. In places this granitic dike is intensely shattered. The tourmalinic breccia is not continuously developed along the course of the dike. It is composed of angular fragments of various rocks cemented together by a black fine-grained aggregate of tourmaline and quartz. This cement is similar in composition and appearance to the "black quartz" at Rimini. Among the rock fragments inclosed in the breccia, granite is most easily recognizable, but many light-colored fragments of fine texture are present, which are probably the highly altered equivalents of the andesitic tuffs. The granite has undergone extreme metamorphism and now consists essentially of quartz, sericite (unusually well developed in fan-shaped groups), tourmaline, and cubical pyrite. Arsenopyrite is found locally.

Isolated bodies of ore-bearing tourmaliniferous rock are found parallel to the tourmalinic breccia. Along the strike, where the tourmalinization was feeble, the tourmaline rock is represented, as in drift No. 812, by a series of vertical stringers of tourmaline 1 inch wide, which consist of a succession of radial groups centered along a crack commonly lined with pyrite.

The ore shipped to the smelter during 1911 was composed principally of iron-black tetrahedrite and pyrite intergrown with perfect radial groups of tourmaline, commonly under half an inch in diameter. The pyrite has a tendency to occur as large irregular or distorted cubes. Sphalerite and galena are rare constituents. Under microscopic examination such ore shows tourmaline, quartz, pyrite, tetrahedrite, sphalerite, and galena. The thin delicate prisms of tourmaline pierce the various sulphides and all the minerals appear to be essentially contemporaneous.

The ore is stated to carry 10 to 25 ounces to the ton in silver, 3 to 5 per cent of copper, and small amounts of gold.

COMET MINE.

The Comet mine, the property of the Montana Consolidated Copper Co., lies 7 miles northwest of Boulder. It has been one of the largest producers in the region and is popularly credited with a production of $13,000,000. For some years no systematic work has been in progress; during 1911 four different parties of lessees were at work getting out ore above the tunnel levels.

The mine lies near the contact of the quartz monzonite and the andesite. On the summit of the ridge northeast of Comet the andesite, which is of massive porphyritic character, is tourmalinized, showing numerous well-developed radial groups of tourmaline. Farther northeast on this same ridge considerable coarse andesitic breccia is exposed and shows much tourmalinization accompanied by development of sericite. The country rock at the Comet mine itself is a fairly coarse grained quartz monzonite. A large pit over 100 feet long and 30 feet wide, on the summit of the hill east of the shaft, contains a few horses of quartz mixed with altered granite, which is intensely sericitized and shows a small development of tourmaline. This feature indicates that the Comet ore body belonged to the older tourmaline-bearing set of deposits. In confirmation of this is the fact that the ore body is cut by a dacite dike 35 feet wide; much rock from this dike can be seen on the mine dumps where, because of its striking appearance, it is quite conspicuous. It shows large quartz phenocrysts and altered feldspars embedded in a gray matrix commonly showing fluxion structure.

The old mine workings are generally inaccessible; the timbers are crushed and the tunnels caved. At one place the lessees are taking out ore from three parallel lenticular masses trending east and west and dipping nearly vertical. The ore is a solid mass of sulphi es, more or less oxidized, and is usually accompanied by a vein of quartz against one or other of the walls. The granite is much shattered and slickensided and reduced to gouge. The ore is commonly kneaded into fragments embedded in vein matter. The ore minerals are essentially galena and sphalerite, with which are associated pyrite and chalcopyrite and rarely arsenopyrite.

CORBIN COPPER CO.'S PROPERTY.

The property of the Corbin Copper Co., comprising about 40 patented claims, is situated at the head of Clancy Creek, a few miles west of Corbin. A large amount of development work has been done here in recent years and a concentrator has been built on the property. At the present time most of the work is being done on the Dewey and Bonanza tunnels.

The country rock consists mainly of andesitic tuffs and interstratified argillaceous beds. The tunnels above the Dewey tunnel show a zone of shattered and leached rocks at least from 60 to 100 feet wide. Near the mouth of the Bonanza tunnel are large reef-like croppings of red-weathering tourmalinized andesite. The rock exposed in the Bonanza tunnel is generally soft and of granitic appearance. It is a gray medium-grained granitoid, in which biotite is the only mineral certainly recognizable, and is evidently an intrusive dike in the andesites. Under the microscope it shows an aplitic texture and is seen to consist of plagioclase, orthoclase, micropegmatite, and biotite. In places in the tunnel this rock has been highly altered, so that it is now made up largely of tourmaline and forms exceedingly hard and resistant material. It is composed, as determined microscopically, of quartz, brown tourmaline, sericite, and pyrite, accompanied by accessory apatite and zircon. Locally masses of ore, composed of galena and chalcopyrite associated with pyrite and sphalerite, occur in the tourmalinic rock. At the time of the writer's visit a raise was being put through on a mass of ore of this kind from the Bonanza tunnel to the Dewey tunnel, 207 feet above.

The Rosalie tunnel, situated 2,000 feet southeast of the preceding tunnels, shows dense-grained argillaceous rocks lying horizontally or inclined at low angles to the south. A drift was run on a narrow vein more than 800 feet. The vein shows a remarkably fine and continuous hanging wall. It is faulted in places, the greatest displacement encountered being 35 feet. The ore was an oxidized pyritic ore, showing considerable tourmalinization. It was of good grade, but on account of the small quantity found work has been suspended on this vein.

In the Montana tunnels a mineralization of an entirely different character and origin from that of the Rosalie tunnel is exposed. It consists mainly of a pyritized conglomerate associated with dacitic tuff and massive dacite, showing flow banding. In the upper tunnel pyritization ceases against the massive dacite, which forms a sort of hanging wall. A winze to the lower tunnel, 35 feet below, shows that the rock is considerably impregnated with pyrite, perhaps to the extent of 3 or 4 per cent. Galena occurs rarely. The rock along the upper tunnel is said to average 8 ounces silver for a distance of 130 feet.

The tuffaceous rock is soft and incoherent in the tunnels but hardens on exposure to the atmosphere. The conglomerate carries well-rounded cobbles, the largest 12 inches long, some being dacite, some alaskite, but the most andesite. It holds irregular lenses of white material, probably tuff, abruptly delimited from the inclosing rock. In the lower tunnel the conglomerate is overlain by a flow of dacite dipping 20° N. At other places massive dacite abuts against the conglomerate along fault contacts.

CORBIN METALS MINING CO.'S PROPERTY.

The Corbin Metals Mining Co., whose property is situated about 2 miles southeast of Corbin, is developing the Silver King and other lodes. An incline has been sunk to a depth of 400 feet and considerable drifting and cross-cutting has been done. Five parallel veins, inclosed in the granite country rock and trending N. 30°–45° E., have been crosscut. The veins are strong shear zones, ranging in thickness from a few inches to 8 feet. They are filled with crushed granite, which has been sheared into small irregular lenticles. Some of the veins are tight and dry, but others let in considerable water. As seen on the lowermost level the gangue material of the veins is somewhat altered by vein-forming solutions and slightly pyritized. There is no evidence of oxidation at this depth, nor that enrichment has taken place, and it is clear that the zone of primary sulphides has been encountered. The metallic minerals noted in material on the dump are pyrite, galena, subordinate sphalerite, and rarely molybdenite.

GREGORY MINE.

The Gregory lode was located in 1864 and is therefore one of the oldest properties in the region. The workings are now inaccessible, the surface plant destroyed, and the smelter is represented by only the stumps of the stacks. The production, according to popular report, was $8,000,000 in lead and silver.

The mine lies near the contact of the andesite and a tongue of diorite intrusive from the main mass of quartz monzonite. The upper Miocene dacites, as shown on the geologic map (Pl. I), occur a few hundred feet south of the mine but are of later origin than the ore bodies. The dumps show mainly andesite, which is commonly pyritized and in places slightly tourmalinized. Diorite is present in smaller amounts and is as a rule pyritized and sericitized. The ore consists of galena, sphalerite, and pyrite. According to Mr. Lindgren, who was assayer at the mine in 1883, the ore worked at that time was extremely high in zinc, and ore carrying as much as 15 per cent zinc was smelted.

HORSESHOE PROSPECT.

The Horseshoe prospect lies 2 miles west of Corbin. Several hundred feet of tunnel have been drifted along an irregular intrusion contact of aplite and andesite. The aplite is highly tourmalinized, pyritized, and sericitized. The andesite also shows a similar set of alterations, but a further alteration has been superposed upon the earlier by the action of downward-moving sulphate solutions. Exposed surfaces in the tunnels are covered with needles of gypsum, and the andesite when broken open is found to be permeated with flat crystals of gypsum. In addition to the aplite and andesite, masses of dacite were encountered in the tunnels and complicate the geology. The contacts of the dacite with the other rocks are sheared, and this shearing is probably a measure of the amount of postmineral movement, as the dacite itself is unmineralized and shows neither the intense tourmalinization nor sericitization that the older rocks do.

The primary mineralization, in which apparently the principal metallic sulphide introduced was pyrite, therefore took place after the intrusion of the aplite and before the intrusion of the dacite. Pyrite has possibly been introduced after the dacite came into place, but in comparatively small amount.

MINAH MINE.

The Minah, one of the old and well-known mines in the Wickes district, is situated 1½ miles northwest of Wickes. According to popular report the production has been $2,000,000, but the property is now idle and the smelter dismantled. During 1901 the output aggregated 3,000 tons of shipping ore, which carried 20 ounces of silver and $12 in gold to the ton.[1]

The country rock is a highly porphyritic dacite, showing large phenocrysts of striated feldspar, numerous small quartzes, and small black flakes of biotite. The ore bodies, however, seem to have been not in the dacite, but in the underlying andesite. The mine was developed by a series of tunnels, the lower of which extends 300 feet through dacite to reach the vein. The upper tunnel is situated at the contact of the dacite with the andesite, which is here a fault contact. Such ore as can now be seen contains large amounts of arsenopyrite in columnar crystals, and also pyrite, galena, sphalerite, and minor chalcopyrite, but it is not known whether this ore is representative of what was the productive part of the deposit.

MINNESOTA MINE.

The Minnesota mine is situated on Clancy Creek, a short distance south of the old town of Gregory. It is one of the oldest located properties in the region; some development work has been done on it in recent years, but it was idle during 1911. The property is developed by a number of tunnels and an open cut. At the upper end of the open cut a small vein of copper-stained quartz is inclosed in much-altered andesite. The strike is east and west, and the dip is steep to the north. On the south wall, near the east end, there is altered granitic rock which contains small veins of tourmaline with quartz and pyrite. The upper tunnel is in altered granitic rock. The lower tunnel shows an irregular intrusion into the andesite of granitic rock, which where fresh appears to be a diorite. Slipping is shown along most of the contacts. The ore occurs in small veins, which cut both rocks but do not appear to follow the contact. They are of workable width in the granite only.

The ore minerals, consisting of galena, blende, pyrite, a minor amount of arsenopyrite, and rare specks of chalcopyrite, are inclosed in a small amount of quartz gangue.

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[1] Fourteenth Ann. Rept. Inspector of Mines, Montana, 1902, p. 67.

NORTHERN PACIFIC MINE.

The Northern Pacific mine lies on the west side of Alta Mountain. The country rock is a highly flow banded andesite. The ore contains galena, pyrite, and sphalerite, in a gangue of manganiferous calcite holding fragments of brecciated andesite.

WICKES-CORBIN COPPER CO.'S PROPERTY.

The property of the Wickes-Corbin Copper Co. is situated a short distance southeast of Wickes in a small gulch known locally as Picnic Gulch. The principal piece of development work is the Bunker Hill tunnel No. 4, approximately 900 feet long. The prevailing country rock at the workings is a dark gray-blue andesite, well exposed on the west side of Picnic Gulch. On the east side of the gulch the andesite is intruded by granitic rocks belonging to the Boulder batholith and shows conspicuous evidence of thermal metamorphism. The summit of the ridge on the east of the gulch is occupied by an intrusive mass of aplite or alaskite, which in places is prominently porphyritic, owing to the presence of large phenocrysts of quartz and feldspar. As a rule it is thoroughly sericitized, approaching a fine-grained greisen in appearance, and it is almost impossible to obtain unaltered rock.

The Bunker Hill tunnel No. 4 is being driven to undercut an extensive outcrop of leached andesites exposed approximately 300 feet above the portal. A tunnel 275 feet above the Bunker Hill tunnel is 200 feet long and traverses leached andesites; drifts extending 50 to 100 feet in a north-south direction are more or less coated with chalcanthite—crystallized copper sulphate—and with gypsum needles. The rocks contain disseminated pyrite, evidently cupriferous, veinlets of solid pyrite, and also some that are galena bearing. The rocks traversed in the lower or Bunker Hill tunnel are exceedingly jointed andesites, which are pierced by a vertical aplite dike, approximately 200 feet wide as exposed along the tunnel. The andesites are more or less pyritized throughout the length of the tunnel and are traversed by pyritic seams. Some weak and poorly defined irregular shear zones are encountered at various places and are veined with discontinuous quartz stringers carrying galena, sphalerite, chalcopyrite, and pyrite. The main lode, lying on the inner side of the aplite contact, is 4 feet wide but does not constitute pay ore. It is believed that the deposit exposed on the surface, if the dip is vertical, will be intersected in tunnel No. 4 at about 900 feet from the portal. If there is any secondary enrichment it can be predicted that it has taken place a short distance below the upper tunnel level, as all ore in the main crosscut is of primary character.

In the Tulare tunnel, on the east side of the gulch, considerable drifting has been done along irregular shear zones in the andesites.

In these workings there were encountered some masses of biotite andesite, a rock related to the dacites that occur in great volume west of Wickes.

BOULDER AND BASIN DISTRICTS.

LOCATION.

Boulder and Basin are situated on Boulder River. Boulder, a town of 800 population, is the county seat of Jefferson County. Little mining is in progress in the district adjoining it. Basin, founded in 1880, lies 8 miles west of Boulder; a concentrator for the treatment of Butte ores was built here because of the abundance of water. Cataract and Basin creeks enter Boulder River near Basin from the north and northwest; the roads that ascend the valleys of these streams render a large part of the Boulder Mountains tributary to Basin.

The Boulder Hot Springs are situated 2 miles south of Boulder. They have been carefully described in detail by Weed,[1] who has shown that the hot waters are in process of forming mineral veins filled with quartz, stilbite, and calcite, which contain small but appreciable amounts of gold and silver.

DESCRIPTIONS OF MINES.

ROBERT EMMET MINE.

The Robert Emmet mine lies at an elevation of 5,600 feet on the south side of the Wickes-Boulder divide near the road between those towns. It is electrically equipped and a shaft has been sunk to a depth of 470 feet, with levels at 200 feet and 350 feet, but these were not accessible at the time of visit. The vein occurs in the granite several hundred yards east of the contact of the granite and andesites, which are well exposed upon the divide; it is said to strike east and west and to average 5 feet in width. The ore in the upper level as seen on the dump consists of sphalerite, pyrite, chalcopyrite, and galena in a quartz gangue. The valuable constituents are silver and copper, together with a small amount of gold ($2 to $5).

AMAZON MINE.

The Amazon mine is situated on the west side of Boulder Valley, 4 miles north of Boulder. The mine was closed down during 1911, but its owners intend to reopen it. The country rock is a granite. The ore contains much sphalerite and galena, with a small amount of chalcopyrite and pyrite in a quartz gangue.

BALTIMORE MINE.

The Baltimore mine is situated on Boomerang Creek, 4½ miles northwest of Boulder. A small crew of men were employed on the property during 1911.

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[1] Weed, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 227-255.

Two separate ore bodies have been exploited. The upper one is opened by tunnels 4, 5, and 6; the lower one by tunnels 1, 2, and 3. Tunnel 1, which enters the hill at an elevation slightly above the bed of Boomerang Creek, is the only one in which work was being done at the time of visit.

The general country rock in the vicinity of the mine is granite, but the principal workings are in intrusive masses of aplite, a light-colored granular rock consisting of orthoclase, quartz, and a minor amount of biotite. There have been encountered also some porphyry dikes of andesitic character, related to the dacites capping the granite on Sugarloaf Mountain, which lies a short distance southwest of the mine. The ore bodies that have been mined were short, irregular veins with numerous branches, but locally swelling to considerable dimensions. In tunnel 5 there remains a large body of ore, consisting mainly of black sphalerite inclosed in a coarse white quartz gangue. Galena, pyrite, and chalcopyrite are associated sulphides. Sphalerite transformed to covellite is found as a rarity. This ore body was too zincky to work formerly, and only the portions containing considerable lead were extracted.

The ore body developed in the three lower tunnels has been largely stoped out to the surface from above tunnel 2. In this tunnel the vein is approximately 130 feet long and is terminated at both ends by faults. The first 65 feet has been stoped out; the remainder of the vein consists of flinty gray and chalcedonic quartz, evidently too low grade to pay for extraction. In the winze between tunnels 2 and 1, 86 feet below, the vein is well shown. It stands vertical and ranges in width from 6 to 8 feet. The hanging wall is sharply defined, but the footwall is less well marked, the vein inclosing some aplite, reticulated with fine-grained siliceous veinlets. The gangue is a coarse white quartz irregularly mingled with dark flinty quartz and carrying a sparse amount of metallic sulphides. Pyrite is the principal sulphide, and sphalerite, galena, and chalcopyrite occur in minor amounts. The ore is stated to contain $7 a ton in gold.

GRAY EAGLE MINE.

The Gray Eagle mine is situated at the head of Bishop Creek, a tributary of High Ore Creek. The lower or main working tunnel is 1,800 feet long, but only 1,000 feet are now accessible; it traverses both granite and aplite. The pit on the surface, however, is in andesite. The course of the vein is N. 75° W. The lower tunnel is approximately 200 feet below the pit, and a shaft inside the tunnel was sunk another 200 feet. Apparently there was one principal ore shoot, which was stoped out to the surface. The estimates of production show a considerable range, but half a million dollars' worth of lead-silver ore seems to be a moderate figure.

COPPER KING PROSPECT.

The Copper King prospect is situated 3 miles northeast of Basin in Hiawatha Gulch. The principal development consists of a tunnel drifted 125 feet along the vein. During 1911 a shaft was being sunk on the vein and attained a depth of 35 feet. Two men were employed.

The ore body is a narrow vein a foot thick at most, trending east and west, inclosed in granite walls. The ore is a quartz carrying tetrahedrite and a small amount of pyrite. The quartz is of coarse glassy character mingled with cryptocrystalline and chalcedonic phases. By sorting, a product containing 24 ounces of silver and $1.60 in gold to the ton and running 94 per cent of silica is obtained. The ore is sorted so as to run high in silica, because it is shipped to the copper smelter for use as converter lining, and a bonus of 15 cents is paid for each unit in excess of 75 per cent of silica.

QUARTZ MASS NEAR BASIN.

A great mass of quartz is inclosed in granite 1 mile east of Basin alongside the track of the Great Northern Railway. This quartz mass was formerly of some ecomomic importance; it was quarried and shipped to Butte as converter lining for the copper smelters.

The quartz mass is 200 feet in altitude from its top to the floor of the pit; most of it forms a sheer face of coarse solid white quartz absolutely devoid of any metallic sulphides; on the level of the pit it is 350 feet wide. Coarse quartz monzonite surrounds the quartz mass, but the actual contact is covered everywhere by loose material. The monzonite shows megascopically no noticeable alteration. In the tunnel, which is 100 feet below the pit, the main rock is a coarsely granular alaskite porphyry slightly pyritized. Only an insignificant amount of quartz is exposed in the tunnel. A noteworthy feature is that small quartz stringers, branching off from the larger masses and penetrating the porphyry, inclose numerous euhedral crystals of orthoclase up to three-fourths of an inch in length, forming a rock resembling a quartzose pegmatite.

EVA MAY MINE.

The Eva May mine is situated on Cataract Creek, 8 miles north of Basin. The mine is developed by a shaft 1,200 feet deep, with levels at every 100 feet down to the 600-foot level, and also at 800 feet and 1,200 feet. The general rock in the vicinity of the mine is a coarse gray quartz monzonite cut by intrusions of a tourmaline-bearing white aplite. The ore is a coarse white quartz carrying pyrite, chalcopyrite, galena, sphalerite, and tetrahedrite. Further, it is noteworthy that some of the ore contains considerable black tourmaline. An interesting fact is that the mine dump shows also considerable blue-gray cryptocrystalline quartz, but the significance of this or its relation to the tourmaline-bearing quartz ore could not be determined on account of the inaccessible condition of the underground workings.

Concerning this mine Weed[1] says:

An example of the economic necessity of carefully observing secondary fractures and accompanying enrichment is shown by the Eva May mine, on Cataract Creek, near Boulder, Montana. In the early history of the mine much high-grade ore was found, consisting of pyrite, together with more or less galena, blende, and chalcopyrite, the whole impregnated with scattered bunches of rich antimonial sulphides of silver. The vein is a large one and shows thick ore shoots of pyritic ore, but the bulk of this, away from the enriching fracture, is too poor to work.

An analysis of a concentrate of the pyritic ore, cited by Weed, shows 9.83 per cent of lead, 6 per cent of zinc, 4.56 per cent of copper, 0.1 ounce of gold, and 1.85 ounces of silver.

The King tunnel, which is being driven to hold some unpatented ground, is 450 feet in length and is drifted along a highly tourmalinic lode 2½ to 3 feet wide. The principal sulphide is pyrite, with arsenopyrite, sphalerite, and galena in minor amounts. Sulphides are contemporaneous with the tourmaline and it is noteworthy that in comby veinlets of quartz the tourmaline fills the central portion of the veins.

UNCLE SAM MINE.

The Uncle Sam mine is an old property, from which in early days some 12,000 tons of ore were taken out and hauled to Wickes. This was said to carry from $30 to $90 a ton. Operations have recently been commenced to reopen the mine. A crosscut tunnel is being driven to intersect the lode at a depth of about 175 feet; the estimated length is 450 feet, of which 250 feet had been completed at the time of visit.

The country rock is aplite, forming a border between the main body of granite, which is encountered in the tunnel, and a capping composed of andesites. An aplite dike, 10 to 15 feet wide, with gouge on both contacts was crosscut in the tunnel. The vein is near the contact of the aplite with the overlying andesites; in fact the pits on the extension of the vein are in andesite. The andesites, or probably more accurately latites, are flow-banded varieties; they have been considerably metamorphosed by the intrusion of the granitic rocks and in consequence are not easily recognizable. They are light colored and because of their light color and highly developed flow banding have been regarded as rhyolites and phonolites.

The old workings took out a shoot of ore extending 80 feet east of the incline shaft and reaching a depth on the incline of 130 feet. The ledge is said to be 12 feet wide and the ore minerals are galena and sphalerite with subordinate tetrahedrite.

[1] Weed, W. H., Genesis of ore deposits, special publication Am. Inst. Min. Eng., 1902, p. 495.

WESTERN RESERVE MINING CO.'S MINE.

The Western Reserve Mining Co. owns the Hattie Ferguson mine on Cataract Creek, 6 miles from Basin. The mine was formerly worked by a shaft 140 feet deep, but a crosscut, now over 1,400 feet long, is being driven and is expected to cut the vein at a depth of 362 feet below the collar of the shaft. The country rock is aplite, which extends northward to the Sirius and Klondike mines, although a small amount of normal granite is encountered in this area. The aplite is somewhat porphyritic, and near the vein this texture is accentuated by the chalky appearance of the feldspar. The ore minerals are galena, pyrite, and sphalerite, and 40 per cent of the value is said to be in gold.

BUTTE AND PHILADELPHIA PROSPECT.

The Butte and Philadelphia prospect is situated on the flank of the group of peaks known as the Three Brothers and lies northwest of the south peak at an elevation of 7,800 feet. The property is reached from the south by the road extending up Basin Creek from Basin. Some machinery was installed and a small amount of development work was in progress during 1911. A series of three parallel veins traverses the granite, one of which is developed by 250 feet of tunnel. The strike is N. 80° W. and the dip 65° N. The ore occupies a 7 to 10 foot crushed zone in the granite. The metallic minerals are chiefly pyrite, with small amounts of galena and sphalerite, associated with very little quartz. Between the pyrite and the heavy zone of gouge that occurs along the hanging wall, there are in places slabs of galena 1 inch thick and from 1 to 2 feet in diameter, showing a banded structure.

BULLION MINE.

The Bullion mine lies at an elevation of 7,400 feet on the northwest side of Jack Mountain, 10 miles by road from Basin. A concentrator and smelter of 200 tons daily capacity was constructed and several thousand feet of drifts and tunnels run, but the property is now idle.

The country rock at the mine is mainly quartz monzonite, intruded, however, by small dikes and masses of tourmaline-bearing aplite. Near the ore the rock is much altered by sericitization and pyritization and is cut by irregular veins, carrying black columnar tourmaline, quartz, and pyrite. The ore minerals in order of decreasing abundance are pyrite, tetrahedrite, galena, sphalerite, chalcopyrite, and arsenopyrite, and are inclosed in a gangue of coarse white quartz. A second and later mineralization has affected the veins and is represented by a gray, flinty quartz carrying minor amounts of metallic sulphides. The ore therefore is of composite origin.

MORNING STAR MINE.

The Morning Star mine is situated on the west side of the valley of Basin Creek, half a mile west of Winters Camp. The ore body strikes east and west and consists of a quartz vein inclosed in a much-altered andesite. The metallic minerals are galena, sphalerite, pyrite, and chalcopyrite in small amount. The richest ore occurs in a 2½-inch streak, consisting principally of galena, and is reported to run 40 ounces in silver and $3.80 in gold to the ton and 50 per cent of lead.

CUSTER MINE.

The Custer mine is situated 1 mile southeast of Basin at an elevation of 6,000 feet. The ore body is a wide quartz vein, in places attaining a width of 30 feet, traversing sericitized granite. The strike of the vein is east and west, but the pay streaks, which are generally under 1 foot in width, are very irregular in width and direction. The ore is a high-grade silver-lead carbonate, which is stated to carry 40 ounces in silver and $18 in gold to the ton.

ALLPORT MINE.

The Allport Mining Co.'s property, consisting of 5 end-on-end claims extending northeast and southwest, is situated 4 miles south of Basin, at an altitude of 7,500 feet. The main development work consists of a shaft 110 feet deep and a number of short levels. During 1911 work was in progress on the 55-foot level, but the vein below this level is flooded with water.

The country rock is a coarse gray granite. On the 55-foot level the vein, which trends N. 36° E. and dips nearly vertical, is from 5 to 6 feet wide and consists partly of quartz and partly of granite. The wall rocks are much altered by sericitization and impregnation with pyrite. The vein on the 100-foot level is said to be 12 feet wide and to assay $16 a ton in silver and gold across the face. The ore is a bluish-gray cryptocrystalline quartz, carrying mainly pyrite in small amount and some sphalerite.

On the northwest extension of the course of the vein some coarse-grained white quartz veinlets were seen that carried considerable tourmaline, but these were said to be valueless. These quartz-tourmaline veinlets have been brecciated and recemented by chalcedonic quartz.

RUBY MINE.

The Ruby mine is situated on Lowland Creek, 4 miles from its junction with Boulder River. The 10-stamp mill on the property is built near the stream at 6,000 feet altitude, but the mine lies half a mile southeast of the mill, at an altitude of 6,750 feet. By air line the Ruby mine is 14 miles north of Butte. The property was located in the seventies and surveyed for patent in 1888.

The production is estimated to be $1,250,000—70 per cent in gold and the remainder in silver. Rich ore was sent to the smelter, and netted from $17 to $302 a ton in carload lots. The mine has been operated only intermittently, having several times been considered as worked out. In September, 1911, the mill was again started and commenced crushing a dump of some 1,200 tons of second-class ore which had accumulated during recent exploratory work.

The main shaft is situated at 6,750 feet altitude and was sunk to a depth of 400 feet. A crosscut tunnel intersects the shaft at 150 feet below the surface. The mine is now flooded with water below the 150-foot level.

The general country rock at the Ruby mine is dacite, or rhyolite, as it is better known locally. It lies in the heart of the great area of dacites that extends southward to Butte and forms Big Butte at that city. At the Ruby mine the original thickness of the superposed succession of dacite lavas and breccias was at least 2,500 feet. The dacite at the mine is a markedly porphyritic rock, showing numerous crystals of quartz and glassy striated feldspar embedded in a light-grayish groundmass of dense texture. In the vicinity of the mill the rock is prevailingly a dacite breccia.

The ore-bearing zone extends from the main shaft to the Columbia claim, a distance of several thousand feet, the general trend being S. 20° E. Within this zone the ore occurs in shoots, or more properly in parallel veins, dipping steeply westward and apparently disposed roughly in échelon fashion. The Ruby shaft was sunk on a shoot of ore which, as shown on the stope map, was 260 feet deep, 40 feet long, and 20 feet wide. The extreme length, which was 70 feet, was on the 200-foot level. This shoot of ore, or pipe, as it is termed locally, yielded $600,000. The country rock in the vicinity of this shoot is extremely sheared and shattered. To the north the ore body is terminated by a southward-dipping fault zone, which is brecciated and mineralized through a width of 40 feet or more.

South of the Ruby shoot another vein was found, in which the productive portion was 170 feet long and 4 feet wide. The walls of this vein are generally well defined. A marked vertical undulation is a characteristic feature of the hanging wall. In places the vein is filled with fault breccia, some fragments of which are 20 inches long. Toward the north the fissure is apparently cut off by a cross fault dipping 45° S., although the fissure is here so small as hardly to be recognizable. The fissure is traceable by a well-defined footwall for a distance of 60 feet south of the productive portion, where it is terminated by a cross fault dipping south. It is not impossible that some of the cross faults are fractures contemporaneous with the major fissuring. The ore consists of angular dacite fragments cemented by quartz, calcite, and minor adularia. The adularia, where embedded in quartz and calcite, is not easily distinguishable, but in places forms crystals up to one-fourth inch in diameter. Its identity was established chemically and optically. The quartz is commonly clear, glassy, and drusy, but where it is solid it is of compact saccharoidal texture. Some of the siliceous veinlets show a porcelain-like texture, but such cryptocrystalline quartz is far less common at the Ruby mine than at the surrounding properties. The sulphides, which are confined to the gangue material that cements the dacite fragments, comprise pyrite, argentite, and possibly others that because of their fine subdivision are not readily recognizable. Native silver is common locally. The grade of the ore decreases with increase in size of the dacite fragments filling the fissure.

The workings extend on the southeast into the Columbia claim, which was recently acquired by the owner of the Ruby mine. The Columbia vein is developed by a number of drift tunnels, one of which now connects with the Ruby workings. A pronounced joint system, trending N. 20° W., occurs in the Columbia tunnels and appears to have governed the trend of the ore body. The Columbia vein represents a zone of brecciation 12 feet or more wide. The individual fragments of brecciated dacite show little movement or deorientation, and the filling of the vein consists for the most part of angular fragments of dacite coated with a crystalline crust of quartz. In places, however, there is considerable white quartz unmixed with country rock. Some of this quartz is identical in appearance with that of the Empire and other veins of Marysville; that is, it is of lamellar habit and shows irregular pyramidal hollows lined with small glassy quartz crystals. Such ore is of low grade, carrying $4 to $5 a ton in gold. The former owner took out only a rich streak along the hanging wall.

KIT CARSON MINE.

The Kit Carson mine is situated on Lowland Creek near the stamp mill of the Ruby mine. The production is said to have been $100,000 in gold and silver. The property has in recent years been worked by lessees, but was idle during 1911.

The main development is a drift tunnel entering the hill from the level of the stream bed. It is approximately 325 feet long and trends N. 10° E. The country rock is porphyritic dacite. At the face of the tunnel is seen 5 feet of highly brecciated porphyry, in which the fragments are irregularly traversed by chalcedonic and porcelainoid veinlets. The west wall (footwall ?) is marked by a zone of soft, white clay. Locally, as shown along the tunnel, the hanging wall seems to have been determined by a platy structure parallel to the flow banding of the dacite.

Material on the dump shows that the dacite was netted with veinlets of silica carrying pyrite. Drusy crystalline, chalcedonic, and porcelainoid varieties of silica are intimately associated together.

The feldspars of the dacite have been altered to chalky spots, in appearance strongly suggestive of kaolin but which prove under the microscope to be cryptocrystalline aggregates of sericite. The quartz veinlets when examined microscopically are found to contain minute crystals of adularia.

MEMPHIS PROSPECT.

The Memphis prospect is on Lowland Creek, half a mile upstream from the stamp mill of the Ruby mine. The geologic features are similar to those of the Kit Carson mine. The dacite is cut by irregular veinlets of cryptocrystalline silica, carrying a little pyrite in cubes and pentagonal dodecahedrons. In addition to the dark gray-blue quartz the porcelainic variety is common.

ELKHORN DISTRICT.

LOCATION AND HISTORY.

The Elkhorn district forms the southeast corner of the region considered in this report. The economic importance of this area has depended almost wholly on the Elkhorn mine, around which grew the town of Elkhorn.

The town of Elkhorn, situated at an altitude of 6,500 feet, lies 12 miles northeast of Boulder, which is on the Butte branch of the Great Northern Railway. It is connected with Boulder by a branch line operated by the Northern Pacific Railway, which runs three trains a week.

The district was prospected before 1870 but did not attain prominence until after the discovery of the Holter lode in 1875, on which was founded the great mine subsequently known as the Elkhorn mine. This property was worked nearly continuously until 1900, when it was regarded as worked out and sold for a small sum, practically for the value of the machinery and equipment. The new owners commenced to rework the old dumps and to reopen the mine in 1901; since 1906 the mine has again been in continuous operation.

STRATIGRAPHIC GEOLOGY.

Elkhorn lies on the eastern margin of the Boulder batholith. The geology here is far more complex than at any other district in the region, owing to the number of sedimentary formations and to the abundance and variety of igneous intrusions. The details, however, have been ably worked out by Weed and must be sought in his report on the district.[1] The purpose of the present report is to show the relation of the ore deposits at Elkhorn to the mineralization of the province as a whole.

[1] Weed, W. H., Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont., with an appendix on the microscopical petrography of the district by Joseph Barrell: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 399–549.

The sedimentary rocks comprise mainly a series of Paleozoic limestones, shales, and quartzites, overlain in angular accordance by a series of Mesozoic sandstones, shales, and impure limestones, all highly altered by contact metamorphism. Overlying the Mesozoic rocks are a bedded series of andesitic breccias, tuffs, and lavas, which make up the summits of Elkhorn and Crow peaks, the culminating points of the district.

The oldest rock of the district is the metamorphosed shale to which Weed has applied the name Turnley hornstone. This is regarded as the local metamorphic equivalent of the Spokane shale of Algonkian age. The lowest formation of the Paleozoic is a white quartzite, 125 feet thick, which is correlated with the Flathead quartzite of Middle Cambrian age. Above this formation is a succession of limestones and shales, ranging in age from Cambrian to Carboniferous, to which various local names have been applied by Weed. Above these rests the Madison limestone of lower Carboniferous age, a massive-bedded white limestone aggregating 1,900 feet in thickness. At Elkhorn it is coarsely crystalline, owing to the thermal metamorphism exerted by the various igneous intrusions. The Quadrant quartzite (of probable Pennsylvanian age) overlies the Madison and consists of quartzites and lime-silicate hornstones totalling 382 feet in thickness.

The Mesozoic rocks overlie the Paleozoic, as already stated, in angular accordance. They are best exposed on the southwest spur of Crow Peak, whence they were termed by Weed [1] the Crow Ridge series and were regarded as including rocks of Jurassic and Cretaceous age, with which Stone agrees.[2] Weed's measured section shows a thickness of 1,680 feet between the underlying Quadrant quartzite and the overlying andesites.

The andesitic rocks at Elkhorn Peak are predominantly tuffs and breccias. The breccia bed at the base of the series contains angular blocks up to a foot in length. According to Weed,[3] the andesitic lava flows, with tuffs and breccias at the bottom, lie on an erosion surface and terminate the series of Mesozoic sediments on Crow Ridge. At the point where the section was measured the actual contact, however, is hidden by talus, so that the existence of an erosion surface and its position in the stratigraphic column are matters of inference and not of observational fact. Certain it is, however, that the andesitic breccias and tuffs rest in angular accordance on the sedimentary rocks below them. It is probable that here as elsewhere in the region the andesites were folded at the same time as the underlying sedimentary rocks.

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 440.

[2] Stone, R. W., Geologic relation of ore deposits in the Elkhorn Mountains, Mont.: Bull. U. S. Geol. Survey No. 470, 1911, p. 82.

[3] Op. cit., p. 441.

Conspicuous features of the geology of Elkhorn are the marble cliffs on the western flank of Elkhorn Peak. They are masses of coarsely crystalline marble intercalated in the andesites and form bold cliffs of brilliant whiteness at the head of Elkhorn Gulch. Weed[1] says: "These inclusions are clearly blocks torn off from the underlying Madison limestone and borne into their present position by the force of the ascending magma." As the inclusions are not fossiliferous the reference to the Madison limestone was probably based on lithologic similarity. Two marble masses are known, the larger of which is 125 feet thick and 3,000 feet long. When this immense size is considered, together with the facts that the andesites below the limestone are predominantly tuffs and breccias and that the limestone is at least 1,000 feet hypsometrically above the nearest outcrop of the Madison limestone, this explanation seems inherently improbable. An alternative explanation, involving less catastrophic processes, is suggested by the fact that fossiliferous fresh-water limestone was found interstratified with the andesites southwest of Elliston. It therefore seemed probable that the supposed inclusions at Elkhorn were merely highly metamorphosed lenses of limestone interstratified with the andesitic series. To test this hypothesis the upper and lower contacts of the marble masses were carefully examined. The larger marble stratum was found to be overlain by a heavy stratum of coarse andesitic breccia and to be underlain by a thin bed of what appeared to be a banded tuff approximately 2½ feet thick. All the rocks are obviously highly metamorphosed owing to the proximity of quartz monzonite and aplite intrusions. The rock beneath the limestone is found in thin section to be composed of andalusite, biotite, plagioclase, orthoclase, and quartz. The texture is typical of hornfels, and the andalusite, which constitutes 25 per cent of the rock, is developed in large irregular prismatic individuals of spongiform or poikilitic habit. Certain of the larger plagioclase particles appear to be of fragmental origin. The abundance of andalusite seems to bear directly on the point at issue; it proves that the material directly below the limestone mass was highly aluminous and indicates that it was probably an argillaceous tuff.

Certain small masses of limestone intercalated in the andesitic series afford even stronger evidence that they are merely interstratified lenses in the andesitic series. Some are underlain by undoubted tuff, which is found to consist under the microscope of irregular angular particles of plagioclase and fragments of various porphyritic andesites embedded in an extremely fine grained matrix. At the altitude of 8,750 feet, near the head of Elkhorn Gulch, a band of finely crystalline limestone 8 feet thick rests on a stratum of coarse breccia 20 feet thick. It is to be noted that if the limestone masses

[1] Op. cit., p. 449.

were floated up by the magma they would be underlain by massive andesite, which would in all probability show some small intrusive tongues extending into the limestone.

INTRUSIVE IGNEOUS ROCKS.

The intrusive igneous rocks include a series of granular rocks and porphyries that were injected prior to the invasion of the region by the quartz monzonite of the Boulder batholith. They include the gabbro of Black Butte (which is of interest because Weed sees in it the source of the metals in the Elkhorn deposit), diorite, diorite porphyry, and quartz diorite porphyry. All are distinct and easily recognizable rocks. They were followed by the granite or quartz monzonite, which is remarkably similar in appearance and composition to the rock at Butte on the western margin of the batholith. Succeeding this came extensive injections of aplite.

CONTACT METAMORPHISM.

The intensity of contact metamorphism and the variety of minerals produced have been greater at Elkhorn than at any other locality in the region. Moreover, the phenomena are of such a character as to appeal to the eye, and the mineralogic changes that have ensued during metamorphism can be determined, in part, at least, without recourse to microscopic analysis. In this respect the district presents a strong contrast to the Marysville district, where the metamorphosed rocks consist predominantly of hornstones of aphanitic texture and of correspondingly obscure character to the eye.

The scapolitic and andraditic metamorphism of the calcareous (?) andesite breccia above the marble stratum on Elkhorn Peak, the andalusite hornfels below it, and the recrystallization of the andesites have already been described (pp. 27–28).

Barrell concluded, as a result of his study at Elkhorn, that "even under the most intense metamorphism the carbonic acid is not expelled from the limestone except by the presence of silica and the other impurities which accompany it."[1] It was shown mathematically that during metamorphism a notable reduction in volume, or increase in porosity, must result. For the Dolcoath stratum a shrinkage of 50 per cent was computed. But these mathematical results were unsupported by chemical analyses and the computations were based on the unverified assumption that the garnet produced during metamorphism is invariably a pure grossularite. Iron-bearing garnets, however, seem, according to the present hasty investigation, to be the prevalent variety at Elkhorn. Some are certainly andradite, especially those occurring in the contact-metamorphic ore deposits, but others are probably intermediate varieties.

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[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 549.

The following analyses made for Weed in 1906[1] show the actual chemical composition of garnetized limestone occurring 2,300 feet north of Black Butte at Elkhorn. No. 135 (analysis I) is the analysis of a rock composed of a closely packed assemblage of subhedral brown garnet grains, interspersed with sporadic patches of calcite containing euhedral garnets. Under the microscope the rock is found to consist predominantly of brown garnet. Zonal structure and optical anomalies are common in the garnet, and a dodecahedral parting is well developed. The cores of many of the garnets have apparently shrunk slightly away from the peripheral zones. By the immersion method the refractive index is found to exceed considerably 1.79 (that of grossularite is 1.744 and andradite 1.85). Calcite, quartz, chlorite, and amphibole occur interstitially. No. 147 (analysis G) is the analysis of a garnet rock of dense massive texture. Microscopically the rock proves to consist largely of garnet poikilitically inclosing diopside, calcite, feldspar, titanite, and apatite.

Analyses of garnet rock, Elkhorn, Mont.[a]

	No. 135.	No. 147.
SiO_2	36.91	40.31
Al_2O_3	6.54	12.11
Fe_2O_3	19.43	8.67
FeO	.67	.40
MgO	1.07	2.65
CaO	31.09	33.61
Na_2O	Trace.	.79
K_2O	.18	.12
H_2O-	.70	.23
H_2O+	1.57	.22
TiO_2	Undet.	.78
CO_2	1.91	None.
P_2O_5	Undet.	.69
	100.07	100.58

[a] Analysis No. 135 by E. C. Sullivan; No. 147 by W. T. Schaller.

The approximate mineral composition, calculated from the chemical analysis in accordance with microscopic diagnosis, is as follows:

Approximate mineral composition of garnet rock, Elkhorn, Mont.

	No. 135.	No. 147.
Andradite	61.50	27.43
Grossularite	22.50	52.70
Diopside	....	15.75
Calcite	4.30	....
Quartz	4.92	....
Chlorite	4.20	....
Feldspar	....	1.08
Titanite	....	1.96
Apatite	....	1.55
	97.42	100.47

[1] Listed by F. W. Clarke, as analyses G and I, in Bull. U. S. Geol. Survey No. 419, 1910, p. 92; the description of the rocks is hitherto unpublished.

These analyses and computations show clearly enough the considerable range in composition of the garnet rocks produced during metamorphism; nevertheless, in the two rocks under discussion, there are no macroscopic features that would serve to distinguish surely the iron-rich from the lime-rich garnet rock.

ORE DEPOSITS.

A wide variety of ore deposits is found within the small area of the Elkhorn district. Several genetically distinct types are included: The magmatic sulphide ore body at the Golden Curry mine, the auriferous contact-metamorphic lode at the Dolcoath mine, the contact-metamorphic bodies of magnetite ore, the tourmaline-bearing galena-quartz ore at the Queen mine, and the lead-silver replacement deposit at the Elkhorn mine.

The great ore body of the Elkhorn mine has overshadowed all others in economic importance, and Weed's report on the district is, as he himself states, essentially a report on the Elkhorn mine. From the present writer's point of view, however, other of the deposits are also of much interest.

The magmatic sulphide body, the details of which are given under the description of the Golden Curry mine, is an ore mass consisting of a mixture of pyrrhotite and chalcopyrite intergrown with augite. Surrounding the sulphide body and grading into it is a zone of dark heavy rock of fresh appearance and of even-grained granitic texture, which proves on microscopic examination to be a pyrrhotitic augite diorite. This rock in turn grades laterally outward into quartz monzonite, composed of plagioclase, orthoclase, quartz, biotite, and hornblende, which is the normal country rock. The sulphide mass has yielded 2,000 tons of ore, carrying $4 in gold, 35 per cent excess iron, and 2 per cent copper.

The ore body at the Dolcoath mine is a stratum 12 to 18 inches thick, composed essentially of garnet (andradite), diopside, calcite, and epidote. The rock is commonly of dense massive texture, but in proportion as the amount of calcite increases, the garnet and epidote show more complete crystallographic development. Sulphide and telluride of bismuth, carrying gold, together with chalcopyrite, constitute the ore minerals and occur in small amount, intergrown both with the silicates and the calcite. That the garnetization and the recrystallization of the calcite took place nearly simultaneously is proved by the fact that perfect crystals of garnet occur completely isolated in the midst of large crystalline patches of calcite.

According to Weed, the Dolcoath ore stratum is composed of nearly equal parts of diopside and grossularite with calcite. The garnet, however, according to the present examination, is not grossularite but is an andraditic variety. Weed, following Barrell, has suggested that the Dolcoath ore stratum represents a bed of limestone rendered porous by contact metamorphism and subsequently impregnated by metalliferous solutions,[1] which also brought in the calcite. This is an exceedingly plausible a priori conception, but the field evidence, as shown by the simultaneous crystallization of the garnet and the calcite, does not support it. Furthermore, if the garnet is largely andradite instead of grossularite, the accuracy of the mathematics employed in calculating the hypothetical porosity produced during contact metamorphism is seriously impaired.

On the north side of Elkhorn Peak occur bodies of iron ore near the contact of the large limestone stratum and the underlying andesite. The iron ore consists principally of magnetite associated with andradite. It has been mined to some extent for a flux. The magnetite is mainly intergrown with the garnet but is also present as thin strings and quartz-magnetite veinlets traversing the garnet rock. The garnet, as determined by the immersion method, has a refractive index considerably higher than 1.79, indicating its andraditic character. Locally axinite is found in coarse-bladed masses, some as large as a fist; some of it incloses euhedral crystals of garnet. Other minerals occurring in the ore bodies in lesser amounts are specular hematite, pyrite, chalcopyrite, and epidote. The deposits are extensively oxidized, and much soft iron oxide, in part derived from the andradite, is present, obscuring the geologic relations. The ore bodies are doubtless largely replacements of the limestone, but it is not improbable that the underlying andesite is also considerably garnetized or otherwise metamorphosed in a manner similar to that of the andesite breccia overlying the great limestone stratum of Elkhorn Peak.

The ore body at the Queen mine is the only representative of the tourmalinic class of deposits in the Elkhorn area. It is an argentiferous galena-quartz ore carrying tourmaline. Arsenopyrite, which is a constant associate of tourmaline the world over, occurs in this deposit but is found nowhere else in the Elkhorn area.

The premier ore deposit of the district has been that of the Elkhorn mine. By 1900 it had produced 8,902,000 ounces of silver, 8,500 ounces of gold, and 4,000,000 pounds of lead. The ore body consists essentially of argentiferous lead ore replacing dolomite beneath the arches of a hanging wall of hornstone. In comparison with the other ore bodies, one of the most interesting features of the Elkhorn deposit is the complete absence of metasomatic gangue minerals. The other deposits of the district show such characteristic minerals as andradite, diopside, epidote, axinite, and tourmaline—all indicative of high-temperature origin—but this, the largest and most productive ore body of the Elkhorn district, is devoid of any evidence that it was formed under conditions of high temperature.

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 458.

DESCRIPTIONS OF MINES.

ELKHORN MINE.

The Elkhorn mine is opened by an incline 2,300 feet long, attaining a vertical depth of 1,439 feet. During 1911 work was in progress on a large number of levels, from those near the surface down to the 2,300-foot level. About 175 men were on the pay roll, but a large number of these were engaged in surface work. All ore from the mine is washed and sorted into milling, shipping, and waste rock. The old dumps are being reworked and yield 5 per cent of their content in milling and shipping ore.

The geologic features of the Elkhorn mine have been described in detail by Weed, so that a brief outline is all that is necessary here. According to Weed:[1]

The ore deposit does not constitute a true vein, though commonly spoken of as a vein or lode. The ore occurs in two principal shoots lying on the under side of folds—i. e., in the saddle of the folds—and conforming to the dip of the stratified beds in which they occur. These ore bodies are found along a bedding plane between indurated shale (hornstone) and dolomitic marble. This contact plane was followed in mining and has commonly been spoken of as the lode. Although there has been some slipping and movement along this plane, the contact is not mineralized, nor does it show any vein quartz or other lode material except in the steeply pitching arches underneath which the ore bodies occur. The ore deposits consist of more or less irregular bodies of rudely lenticular cross section lying against the hanging-wall hornstone, and as isolated masses forming so-called "chamber" deposits in the underlying dolomite.

The hanging-wall ore bodies consist of solid quartz[2] carrying galena, tetrahedrite, pyrite, and blende; the footwall bodies consist mainly of replacement masses of galena, sphalerite, and pyrite in the dolomite beneath the hanging-wall hornstone.

At the time of Weed's examination the ore deposit was supposed to have a definite footwall—a thin stratum of argillaceous limestone occurring about 35 to 50 feet from the hanging wall, as measured along crosscuts into the footwall country. This is now known as the "40-foot contact." It is particularly well shown on the 350-foot level south; where unsheared, it consists of a somewhat argillaceous stratum averaging 3 inches in thickness. It swells and constricts and has evidently been a locus of movement. The dolomite above and that below this stratum seem to be alike. The new owners of the Elkhorn mine, who acquired the property in 1899 after it had been regarded as worked out, have explored the footwall country below the 40-foot contact and have discovered other ore bodies. They have found two other "contacts," known as the 80-foot and 160-foot contacts. In other words, the thickness of the ore-bearing zone has been found to be 160 feet instead of 40 feet (or 80 and 20 feet, if

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 470–471.

[2] Aragonite in fibrous aggregates over an inch long was noted (and verified chemically) by the writer to be intergrown with quartz from the 1,750-foot level.

measured normal to the dip of the stratification). The 80-foot contact is apparently a stratification plane and is not particularly well marked. The dolomite shows no recognizable change above or below this plane. The 160-foot contact is even more feebly marked than the 80-foot contact.

The ore masses, which after extraction are represented by extremely irregular caverns and crooked pipes, are known as first, second, or third contact bodies, according to the contact on which they were discovered. Many of them extend by exceedingly devious courses back to the hanging-wall hornstone, or slate, as it is known locally. Great ore masses have been found whose major dimensions cut across the bedding of the dolomite. In this respect the Elkhorn deposit departs strongly from the saddle-reef type of ore body, with which Weed has identified it, but in the broader feature—the localization of the ore shoots beneath anticlinal arches, so clearly shown on Plate LVII of Weed's report—it is in striking accord with the saddle-reef type.

GOLDEN CURRY MINE.

GENERAL FEATURES.

The Golden Curry, or Jacquemin mine, as it is shown on the Elkhorn map,[1] is located near the intrusive contact of the quartz monzonite and a series of thin-bedded limestones, to which Weed gave the name Starmount limestone. The limestones have been highly metamorphosed into various lime silicates, forming dark-colored banded hornstones of dense texture. Locally heavy garnet rocks have been produced and in places the garnet (probably andradite) is coarsely crystalline, especially near calcite patches; where the calcite has been partly leached out by weathering a porous rock is produced, showing druses lined with crystalline garnet. Some of the garnet rock contains a little intergrown chalcopyrite and is said to constitute ore. Above the main pit of the mine are found considerable amounts of a somewhat notable rock composed of garnet and opal. Some of it consists of garnets set in a matrix of conchoidally fracturing opal of light-yellowish color. Under the microscope a specimen of the garnet-opal rock was found to consist of garnet, diopside, calcite, opal, and cryptocrystalline silica, in part spherulitic. The evidence seems to show that the garnet had been fractured, crushed, and recemented by opal and cryptocrystalline silica. It is to be noted that the cryptocrystalline silica mixed with yellowish opal produces a "hornstone" indistinguishable by the eye from the "hornstone" due to a mixture of contact-metamorphic silicates.

The main workings of the mine consist of a large open pit from which some 50,000 tons of iron ore have been mined, mainly as a

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, Pl. XLV.

flux for the smelters. The ore averaged 40 per cent iron and carried from $4 to $5 a ton in gold. The pit is located at the immediate contact of the metamorphic rocks and the granite, and at first inspection it might appear that this deposit of iron ore was of the same type as those so common at many granite and limestone contacts in the Western States, namely, a deposit of magnetic iron ore developed in the limestone during contact metamorphism. In this deposit, however, the magnetite does not occur intergrown with the contact-metamorphic silicates but forms veins in the granite itself, some of the veins attaining a thickness of 3 feet. In some of the underground workings beneath the main pit, namely in tunnel No. 1, there are found some lodes of heavy red jasper-like material which chemical analysis shows to be a hydrous ferric silicate.

Partial analysis of iron ore from the Golden Curry mine, Montana.

[J. G. Fairchild, analyst.]

Fe_2O_3	59.23
SiO_2	31.37
H_2O (loss on ignition)	8.40
	99.30

This material is also mined as iron ore. It contains considerable martite and rarely some pyrite. The analysis above, however, represents only the homogeneous, conchoidally fracturing portion.

In a raise above this lower tunnel a large chamber of ore inclosed in granite has been stoped out. This ore presents many features similar to the pyrrhotite body about to be described. It consists of pyrrhotite, magnetite, and subordinate chalcopyrite intergrown with brown-green augite. In places pyrrhotite predominates, in others magnetite predominates, and locally they are commingled in equal proportions. This body of ore is bounded on one side by a thick zone of gouge, along which occurs iron-bearing jasperoid similar to that of which the analysis has been given.

These iron deposits are unconnected with the body of sulphide ore described below. The Golden Curry mine affords a striking illustration of the fact that the ore at a single mine may be of very diverse origin and mode of occurrence, at least four kinds being recognizable at this property: Magmatic, contact-metamorphic, magnetite veins in granite, and hydrous ferric silicate masses apparently formed by downward-moving waters that derived their iron from the oxidation of sulphide masses.

THE PYRRHOTITE ORE BODY.

A mass of sulphide ore was encountered during the underground exploration of the mine 250 feet southwest of the magnetite deposits found at the contact. This body of sulphide was wholly inclosed in the granite and isolated from the other ore deposits. It is elliptical in shape, its dimensions being: Length, 100 feet; maximum width, 18 feet; and it has been stoped upward to a height of 10 or 12 feet. From it were extracted 2,000 tons of ore running $4 in gold, 35 per cent excess iron,[1] and 2 per cent in copper. The ore consisted of a mixture of pyrrhotite and chalcopyrite in a gangue of pyroxene. Under the microscope it is found that the ore is composed essentially of the monoclinic pyroxene augite intergrown with the two sulphides. The augite is in places intergrown with a small amount of pleochroic brown hornblende of the kind usually found in deep-seated igneous rocks. Other silicate minerals found more rarely are biotite, plagioclase feldspar, orthoclase, and quartz, but these constitute an insignificant proportion of the whole. Texturally the augite forms an allotriomorphic assemblage of anhedral grains. The sulphides, which are mutually intergrown, occur interstitially between the augite grains or irregularly intergrown with them. It is a noteworthy fact, however, that although the augite is usually anhedral it shows, where adjoined or surrounded by sulphides, a closer approximation to its idiomorphic outlines. The contours are as a rule somewhat rounded and smoothed by corrosion, and the sulphides often form distinct embayments into the augite which resemble those so common in the magmatically resorbed quartz phenocrysts of rhyolitic rocks. On account, however, of the general tendency of the sulphides and the pyroxene to be intergrown in allotriomorphic fashion, exactly as in gabbroic rocks, the microscopical evidence based on the texture alone is perhaps not conclusive as to the primary igneous origin of the sulphides.

Surrounding the sulphide mass and grading into it is a body of dark, heavy rock of fresh appearance and even-grained granitic texture. Under the microscope this rock is found to consist of approximately equal amounts of pyrrhotite, augite, and plagioclase of the composition $Ab_{65}An_{35}$. The texture is allotriomorphic granular and the rock may be appropriately termed a pyrrhotite-augite diorite. This rock is, however, somewhat variable in composition, in places containing considerable primary quartz, but the essential feature in all places is the dominant amount of augite. The rock grades laterally outward from the ore deposit within a distance of 6 to 12 feet to a quartz monzonite of normal appearance. Such rock 12 feet from the ore lens consists of a hypidiomorphic granular assemblage of plagioclase, orthoclase (the two feldspars occurring in approximately equal amounts), quartz, biotite, and hornblende. A specimen taken 50 feet from the periphery of the ore lens shows essentially the same features, the only noticeable difference being that the plagioclase feldspar is slightly more calcic, having the composition corresponding to $Ab_{55}An_{45}$. A chemical analysis of the quartz monzonite (No. 5, p. 30) is available;

[1] That is, iron in excess of silica; excess iron is the basis of the price paid by the smelter.

the specimen was taken 1 mile from the contact at this locality, and is typical of the general rock mass in which the ore body is inclosed.

To summarize briefly, the primary igneous origin of the sulphides is indicated by the following facts:

1. All the rocks, including those composing the ore body and those surrounding it, show an entire lack of hydrothermal alteration, such as the development of sericite, chlorite, carbonates, or other secondary minerals. They are fresh, unaltered rocks in which the ferromagnesian minerals are notably lustrous and the feldspars are clear and vitreous.

2. The textural relation of the sulphides to the augite, as displayed by the tendency of the pyroxene to show idiomorphic boundaries against the sulphides. This is a feature not easily explainable other than by the hypothesis of an igneous origin.

3. The marked differentiation that has taken place in the magma concurrently with the segregation of the sulphides. This is expressed mineralogically by the decrease of orthoclase, quartz, and biotite and the concurrent increase in ferromagnesian mineral as the ore body is approached. Instead of hornblende or biotite, however, it is augite that appears in the ore body.

In conclusion, the important features of this deposit as a member of the class of magmatic ore bodies are: (1) That it has segregated from a comparatively acidic rock; other pyrrhotite-chalcopyrite bodies of this type have separated from magmas of gabbroic composition; (2) its relatively high gold content, which is unusual, as most magmatic ore bodies are poor in gold.

QUEEN MINE.

The Queen mine lies 2 miles south of Elkhorn. It was worked to a depth of 500 feet by a shaft 300 feet deep and by winzes extending 200 feet deeper. The property has furnished a considerable quantity of ore, but no work has been done on it during the last 10 years.

The ore body is situated at the contact of quartz diorite porphyry and limestone and formed, as seen from the surface, an elliptical chimney measuring approximately 25 by 50 feet. The ore is a coarse vitreous white quartz of drusy and vuggy texture. Galena is the principal sulphide and is the mineral that gave value to the ore. Other sulphides present are pyrite and black sphalerite, but they are not common. The quartz contains a fair amount of black tourmaline in nests and groups of delicately radial structure. In places the galena is pierced by acicular tourmaline. Some altered porphyry found on the dump is thickly studded with well-crystallized arsenopyrite; galena is locally intergrown with the arsenopyrite.

The ore of the Queen mine was a silver-lead ore and is stated to have averaged from $10 to $15 a ton.

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